

WELDING *Journal*

APRIL 2020



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NOMINATION DEADLINE FOR AWS FELLOW OF THE SOCIETY



American Welding Society®

IMPORTANT
Announcement!

Friends and Colleagues:

The American Welding Society, in 1990, established the honor of Fellow to recognize members for distinguished contributions to the field of welding science and technology, and for promoting and sustaining the professional stature of the field. Election as a Fellow of the Society is based on outstanding accomplishments and the technical impact of the individual. Such accomplishments will have advanced the science, technology and application of welding, brazing, or soldering, as evidenced by:

- Sustained service and performance in the advancement of welding and joining science and technology
- Publication of papers, articles and books which enhance knowledge of welding and allied processes
- Innovative development of welding and allied technologies
- Society and Section contributions
- Professional recognitions

I want to encourage you to submit nomination packages for those individuals whom you feel have a history of accomplishments and contributions to our profession consistent with the standards set by the existing AWS Fellows. In particular, I would make a special request that, in considering members for nomination, you look to the most senior members of your Section or District. In many cases, the colleagues and peers of these individuals who are the most familiar with their contributions, and who would normally nominate the candidate, are no longer with us. I want to be sure that we make the extra effort required to ensure that those truly worthy are not overlooked because no obvious individual was available to start the nominating process.

For specifics on nomination requirements, please contact Chelsea Steel at csteel@aws.org at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form located at www.aws.org/fellow. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is **August 1, 2020**. The Fellows Committee looks forward to receiving numerous Fellow nominations for 2021 consideration.

Sincerely,

Dr. Sudarsanam Babu
Chair, AWS Fellows Committee



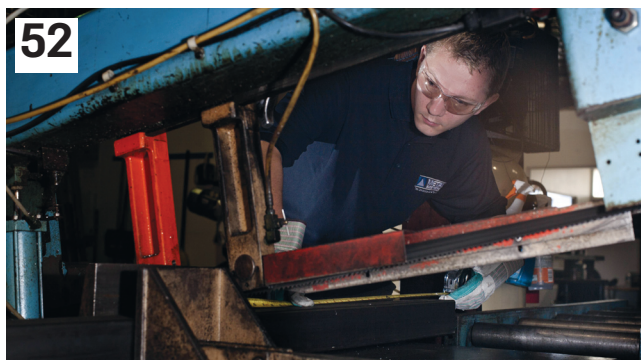
Do you know a leader
with outstanding
contributions to the
advancement of
welding science and
technology?

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for the honor of
Fellow of the
Society!**

August 1, 2020
Submission Deadline

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On the cover: Position your head adjacent to the joint to see the electrode and its relationship to the weld pool. (Credit: ESAB Welding & Cutting Products.)

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AWS Promotes Diversity

AWS values diversity, advocates equitable and inclusive practices, and engages its members and stakeholders in establishing a culture in the welding community that welcomes, learns from, and celebrates differences among people. AWS recognizes that a commitment to diversity, equity, and inclusion is essential to achieving excellence for the Association, its members, and employees.

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AWS COUNSELOR NOMINATION



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Friends and Colleagues:

The American Welding Society established the honor of Counselor of the Society to recognize members for a career of distinguished leadership contributions in the advancement of welding science and technology. Election as a Counselor is based upon an individual's career of outstanding achievements and accomplishments. The selection committee is seeking qualified individuals who can demonstrate their leadership in the welding industry as evidenced by:

- Sustained service and performance in the advancement of welding science and technology
- Publication of papers, articles and books which enhance knowledge of welding
- Innovative development of welding technology
- Society, National and Section contributions
- Professional recognition
- Leadership in AWS or other corporate levels, particularly as it impacts the advancement of welding technology
- Facilitating others to participate as a volunteer in the advancement of welding technology

For specifics on the nomination requirements, please contact Chelsea Steel at csteel@aws.org at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form located at www.aws.org/counselor. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is **July 1, 2020**. The Counselor Committee looks forward to receiving numerous Counselor nominations for 2021 consideration.

Sincerely,

David J. Nangle
Chair, Counselor Committee

Now is your
opportunity to
recommand someone
with a career of
outstanding
achievements and
accomplishments in
the welding industry.

**Nominations
For Counselor of
the Society are
Open!**

July 1, 2020
Submission Deadline

Changes in the New AWS D1.1 Code



Tom Schlafly
Former Chair of the
AWS D1Q Subcommittee on Steel



Phil Torchio
Current Chair of the
AWS D1Q Subcommittee on Steel

“Thousands of volunteer and staff hours have been devoted to the review of this important code to improve its usability and accuracy. The committee has now turned its attention to the next edition due in 2025.”

The first new edition in five years of the American Welding Society’s (AWS’s) D1.1/D1.1M:2020, *Structural Welding Code — Steel*, has just been published and may provide an immediate shock to many users. It’s available for purchase at pubs.aws.org.

A lot has changed. The first change most people will notice is that it has been reorganized. This is not change for change’s sake, but rather, a conscious effort to make the code clearer through putting clauses in a more rational order — an order that is consistent with other AWS codes. To accomplish this, many editorial changes have been made, including moving essential information out of the appendices in the back of the code to the front. Normative References now reside in Clause 2. Terms and Definitions specific to this standard are now in Clause 3. Endeavoring to unify the format of the structural welding codes, clauses are now introduced by a scope and are divided into parts to simplify reader understanding/use.

This has resulted in a shift of all clauses after Clause 1, General Requirements, in the 2015 edition to new locations in the 2020 code. A two-clause number shift applies to Design through Stud Welding; in other words, former Clauses 2–7 are now Clauses 4–9. Tubular Structures has moved from Clause 9 to Clause 10. Strengthening and Repair of Existing Structures is now Clause 11.

The appendix letter identifications have also shifted with the move of Normative References, Definitions, and Annex A Effective Throat to Clauses 2, 3, and 4, respectively. Perhaps our best suggestion is to tab the foreword of the code starting on page xiii, which provides a roadmap of new locations for the code provisions.

In addition to the above listed changes, new specific editorial and substantive changes have been made, as outlined below.

- Clause 4, Design, has moved the Annex A fillet weld effective throat illustration to Figure 4.1.

- Clause 5, Prequalification of Welding Procedure Specifications (WPSs), has been editorially reordered to more closely follow a logical sequence a contractor would follow in writing a prequalified WPS. This results in renumbering the clause content, tables, and figures to follow the order they are referenced in the clause. D1.1/D1.1M:2015, Table 3.7 Prequalified WPS Variables, now Table 5.2, has been retitled Essential Variables for Prequalified WPSs. The tolerances for variables are separated from the list of variables.

Substantive changes in Clause 5 include adding new materials to Table 5.3 Approved

Base Metals for Prequalified WPSs and new Table 5.7 Prequalified WPS Shielding Gas Options for GMAW Electrodes Conforming to AWS A5.18/A5.18M.

- Clause 6, Qualification, adds requirements for WPS qualification using waveform-controlled processes, and welder qualification retest requirements have been clarified. Qualification sections have been added to clarify there are various methods to qualify partial joint penetration welds. There are also new provisions for qualifying WPSs with Charpy V-notch (CVN) toughness, including a new method for locating the CVN specimens, and CVN testing requirements have been added to Table 6.6.

- Clause 7, Fabrication, has revised provisions for weld restoration of base metal with mislocated holes.

- Clause 8, Inspection, has revised requirements for welding inspection personnel qualification, engineer’s responsibilities regarding inspection, digital radiography, digital unsharpness, and ultrasonic testing attenuation factor determination.

- Clause 9, Stud Welding, has a new requirement for manufacturer’s identification marks on headed studs and deformed bars and rewritten provisions to the contractor’s option for fillet welding studs.

- Clause 10, Tubular Structures, has removed provisions for calculating static strength of welded tubular connections, and designers are directed to ANSI/AISC 360 and AISC Design Guide No. 24.

- While phased array ultrasonic testing (PAUT) was added to D1.5M/D1.5:2015, *Bridge Welding Code*, it has now been included in the new edition of D1.1. The requirements for using PAUT can be found in Annex H. There is also new commentary for this.

- Annex R contains modified provisions for preliminary design of circular tube connections that were previously contained in the tubular structures clause.

Thousands of volunteer and staff hours have been devoted to the review of this important code to improve its usability and accuracy. The committee has now turned its attention to the next edition due in 2025.

If you have a concern about the code or a revision you would like to propose, contact Jennifer Molin at jmolin@aws.org for the form to complete. The subcommittee is always looking for dedicated volunteers. In particular, the Design, Materials, Prequalification, and Stud Welding Task Groups are looking for new members. Apply by completing the application at aws.org/library/doclib/Technical-Committee-Application.pdf. 

OSHA Establishes Coronavirus Webpage

The U.S. Occupational Safety and Health Administration (OSHA) has created the following webpage to provide information for workers and employers about the evolving coronavirus (COVID-19) outbreak: osha.gov/SLTC/covid-19/. Although the website notes “without sustained human-to-human transmission, most American workers are not at significant risk of infection,” OSHA cautions exposure risk may be elevated for some workers who interact with potentially infected travelers from abroad. This includes those involved in travel to areas, such as parts of China, where the virus is spreading. While acknowledging there is no specific OSHA standard covering COVID-19, the organization points out some of its requirements may apply to prevent occupational exposure. These include OSHA’s Personal Protective Equipment standards, which require the use of gloves, eye and face protection, and respiratory protection, as well as the General Duty Clause, which requires employers to provide each worker with “employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm.”

MADE HERE Act Encourages Manufacturing Clusters

The Manufacturing American Dynamism in Entrepreneurship and Harnessing Education to Retool Employees (MADE HERE) Act, introduced in the House last month, will direct the National Institutes of Science and Technology, the Department of Energy, and the Department of Defense to support three-phase manufacturing cluster programs. Each phase will be awarded through a competitive process in which regional manufacturing clusters — comprised of educational institutions, private companies, nonprofits, labor groups, and government-funded resources — implement activities to address an emerging technical area of need in the manufacturing industry. Awardees would receive up to \$3 million over three years to implement activities, including building infrastructure and carrying out educational initiatives, and then up to an additional \$10 million over five years to continue their efforts focused on addressing emerging technical areas of need.

Legislation Aims to Provide Funding to States and Community Colleges

The Assisting Community Colleges in Educating Skilled Students to Careers Act would launch a community college and career training grant program for funding to states and community colleges to address the evolving demands of the labor market. The bill would authorize grants to states for developing innovative models that support student success and workforce preparedness, including partnerships between local community colleges with employers and workforce entities, to create pathways to in-demand industries. The legislation would also authorize grants to community

colleges and consortia of community colleges to carry out program activities; increase the number of students who attain postsecondary credentials in high-skill, high-wage, or in-demand industry sectors; and assist colleges to develop and improve strategies to support student success.

Hearing Held on International Intellectual Property

The United States Trade Representative (USTR) recently met for its annual Special 301 review to identify countries that deny adequate and effective protection of intellectual property rights or fair and equitable market access to U.S. persons who rely on intellectual property protection. Based on this review, the USTR determines which countries should be placed on the Priority Watch List. This year’s hearing focused on the increase of fake products sold in the United States, sophisticated efforts to steal U.S. companies’ trade secrets, and attempts at international organizations to weaken intellectual property protections in the name of other policy priorities, such as public health and environmental protection.

Method for Calculating Annual Revenues for Small Businesses is Modified

The U.S. Small Business Administration (SBA) has changed its regulations on the calculation of annual revenues from a three-year averaging period to a five-year averaging period. The change may result in firms regaining or retaining their small business status. The aim is to extend the time a small business entity may have to receive preferential treatment in competing for government contracts and continue its participation in the SBA program.

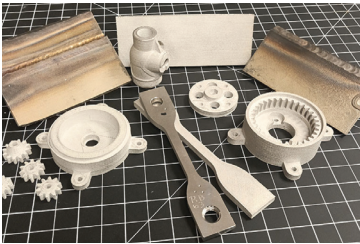
Bill Works to Promote Future Technologies

The Industries of the Future Act of 2020 (S. 3191), intended to advance U.S. global leadership in certain industries including artificial intelligence and advanced manufacturing, would, among other things, require the Administration to develop a plan to increase federal spending in so-called industries of the future to \$10 billion by the 2025 fiscal year.

Bill Expands Employee Size Standards

The Capturing All Small Businesses Act of 2019 (H.R. 5130) lengthens the calculation period used to determine average employee count, one of the size standards used by the U.S. Small Business Administration to determine if a business is small. Specifically, this bill extends the calculation period for the employee-based size standard from 12 to 24 months. The intent is to mitigate the effects of sudden growth, protecting small businesses from being prematurely forced out of the small business category. **WJ**

Somerset Community College 3D Prints Stainless Steel Parts; Demonstrates Weldability



Stainless steel parts produced on a desktop 3D printer are shown, with the back left and right plates welded after printing. (Credit: Somerset Community College.)

At Somerset Community College (SCC), Somerset, Ky., the additive manufacturing program has successfully produced stainless steel parts using a \$600 desktop 3D printer. SCC has also gas tungsten arc welded several of these parts.

This project is said to be one of the first times fully metal parts were 3D printed on an inexpensive desktop printer

and then welded using ordinary welding methods.

SCC was able to customize low-cost desktop 3D printers for metal filament extrusion for less than \$600 per printer. The parts were 3D printed and heated to remove the plastic and fuse the remaining metal. This results in parts made entirely of metal — in this case, stainless steel. The final step was to hand the parts to SCC's welding department.

Welding Professor Karl Watson used gas tungsten arc welding on the parts.

"The welds flowed very smoothly, and we had very good penetration control," Watson said. "Because of the nature of 3D printing, I expected to see more porosity in the weld, but that wasn't the case at all. I am looking forward to doing some bend tests to determine the potential malleability."

SCC's goal is to bring this low-cost metal 3D printing technology to students, teachers, and businesses throughout Kentucky. It will begin to provide state-wide training workshops for select educators in high schools and community colleges.

This work is funded by the National Science Foundation.

"Being able to bring truly low-cost metal 3D printing and advanced product design directly to schools and colleges across Kentucky is a chance of a lifetime opportunity for us, and we are very excited to get started," said Additive Manufacturing Professor Eric Wooldridge.

Additional details are available at 3dprintingindustry.com.

AWS Certified Resistance Welding Technician Credential Sets a New Standard

The American Welding Society (AWS), Miami, Fla., has launched its newest certification, the Certified Resistance Welding Technician (CRWT). Co-developed by AWS and the Resistance Welding Manufacturing Alliance (RWMA), the CRWT provides a benchmark to evaluate resistance welding personnel and separates the qualified from the untested.

"Until now, the only real measuring stick for employers to gauge an individual's knowledge of the resistance welding process was to ask if they had taken the RWMA welding course," said Don DeCorte, vice president, RoMan Manufacturing Inc. "The fact that it will be managed and maintained in the same way that all AWS certifications are managed will allow employers to know before they hire someone that they



American Welding Society®



RWMA



Certified Resistance Welding Technician (CRWT)

DETAILS
EXAM REGISTRATION
EXAM PREP SEMINAR
CORPORATE TRAINING
PRICING & PACKAGES
RWMA SCHOOL
SIGN UP

A New Benchmark for the Evaluation of Resistance Welding Personnel

Resistance welding combines heat, time and pressure to create secure, long-lasting welds used primarily in the manufacture of automobiles, appliances, and other wire or sheet metal products. The Resistance Welding Industry is competitive and high production, using costly and valuable equipment operated by skilled technicians and engineers.

To learn more about the new Certified Resistance Welding Technician credential, visit aws.org/crwt.

have a specific working knowledge of the process. This is win/win for both employer and employee."

The CRWT exam tests the candidate's knowledge, skills, and abilities in conducting the setup, operation, maintenance, testing, and quality control of resistance welding equipment. Additional training prior to taking this exam is not mandated, but candidates are encouraged to leverage one or more AWS-authorized study methods.

For more information, go to aws.org/crwt and refer to Denny Smith's feature article "AWS Announces New Certifications" in the December 2019 *Welding Journal*.

Greater Lawrence Technical School Receives \$100,000 Grant for Career Training

Greater Lawrence Technical School (GLTS), Andover, Mass., which offers "after dark" programs to address the growing demand for career and technical education (CTE) among students, has been awarded \$100,000 from the Department of Elementary and Secondary Education to expand that initiative.

The school launched its "after dark" CTE partnership program with Lawrence High School during the 2018–2019 school year, allowing 21 juniors to take their core academic courses at Lawrence High before traveling to GLTS to study machine tool/technology/advanced manufacturing. This school year, GLTS launched a second, two-year program that will allow students in their junior and senior years to earn a certificate in advanced manufacturing or heating, ventilation, and air conditioning.

"Unfortunately, every year we receive more applications than we have space for," Superintendent John Lavoie said. Approximately 1000 students apply to GLTS annually, with about 400 being accepted.

"These career fields are booming and have a wealth of employment opportunities, and we're thrilled to open up our programming to more students," he concluded.

voestalpine Böhler Welding Acquires Selco

voestalpine Böhler Welding, Düsseldorf, Germany, a global company in the field of welding technology, has recently acquired a majority stake in the traditional Italian manufacturer Selco s.r.l. for welding machines.

"With the participation in Selco s.r.l., we not only strengthen our position as a full welding solution provider in the welding industry, we also offer a perfectly coordinated combination of welding consumables and welding machines," said Stefan Glanz, CEO of voestalpine Böhler Welding. 

Mastercard Pledges to Break Down STEM Barriers for Girls in Dubai



In partnership with Expo 2020 Dubai, Mastercard has committed to train girls in Dubai for careers in STEM through its Girls4Tech education program. Seen here are students from Foremarke School, Dubai, United Arab Emirates.

Mastercard®, a financial services company, has partnered with Expo 2020 Dubai to equip girls in Dubai with the skills required for careers in science, technology, engineering, and mathematics (STEM) through its Girls4Tech™ program.

Slated to run from January 2020 to the end of the expo in April 2021, Girls4Tech's curriculum trains young girls in payments technology and innovation, which includes encryption, fraud detection, data analysis, digital convergence, cybersecurity, and artificial intelligence. It also emphasizes skills such as collaboration, creativity, and communication to enable young girls to apply their technical skills to solve real-world challenges. To better serve the Middle East, the program is being offered in Arabic.

The company has also recently announced its commitment to reach 1 million girls globally by 2025. Now in its fifth year, Girls4Tech has trained more than 500,000 girls in 28 countries.

"Inclusion, opportunity, and the empowerment of girls and women are global priorities at Mastercard, and Expo 2020 gives us an unprecedented opportunity to leave a positive legacy for the future generation of technology leaders," said Beatrice Cornacchia, Mastercard's senior vice president of marketing and communications, Middle East and Africa. "With our employees serving as role models and mentors, we hope to inspire girls to pursue careers in STEM fields as we strive to achieve greater gender parity . . ."

Collaborative Robots Hub to Open in Denmark

Collaborative robot (cobot) manufacturers Mobile Industrial Robots (MiR) and Universal Robots (UR) have acquired a 538,000-sq-ft building site in Odense, Denmark, where \$36 million will be invested in the construction of a cobot hub. With financial backing from their joint U.S. parent company, Teradyne Inc., the hub will support Teradyne's mission to strengthen the leads both MiR and UR have established globally.

The building site is in Odense's industrial district close to UR's current headquarters, which will become part of the new cobot hub. Although the two companies will share the 334,000-sq-ft building, they will continue to function as separate entities. Sharing the space will allow them to create an environment that brings in new employees, thus facilitat-

ing continued growth in the coming years.

"Denmark has a significant lead in the global market for cobots. Investing ambitiously in building the world's largest cobot hub right here in Odense makes a lot of sense," said Thomas Visti, MiR's CEO. "Offering a strong, professional environment with superb facilities enables us to attract talent from all over the world."

French Canadian College Offers Welding Training for Indigenous Women

Collège Boréal's Kapuskasing campus in northern Canada has launched a 20-week welding training program for indigenous women. This is the first time the college has offered welding training in Kapuskasing.

The program is funded by the region's First Nations training and employment services, and its pedagogical content was designed by the Canadian Welding Bureau Group. The school has also partnered with the Conseil Scolaire Catholique de District des Grandes Rivières (CSCDGR), the region's school board, to deliver the course in a trades workshop at École Secondaire de la Cité des Jeunes, a public high school.

"We are proud to live and work together to ensure the success of Collège Boréal students," said Sylvie Petroski, director of education, CSCDGR. "Sharing our workshop with Boréal students is a win-win partnership for our entire Francophone [French-speaking] community."

LIFT and TWI Agree to Future Collaborations



Detroit-based LIFT signed an agreement to collaborate with TWI Ltd., Cambridge, UK, through the sharing of facilities and the undertaking of research and development. Pictured is LIFT's High Bay facility for lightweighting applied research and development.

LIFT, an advanced manufacturing innovation institute in Detroit, Mich., has signed a Memorandum of Understanding with The Welding Institute (TWI) Ltd., an independent research and technology organization in Cambridge, UK. Agreeing to collaborate in the future, the companies plan to undertake research and development work together, as well as share access to facilities.

"We are pleased to welcome TWI Ltd. into our important ecosystem, focused on advanced materials, manufacturing processes, and systems," said Nigel Francis, chief executive officer and executive director for LIFT. "We are thrilled to have this agreement in place to share the facilities and the know-how of our colleagues overseas." [WJ](#)

Shining a Spotlight on Welding Education



As recipients of the inaugural Light a Spark Grant from the AWS Foundation with Miller Electric Mfg. LLC, eight high schools will get a Miller® welding starter pack. Shown is a welder using the Multimatic® 220 AC/DC power source. (Source: Miller Electric.)

From grants to program expansions, here's a welding education news round-up from across the country.

- The **American Welding Society (AWS) Foundation**, Miami, Fla., in partnership with **Miller Electric Mfg. LLC**, Appleton, Wis., has announced the recipients of the inaugu-

ral Light a Spark Grant. They are as follows: Blairsville-Saltsburg School District, Pennsylvania; Easton Valley High School, Iowa; James Hillhouse High School, Connecticut; Regional Apprenticeship Pathways, Washington; Republic-Michigamme School, Michigan; Swanville High School, Minnesota; Union Mine High School, California; and Waltrip High School, Texas.

These eight high schools will receive a Miller® welding starter pack, including equipment, supplies, and personal protective equipment valued at more than \$12,000, allowing the schools to introduce welding to their students.

"The AWS Foundation is extremely pleased to offer these grants to high schools that do not currently offer a welding program, thus providing hundreds of students the opportunity to experience welding for the first time and consider the possibility of welding as a career," said AWS Foundation Executive Director Monica Pfarr.

"We are proud to partner with the AWS Foundation to provide these schools with the equipment and supplies needed to introduce their students to the craft of welding," said Becky Tuchscherer, group president, Miller Electric.

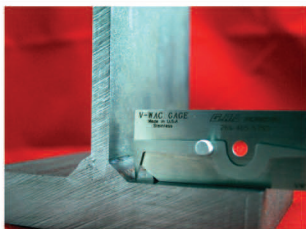
- At the February 5th ribbon cutting for **Lehigh Career & Technical Institute's (LCTI's)** new Welding Technology Center in Schnecksville, Pa., Jordan Everett used an oxy-acetylene torch. The 18-year-old sent sparks flying as he made quick work of a ceremonial ribbon, drawing applause from more than 100 people gathered for the celebration.

The \$4.25-million facility has 40 welding booths and ten

— continued on page 12



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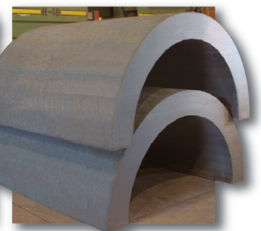
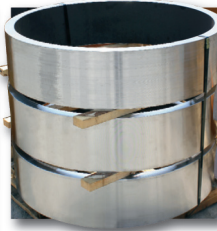
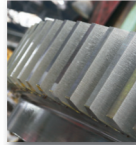


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NEWS OF THE INDUSTRY

— continued from page 10



More than 100 people gathered for the Welding Technology Center grand opening at LCTI. (Credit: LCTI.)

workstations. Fifty students can weld simultaneously.

State and local officials joined school staff and students for the event, which had remarks from Lehigh Valley Economic Development Corp. President and CEO Don Cunningham and AWS District 3 Director Sean Moran. Cunningham praised the institute's administrators, plus the leaders who have supported their years-long effort to expand LCTI's welding technology program by building the center.

"You've more than doubled your capacity to turn out welders, and that's a good thing because just in the last three years in the Lehigh Valley, we've had a demand for 275 more welders, primarily due to retirements," he said. "Today, 38 percent of the welders working in the Lehigh Valley are now under the age of 35, which is extraordinary. We are replenishing our skilled workforce with young talent."

Moran pointed out demand for welders is on the rise nationwide. "By 2023, we [will] see a need for 375,000 additional welders in the workforce. That's a bunch. And how do we meet that need? We do it through schools like this," he said.

With 10,000 sq ft of instructional space and another 2000 sq ft for storage, the center is twice the size of LCTI's former program lab and filled with equipment purchased, in part, with a \$50,000 Pennsylvania Department of Education grant.



AWS District 3 Director Sean Moran (center, right) is seen with LCTI welding teachers Brad Brandmeir (left) and Tom Uff (right) as well as student Jordan Everett (center, left). (Credit: LCTI.)

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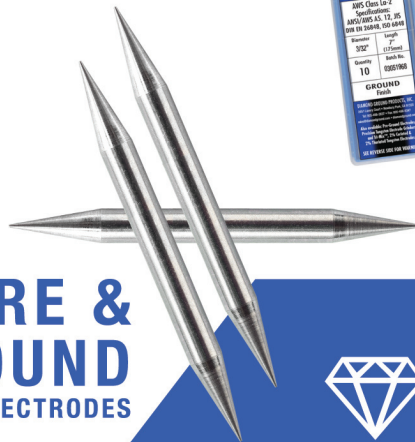


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NEWS OF THE INDUSTRY

— continued from page 12

• **Hobart Institute of Welding Technology (HIWT)**, Troy, Ohio, has earned the 2020–2021 Military Friendly® School designation. Institutions earning this distinction were evaluated using public data sources and responses from a proprietary survey. More than 1000 schools participated in the 2020–2021 survey, with 695 earning the designation.

Scott Mazzulla, president and CEO of HIWT, said the following: “Hobart Institute of Welding Technology is celebrating 90 years of educating welders (1930–2020). Throughout this time, we have been committed to training military veterans, dating back to 1945 when the Montgomery GI Bill offered educational benefits to help soldiers returning from World War II. Today, as it was back then, our military veteran graduates are highly skilled in welding and sought after by many employers. We take pride in the quality welding education we deliver to all our students.”

• **Texas State Technical College’s Workforce Training** office recently finished creating a mobile welding training lab inside a 42-ft trailer. It features four welding bays, one being wheelchair accessible, along with multipurpose welding machines, a fume extraction system, and a hydraulic wheelchair ramp. Staff expect the mobile lab to be taken to high schools, trade shows, and companies making requests for on-site qualifications. The welding qualifications that can be performed on board range from 1F to 6G.



The mobile welding training lab from Texas State Technical College’s Workforce Training office contains four welding bays, multipurpose welding machines, and more.

• **John Wood Community College**, Quincy, Ill., has received two equipment donations totaling \$33,000 to its welding program to provide submerged arc welding (SAW) training for students. Quincy-based **Titan International**, a manufacturer of off-the-road tires and wheel technology, made a \$23,000 donation of a SAW equipment and custom-made welding table. Additionally, **Lincoln Electric**, Cleveland, Ohio, which designs, develops, and manufactures arc welding products, robotic arc welding systems, and plasma and oxyfuel cutting equipment, donated an additional \$10,000 to the project in the form of a travel carriage, adjuster, mountings, and cabling.

• **Universal Technical Institute (UTI)**, Scottsdale, Ariz.,



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has expanded its welding technology program to two additional campuses. The program in Houston, Tex., will open in April, with classes at the Long Beach, Calif., campus to begin in August. The company currently has welding programs in Avondale, Ariz.; Dallas, Tex.; and Rancho Cucamonga, Calif. In addition, UTI plans to offer welding technology at a minimum of one additional campus in 2021, for a total of six welding technology programs.

NAM Unveils Creators Wanted Campaign

The National Association of Manufacturers (NAM), Washington, D.C., and The Manufacturing Institute, the workforce and education partner of the NAM, have unveiled their Creators Wanted campaign. This nationwide effort aims to reshape America's perception of manufacturing and confront the industry's skills gap.

By 2025, the campaign intends to reduce the skills gap in the United States by 600,000, expand the number of students enrolling in technical and vocational schools or reskilling programs by 25%, and increase the positive perception of the industry among parents to 50% from 27% today. Also, as part of the campaign, the NAM announced more than \$14 million in initial sponsorships from manufacturing companies for the Creators Wanted Fund. This will support programs and activities in 2020 and beyond.

The initiative will include an interactive mobile tour to inspire Americans in more than 20 states to pursue high-tech, high-paying jobs in modern manufacturing; a year-

long, nationwide digital campaign to recruit new talent to the industry; and a Making America Festival in Cincinnati, Ohio, in September.

Sikorsky Receives Second Contract to Build Presidential Helicopters



Photographed is a VH-92A® helicopter on the tarmac at Naval Air Station, Patuxent River, Maryland. The test aircraft has proven production readiness by undergoing U.S. government testing and operational assessments. (Courtesy: U.S. Navy.)

Sikorsky, Stratford, Conn., a Lockheed Martin company, will build six production VH-92A® Presidential Helicopters under a contract from the U.S. Navy. They are part of the 23

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Under the terms of the contract, known as Low Rate Initial Production Lot II, Sikorsky will begin deliveries of these helicopters in 2022.

"The program continues to progress on budget and within our planned acquisition timeline," said Col. Eric Ropella, PMA-274 presidential helicopter program manager.

The VH-92A aircraft at Patuxent River, Md., has proven production readiness by undergoing U.S. government testing and operational assessments, including more than 1000 flight test hours. The program is on track to enter initial operational test and evaluation later this year.

Bureau Veritas Partners with Infrastructure Preservation to Present Robotics Technology

Bureau Veritas, New York, N.Y., a provider of testing, inspection, and certification services, has entered into an exclusive partnership agreement in North America with Infrastructure Preservation Corp., Clearwater, Fla., a bridge and infrastructure inspection, nondestructive examination, and robotics engineering company. The company will deliver robotics and technology inspection solutions in the United States and Canada.

Bureau Veritas inspectors will utilize the impact of the robotics technology developed by Infrastructure Preservation to determine the condition and deterioration of bridges, roadways, and infrastructure to better protect public safety, reduce costs, better budget for maintenance and

repairs, and prolong a structure's life expectancy through early detection and repair. Delivering the inspection capabilities through the use of robotics allows the inspections to be completed without lane closures.

Industry Notes

• **FIRST®**, Manchester, N.H., a robotics community that prepares young people for the future, has named nine grants to address inequities in access to science and technology. The grants range from \$5000 to \$50,000, with an average of \$35,000. Its STEM Equity Community Innovation Grant winners include the following: Cleveland Public Schools, Ohio, to start five new robotics competition teams and support 24 existing regional teams, as well as the New York City Department of Education to support the creation of up to 16 new teams in School District 6.

• **Sunstone Engineering**, Payson, Utah, a manufacturer of precision micro-welding units and engraving systems, is collaborating with **EWI**, Columbus, Ohio, an engineering service provider, as a strategic technology member. They will collaborate to advance pulsed arc welding and micro-resistance welding technology. Sunstone is providing EWI with three pulsed arc micro-welding systems, two resistance micro-welding systems, and a tabletop micro laser welding unit. Its contribution to EWI's microjoining lab will

— continued on page 85

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ESAB Transitions to Exaton™ for Welding Filler Metals Portfolio

ESAB Welding & Cutting Products, Annapolis Junction, Md., a producer of welding equipment, consumables, and automation equipment, has finalized the Exaton™ brand name for all welding filler metals involved with its acquisition of Sandvik Welding Consumables.

For stainless consumables, the Sandvik name has been replaced with the Exaton followed by the American Welding Society/American Society of Mechanical Engineers (AWS/ASME) classification of the product. Additionally, the nickel-based consumables, previously sold under Sandvik and Sanicro, have been renamed with the Exaton followed by the AWS/ASME classification of the product.

“We believe that keeping the alloying number structure will minimize the change for customers and distributors, as will keeping all article numbers the same,” said Henrik Calander, general manager of specialty alloys, ESAB.

The change is solely related to the Exaton brand transition and only affects product names on labels, packaging, certificates, and Material Safety Data Sheets. Users can find a complete list of Exaton product names at esabna.com.

Toyota Indiana Completes \$1.3 Billion Modernization Project; Commits \$1 Million to Regional Workforce Program



Toyota Indiana Plant President Leah Curry presents a \$1 million donation to the 4T Manufacturing Academy in Princeton, Ind.

Toyota Indiana, located in Princeton, has invested an additional \$700 million and added 150 new jobs to complete its plant modernization project. In total, the project has included 550 new jobs and an investment of \$1.3 billion, which was used for retooling, new equipment installation, and advanced manufacturing technologies to modernize the facility and meet demand.

This new investment is part of a broader commitment from Toyota to invest \$13 billion in its U.S. operations over a five-year period through 2021.

“For more than 20 years, Toyota has been providing quality career opportunities and helping train Indiana’s future workforce. I am so grateful that Toyota remains committed to Indiana, and am thankful for all they are doing to continue making Indiana the best place to live, work, and play,” said Indiana Governor Eric Holcomb.

In addition to the plant investment, Toyota Indiana has committed \$1 million to a regional workforce program that will connect students with career opportunities in advanced manufacturing while still in high school.

“This program will allow students to get a jump start on

their careers while receiving hands-on training with industry experts and educators,” said Leah Curry, Toyota Indiana plant president. “By collaborating with our local schools, we are creating a workforce solution — but, more importantly — providing greater visibility to student career options and pathways in the region.”

U.S. Department of Labor Celebrates Women’s Bureau Centennial

The U.S. Department of Labor has commemorated the centennial anniversary of the Women’s Bureau — one of the department’s longest-serving agencies — with a yearlong celebration to mark its establishment on June 5, 1920. The department plans to celebrate the agency’s centennial with the theme, “Our Purpose. Your Work.”

“For a century, the Women’s Bureau has been a consistent source of information, advocacy, and innovation for working women,” said Women’s Bureau Director Laurie Todd-Smith. “As the 19th director in the proud history of the Women’s Bureau, I am grateful to lead the agency as we set this monumental milestone, honor the valuable work, and pave a path forward to support all of our nation’s working women.”

During the centennial, the Women’s Bureau will collect testimonials on how the agency’s purpose and efforts have affected the lives and work of women and their families. These stories will be highlighted on the Women’s Bureau webpage and on social media with the hashtag #WB100.

Learn more about these commemoration activities and events at dol.gov/wb100.

Team Industries Recognized as Top Supplier for Bechtel



Team Industries Inc. received the 2018/2019 Supply Chain Excellence Award from Bechtel Corp. (Photo courtesy of Bechtel National Inc.)

Wisconsin-based Team Industries, a distributor of shop-fabricated pipe, piping assemblies, pressure vessels, tanks, supports, modules, and structural steel weldments, has received the 2018/2019 Supply Chain Excellence Award from Bechtel Corp., Reston, Va., an engineering, procurement, construction, and project management company, in recognition of its on-time delivery of pipe and vessel fabrication for multiple Bechtel projects.

Supplier companies were evaluated on multiple factors, including overall performance; delivering quality services/supplies on time; working collaboratively to meet milestones; and meeting or exceeding project expectations in aspects of safety, performance, technical expertise, and environmental compliance. [WJ](#)

Q: I am quite often asked, "Should I use ER4043 or ER5356 filler metal?"

A: Aluminum filler metals ER4043 and ER5356 (both of which have been around for more than 65 years) are the two most widely used filler metals in the aluminum fabrication industry. It is sometimes thought one or the other of these two filler metals can be used to successfully weld all aluminum base metal. This is not correct; there are often applications where other filler metals are required to produce welds appropriate to a specific requirement. However, there are many applications where ER4043 or ER5356 will suffice.

It is generally accepted all the arc-weldable (see note 1 in the conclusion) 6xxx series base metals, such as 6005, 6061, 6063, 6082, 6351, and all the 5xxx base metals, can be successfully welded with ER5356.

Also, all the arc-weldable 6xxx series base metals, plus any 5xxx series base metals with less than around 2.5% magnesium (Mg), such as 5005, 5050, and 5052, can be successfully welded with ER4043 (5052 being the highest Mg content 5xxx series base metal generally accepted as being suitable to be welded with 4043).

After recognizing the limitations based on the chemical composition of the base metals as outlined above, consider the following facts about each of these popular filler metals before selecting between the two.

Making the Choice

As a basic description, ER4043 is an aluminum filler metal with 5% silicon added, and ER5356 is an aluminum filler metal with 5% magnesium added.

- As mentioned above, ER4043 is not recommended for welding any of the magnesium base alloys (5xxx series) that contain more than 2.5% Mg, such as 5086 or 5083 base metals. The 5% silicon in the ER4043 filler metal, when combined with the higher magnesium in these base alloys, can produce undesirable mechanical properties in the weld.

- The ER4043 filler metal is suitable

for service temperatures greater than 150°F. However, the ER5356 filler metal, because of its 5% magnesium content, is not suitable for prolonged elevated temperature applications and, if used in such environments, may result in the formation of a continuous grain boundary network of precipitates that are highly anodic to the aluminum-magnesium matrix. This, in turn, can result in premature failure of the welded structure.

- The ER4043 filler metal has lower ductility in the as-welded condition than ER5356. If forming after welding, consider this fact when choosing the most appropriate filler metal. In addition, if ER4043 is used, special bending requirements are necessary when conducting guided bend tests for welding procedure and welder performance qualification because of this ductility difference.

- ER4043 is a softer alloy in the form of spooled welding wire than ER5356. Typically, when gas metal arc welding (GMAW), feedability will not be as critical when feeding the more rigid ER5356 filler metal. Compared to steel, feedability of any aluminum welding wire can be an issue, especially with the smaller diameter wires. The less rigid filler metals, such as 1xxx and 4xxx series, can compound this problem.

- The ER4043 filler metal will typically provide a higher rating for weldability and provide lower crack sensitivity than ER5356. ER4043 will generally produce welds with improved cosmetic appearance, smoother surfaces, less spatter, and less weld smut. For this reason, the ER4043 filler metal is sometimes more appealing to the welder.

- If there is a requirement for post-weld anodizing, the ER4043 filler metal is not a good choice because it will typically turn dark gray in color after the anodizing process. ER5356 will provide a much closer color match after anodizing, particularly on the 6xxx series base metals.

- When there are requirements to meet base metal as-welded transverse tensile strength in complete penetra-

tion groove welds (typically for welding procedure qualification), the ER5356 filler metal will not meet the minimum requirements for some 5xxx series base metals. It will typically meet the minimum as-welded strength requirements for 5005, 5050, 5052, and 5086 base metals; however, it will not typically meet the minimum as-welded strength requirements for 5083 and 5456 base metals.

- ER4043 has a lower tensile strength than that of ER5356. This lower strength also relates to shear strength and is important when calculating the size of fillet welds. The nominal as-welded tensile strength of ER4043 is around 24 ksi, and the nominal as-welded tensile strength of ER5356 is around 35 ksi. These differences are substantial and, if not fully understood and taken into consideration, may affect the service performance of a welded structure.

A New Alternative to 4043 and 5356 Filler Metals

In 2011, a new aluminum filler metal, Alloy 4943, was registered with the Aluminum Association and added as a new classification into the 2012 edition of the American National Standard, American Welding Society (AWS) A5.10, *Welding Consumables — Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum Alloys — Classification* as ER4943 and R4943. This alloy was designed to provide industry a filler metal with all the same positive characteristics of filler metal 4043, but with a higher as-welded strength.

Filler Metal 4943 is recognized by ASME Boiler and Pressure Vessel Code Section IX and AWS B2.1, *Specification for Welding Procedure and Performance Qualification*, as being the same F-Number as 4043 (F23). In terms of nominal as-welded tensile strength, ER4943 (30 ksi) is between ER4043 (24 ksi) and ER5356 (35 ksi). ER4943 can be used in the same applications as ER4043 and has the same limitations, as outlined earlier. One significant difference between 4043, 5356, and 4943 is 4943 is a heat-treatable filler metal, whereas 4043 and 5356

are not. Excellent results have been seen when filler metal ER4943 has been used in postweld heat treatment of 6xxx series base metals.

Conclusion

There are many aluminum base metals that provide the option of welding with 4043, 4943, or 5356 filler metal. However, based on the facts presented, understand and select the most appropriate filler metal for the job. The application and service conditions of the finished welded structure are generally governing factors and will often dictate the most suitable filler metal selection. When considering filler metal selection, use a filler metal selection chart to assist with choosing the most appropriate filler metal. In addition, conduct procedure qualification testing to evaluate the filler metal selected and verify its performance characteristics. If you would like a filler metal selection chart, email me at tony.anderson@millerwelds.com with your mailing address, and I will send you one for free.

Note 1. There is a small selection of 6xxx series base metals designed for their machineability, not weldability. These base metals are typically recognized as being unsuited to the arc welding processes. One such base metal is 6262, which contains 0.40 to 0.7% bismuth and 0.40 to 0.7% lead. The addition of bismuth and lead greatly assists in chip formation in these free-machining base metals. However, because of the low solidification temperatures of bismuth and lead, these base metals become very susceptible to hot cracking and, for this reason, are not generally arc welded. **WJ**

TONY ANDERSON is director of aluminum technology, ITW Welding North America. He is a Fellow of the British Welding Institute (TWI), a Registered Chartered Engineer with the British Engineering Council, and holds numerous positions on AWS technical committees. He is chairman of the Aluminum Association Technical Advisory Committee for Welding and author of the book *Welding Aluminum* — Questions and Answers currently available from AWS. Questions may be sent to Tony Anderson c/o Welding Journal, 8669 NW 36 St., #130, Miami, FL 33166-6672, or via email at tony.anderson@millerwelds.com.



Do You Have an Aluminum Question?

Email your submission to the *Welding Journal's* Aluminum Q&A author, Tony Anderson, at tony.anderson@millerwelds.com or send it to his attention at

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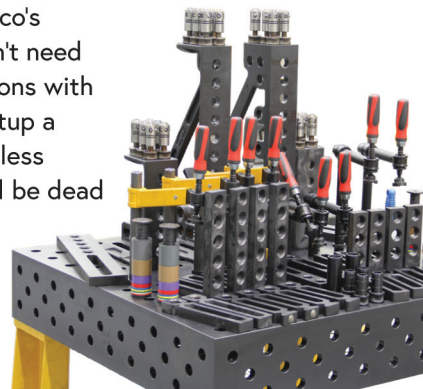
Your aluminum question may be chosen for this bimonthly column and help other individuals better understand how to solve a particular problem.



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Q: We are brazing honeycomb rings onto the inside diameter of some metal ring housings for aero applications, but we've occasionally seen some of the honeycomb pull away from the substrate during the furnace brazing process. We thought we were tack welding the honeycomb to the substrate correctly, but wonder why some of those honeycomb rings fail to remain fastened to the substrate and pull away instead. What might cause this to happen?

A: The photos that you sent seem to indicate that your tack welding may not be sufficient to hold the honeycomb in place on the inside diameter (ID) surface of the substrate during the full heating and cooling cycle of the brazing process. Another issue may relate to your application of brazing filler metal (BFM) in the honeycomb. A third issue may relate to the furnace brazing cycle that you used. Let's look briefly at each of these three possibilities.

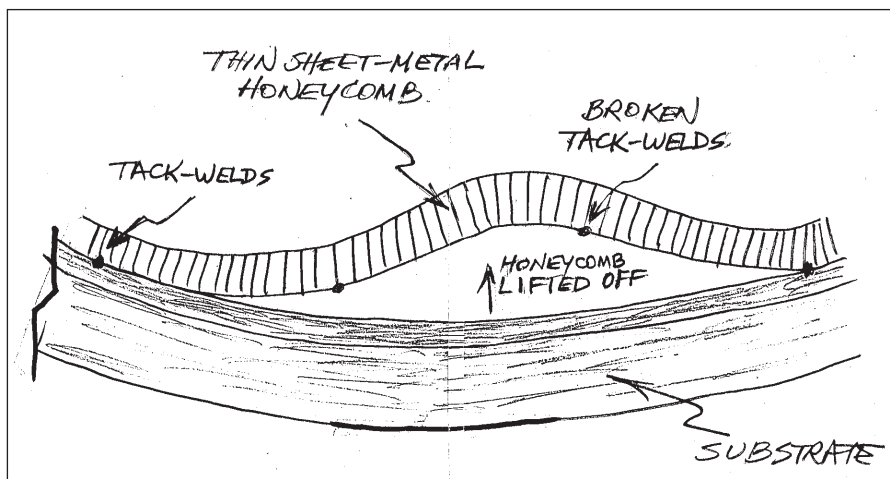


Fig. 1 — If the tack welds are insufficient in number, or too weak, the honeycomb might pull away from the substrate during heating.

Expansion/Contraction

First of all, a major factor in this entire honeycomb brazing process relates to the expansion and contraction of the metals themselves. All metals expand when heated, and then shrink (contract) when cooled, the amount of

which depends not only on the so-called coefficient of thermal expansion (COE) rate of each of the two base metals, but will also depend a lot on the mass/weight of those metals. More massive structures (such as the substrate on which the honeycomb is placed) will take more time to absorb

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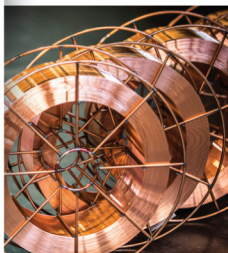
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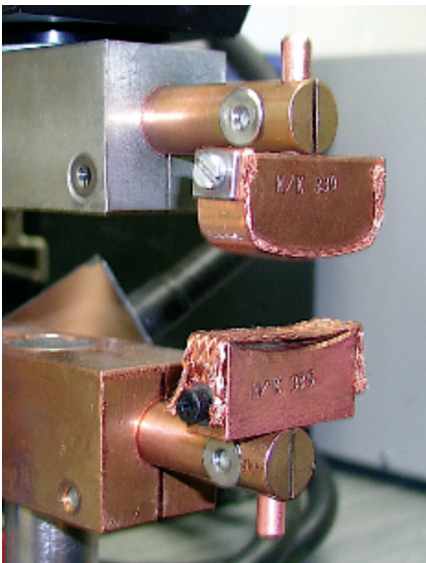


Fig. 2 — A typical spot welding machine modified to hold honeycomb tack welding heads that will conform to the shape of the honeycomb and substrate. (Photo courtesy of Honeywell.)



Fig. 3 — Honeycomb assembly is pressed between the two spot welding heads using controlled pressure and discharge power. (Photo courtesy of Aimtek/Soudax.)

heat and grow (expand), whereas very thin sheet metal structures (the honeycomb itself) can rapidly absorb heat and expand quickly compared to the heavy substrate, even if their COE rates were very similar. This is important.

Let's assume for a moment that the honeycomb and the substrate were made from almost identical materials that had almost identical COEs. It can be easy for some people to believe that since the COEs were essentially identical, that just a few light tack welds should hold the honeycomb in place until brazing is completed, since the honeycomb and substrate will grow and contract at the same rate. Unfor-

tunately, that just doesn't happen because you must take the relative mass of the two metals into account also.

As shown in Fig. 1, the thin honeycomb will grow rapidly during heating, faster than the substrate — so much so that the honeycomb can actually buckle slightly, pulling away from the substrate during heating, perhaps even breaking some tack welds (if the welds were very weakly made). This results in portions of honeycomb that will not braze, since they are no longer intimately in contact with the substrate.

Proper Tack Welding of Honeycomb to Substrate

It is your job to be sure that when the metals are heated and want to grow, the thinner honeycomb and the heavier substrate will expand and contract together, as much as possible. The only way for this to happen, realistically, is for the lightweight honeycomb to be strongly fastened to the heavy substrate along their complete interface, so much so, that the honeycomb will be "forced to conform" to the heavier substrate, and expand/contract along with that heavier substrate. This can be achieved through tack welding the honeycomb to the substrate in many places along the length of the honeycomb.

Figures 2 and 3 show typical setups used for tack welding the honeycomb to the substrate. This kind of tack welding setup uses a capacitive discharge spot welding machine that sends high energy through the honeycomb and melts a tiny bit of the honeycomb and the substrate metal below it to form a continuous path between the two that allows the electrical energy to flow through the grounded substrate.

The size of the weld bead that is formed by this instantaneous discharge of electricity depends on the amount of power sent between the two spot welding machine heads, the conductivity of the metals, and the pressure being used. Thus, the higher the conductivity of the metals involved, the greater the power that will be needed to generate a sufficient tack weld to hold the honeycomb in place throughout the subsequent brazing cycle.

Please be aware that, as shown in Fig. 3, the flexible copper sheet on the top electrode is pressed against the



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honeycomb and the discharge of electricity will seek the quickest path through the honeycomb and substrate, thus forming a light tack weld along that shortest, low-resistance, electrical flow path. As such, only one tack weld will be generated along the width of that honeycomb to hold it to the substrate. If you want to have the complete width of that honeycomb bonded to the substrate, then you'll need to shift the honeycomb slightly between those two heads to get a tack weld in a slightly different spot.

To have the honeycomb properly fixtured to the substrate via tack welds, it will be necessary to create a myriad of tacks along the width and length of the honeycomb. Otherwise the honeycomb may not remain firmly attached to the substrate during heating/cooling in the brazing process.

It is important to note the amount of discharged electrical energy must be sufficient to hold the honeycomb in place to the substrate throughout the brazing cycle, but should not be so intense as to cause arcing/sparking/oxidation at that weld location, since the molten BFM will not braze to oxidized surfaces.

It is also important to note the amount of pressure used between the two weld heads at the time of electrical discharge is important, but must not be so high as to crush the honeycomb, or so weak that it does not adequately close the gap between the honeycomb

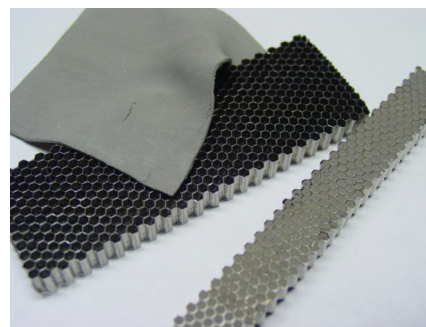


Fig. 4 — Brazing tape is a flexible, gum-like sheet that can be pressed into the bottom of the honeycomb so the BFM can join the honeycomb to the substrate on which it is sitting. The surface of the honeycomb cells on the right of photo must now be scraped clean before actual brazing. (Photo by Dan Kay.)

and the substrate to which it is being tacked.

BFM in Honeycomb Cells

The BFM is typically applied as a tape, and rolled into the honeycomb structure — Figs. 4, 5. It can also be applied as powder into the honeycomb cells after the honeycomb has been properly and fully tacked to the substrate. You indicated that you used brazing tape in your application. It is very important to remember the BFM must be thoroughly scraped off the bottom ends of the honeycomb cells before attempting to tack weld the honeycomb

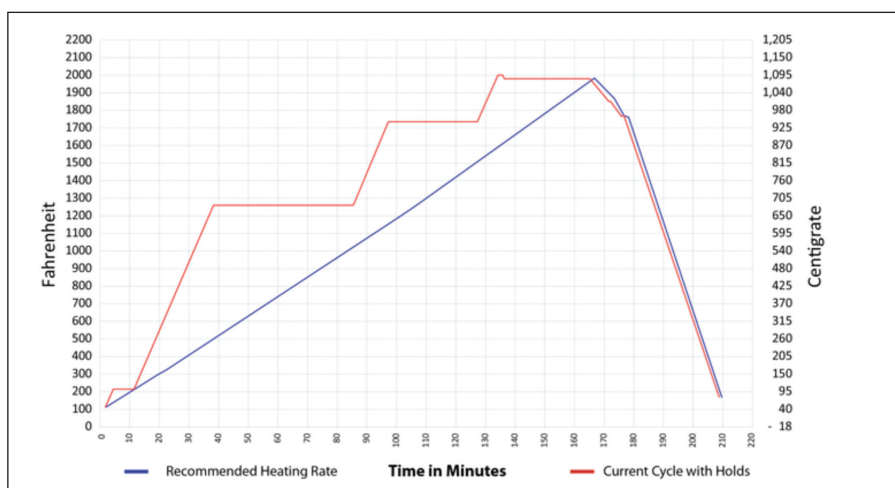


Fig. 5 — Proper heating up to brazing temperature does not involve any built-in holds, but follows a steady line up to the brazing temperature. The only reason holds are needed is because the heating rates used are much too fast, thus potentially leading to distortion on the way up to the brazing temperature. (Drawing by Dan Kay.)

to the substrate, so there is a clean metal-to-metal contact between the bottom of the honeycomb and substrate when they are pressed together for tack welding. The “taped” honeycomb cells on the right side of Fig. 4 show the presence of BFM on the honeycomb cell surfaces that need to be removed prior to tack welding to the substrate.

Brazing Cycle

Many companies heat their assemblies too fast for brazing, thus necessitating built-in “holds” to be instituted during the heating of the parts to allow for temperature equalization on the way up to brazing. This is very poor practice and can be especially dangerous during honeycomb brazing. As shown in Fig. 5, you should find the heating rate will allow you to go up to brazing temperature without the need for built-in holds. By so doing, the honeycomb and substrate can remain

in much better contact throughout the brazing cycle, and some of the problems, such as that you are asking about, could be eliminated.

Conclusion

Figure 6 shows what can happen when tack welding is not done properly, and/or the brazing cycle is much too fast. In this particular case, because there were only a few tack welds made along the length of the honeycomb, the buckling of the honeycomb during heating prevented it from bonding to the substrate in a number of spots along its length when it reached brazing temperature and then, during cooling, the very lightweight honeycomb structure shrunk (contracted) much faster than the substrate below it, pulling away from the surface.

Take the proper amount of time to be sure the honeycomb is properly and thoroughly tacked to the substrate,



Fig. 6 — Improperly brazed honeycomb has pulled away from its substrate, as seen in this post-braze picture. (Photo courtesy of Aerovision.)

the BFM application was done correctly in each honeycomb cell, and the brazing cycle allows everything to come up to brazing temperature together. When that happens, beautiful honeycomb brazing will result. **WJ**

DAN KAY (dan.kay@kaybrazing.com), with 45 years of experience in the industry, operates his own brazing training and consulting business.

This column is written sequentially by TIM P. HIRTHE, ALEXANDER E. SHAPIRO, and DAN KAY. Hirthe and Shapiro are members of and Kay is an advisor to the C3 Committee on Brazing and Soldering. All three have contributed to the 5th edition of the AWS Brazing Handbook.

Readers are requested to email their questions for use in this column to the authors, cweihl@aws.org, or send to their attention at Welding Journal, 8669 NW 36 St. #130, Miami, FL 33166.

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Welding Sisters Make Their Mark in Male-Dominated Field through Dunwoody College

The Welding Journal reached out to the next generation of welders to share their journey from the service industry to welding.



Welding Sisters (from left) Tonya Robarge and Rene Nichols, Dunwoody College of Technology welding graduates, are making a name for themselves in the welding industry. (Photo courtesy of Dunwoody College.)

Rene Nichols and Tonya Robarge aren't just sisters. They're welders, and they are making a name for themselves in a previously male-dominated field.

More than 20 years ago, it was rare to see a woman behind a welding mask. Now that image is gaining popularity, but according to the Bureau of Labor Statistics, females still only make up about 6% of the workforce nationally in the areas of welding, brazing, and soldering. However, a new generation of female welders, including Nichols and Robarge, is looking to change that statistic — and the face of the industry.

From the Service Industry to the Welding Shop

Nichols didn't initially set out to defy long-standing gender stereotypes. Working various positions in the service industry, such as a restaurant host, sandwich maker, delivery driver, shift manager, and more, she was only looking for a way out.

"I had been working in the service industry for 12 years in many roles . . . I remember one day I was so unsure of my future, I started browsing reasonable local colleges and found Dunwoody [College of Technology, Minneapolis, Minn.], which is just 1.5 miles from my house. I always

thought welding looked so cool . . . so I signed up, found an amazing scholarship program called Women in Technical Careers that is run through Dunwoody, which awarded me \$10,000 as long as I kept my GPA up, got accepted, and went to college for the first time in my life at 30 years old . . . What led me to welding and enrolling into the welding program at Dunwoody was that I was just ready to move on with my life," said Nichols.

Dunwoody College's welding program curriculum is closely aligned with standards set forth by the American Welding Society (AWS), which ensures students graduate with the skills employers are looking for. For example, all faculty members are AWS Certified Welders.

Additionally, Dunwoody established the Women in Technical Careers scholarship program to help female students succeed in a technical degree program and launch into a career.

"Just getting accepted into college was huge for me. I felt scared and excited and so unsure of myself for the first two weeks. After that, I really took hold and committed myself to learning and being the best that I could be . . ." Nichols recounted. "I woke up early and excited every day that I got to go to school. I was the only one in my class (of 18 people; 4 women, 14 guys) who had never touched a [welding machine] before. I was instantly drawn to the arc . . . Only two months into the welding program, I applied at a local South Minneapolis welding shop called LeJeune Steel Co. and was hired as a welder, even though I was so new to everything."

Nichols found mentors through her instructors in the welding program. She recalled Welding Instructor Mark Schwendeman's drive helped prepare her for a job in the industry. But her inspiration came in the form of her female welding instructor, Denise (Seven) Bailey.

"It was so cool to have a womyn* teacher and mentor to me," she said. "In high school, they had the girls take cooking classes, and the guys got to do shop. What I learned and saw from Denise was that we belong in the shop, or wherever we please, too. I never felt so empowered until I knew Denise." (Note: Nichols spells "woman" this way because it is inclusive to all people.)

Following in Her Sister's Footsteps

Robarge's path to welding followed similar paths as that of her sister.

"I didn't do well in school. I had a hard time sitting still long enough to do homework or study for tests," said Robarge. "I honestly remember thinking there was something wrong with me, and that I'd never be able to make a life for



Rene Nichols and Tonya Robarge work on setting up a welding machine. (Photo courtesy of Dunwoody College.)



Tonya Robarge works at LeJeune Steel Co., where she is employed as a welder/fabricator.

myself, so I had no ambitions to go on to college after graduating high school.”

Like Nichols, Robarge worked for more than a decade in various roles within the service industry, including Petco and other retail stores. After the birth of her son, Robarge knew she needed to make more money. She found employment with a drywall installer, which she unexpectedly came to enjoy.

“I loved it!” said Robarge. “It was everything I had wanted in a job, but never knew. I got to stay busy mentally and physically, and I got to work with my hands and create things that would be around for hundreds of years, and I made four times more per hour than I had ever made. I had figured out who I was and what I was capable of . . . Things were going so well, and I remember thinking that I had made it.”

Then the housing market crashed, and Robarge found herself laid off. She went back to the service industry, making minimum wage at a sandwich shop in 2009. Although she worked her way up to general manager, she was unhappy.

“Eventually, it just got too painful to go into a job that I hated more every day . . . so I cut my ties and never looked back. I got a full-time job right away making decent money at Home Depot, which was at least closer than the sandwich shop and to what I wanted to be doing, in April of 2018. And then my sister started talking about the welding program at Dunwoody. I had never really considered going back to school, because I just didn’t see any way that I could possibly afford it, and I was terrified of being just as bad of a student as I was in high school and then having to pay for it to boot.”

Through Nichols’ enjoyment and praise of the college’s welding program, Robarge took the leap and enrolled.

“I was 36 when I started at Dunwoody, and I really never in a million years saw myself going back to school. So just making the decision to do it and having it pay off 100% has been like winning the lottery for me,” said Robarge. “I’m so grateful to her [Nichols] for having the courage to jump into the unknown like that, because I don’t think I would’ve ever been able to take that leap without her. But she loved it so much that I followed right behind her.”

Sources of Encouragement

Both women also have their father as inspiration. Their father worked in the construction industry as a carpenter

his whole life. Nichols and Robarge recall him pointing at skyscrapers and saying, “I helped built that.”

“The fact that he built things with his hands that were going to be around for hundreds of years was so impressive to me,” said Robarge.

Nichols has received many achievements during her time in the welding program. She was on the Dean’s List, graduated with a high GPA, and was featured on the Trades Hub website as a welder. She hopes to inspire the younger generations to get into the trades and defy the odds.

“They want women out there. It’s not just a man’s job; they need you,” she said. “There are going to be around 400,000 welding jobs open in the next 10–15 years, baby boomers are all about to retire, and we need more young people to get into the trade.”

Nichols is currently a welder/fitter at LeJeune Steel Co., Minneapolis, Minn., which has worked on U.S. Bank Stadium, Target Field (the home ballpark of the Minnesota Twins), buildings and bridges, and infrastructures. Robarge is also a welder/fabricator at LeJeune. They hope to parlay the knowledge they’ve gained from Dunwoody and LeJeune to inspire people as well as pass on their skills to the next generation.

“Thinking back to all of that, my life has been affected so positively just from learning a skill/trade that is so important and I will have for the rest of my life. Being a woman in a male-dominated field has also affected me in a positive way. I feel like us women out here are really making a name for ourselves, and that makes me excited for the future,” said Nichols.

Future Hopes and Dreams

“Me and my sister are talking about opening our own welding shop once we’ve gained more experience. I’m definitely going to teach my kids how to weld, and it feels good knowing I can pass on my dad’s legacy from me to them,” concluded Robarge. **WJ**

ROLINE PASCAL (rpascal@aws.org) is education editor of the *Welding Journal*.

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nual growth rate of 6.3% in revenue from 2020 to 2027. The 133-page report identifies the rising demand for stainless steel in consumer goods as a major factor driving this market's growth. Because stainless steel is resistant to corrosion, exhibits high toughness and ductility, and requires low maintenance, its utilization in consumer products (i.e., cookware, showpieces, and stoves) has increased. This demand is predicted to continue to propel the stainless steel market over the coming years. According to the report, another factor driving this market's growth is the increased production of automobiles, mainly in the emerging economies of Asia Pacific, the Middle East, and South America. However, the report also states the increased usage of carbon fibers, especially in the automotive industry, is expected to critically impact the stainless steel market over the coming years.

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— continued on page 85



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- Union Mine High School (Calif.)
- Waltrip High School (Texas)

Congratulations to these eight high schools!

Welding Educators Recognized for Going Above and Beyond

As part of the 2019 Harbor Freight Tools for Schools Prize, four high school welding instructors were among the 18 winners to receive more than \$1 million in awards

BY ROLINE PASCAL



Sikeston Career and Technology Center Welding Instructor Brent Trankler (left) reacts to being a first-place award recipient of the 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence during a surprise assembly in his classroom. Also pictured is Scott Springer, Harbor Freight Tools for Schools consultant. (Photo courtesy of Aaron Eisenhauer for Harbor Freight Tools for Schools.)

Harbor Freight Tools for Schools, a program of The Smidt Foundation, has dedicated itself to skilled trades education in America. This program was created to shine a light on excellence in skilled trades education in public high schools, which it has done since its creation in 2013.

One of its flagship programs is the Harbor Freight Tools for Schools Prize for Teaching Excellence, launched in 2017, which recognizes and awards skilled trades teachers and programs in public high schools across the United States. Like the skilled trades, the prize application and process require hard work, time, focus, and a commit-

ment to excellence.

In 2019, Harbor Freight Tools for Schools awarded more than \$1 million in prizes overall, including three first-place prize awards of \$100,000, with \$70,000 going to the public high school skilled trades program and \$30,000 going to the skilled trades teacher or teacher teams behind the winning application; and 15 second-place winners awarded \$50,000, with \$35,000 given to the public high school program and \$15,000 to the teacher or teacher team. The winners would also have the opportunity to work with other professionals and a network of instructors within the career and technical education (CTE)

community from all over the United States to develop curriculum and projects using best practices.

Four public high school welding teachers were amongst the 18 winners of the award — First-Place Winner Brent Trankler of Sikeston Career and Technology Center, Sikeston, Mo.; and Second-Place Winners Jacob Leair, Grants Pass High School, Grants Pass, Ore.; Jodi Lancaster, Livingston Area Career Center, Pontiac, Ill., and Michael Schweinsberg, Carroll County Career and Technology Center, West Minster, Md. The *Welding Journal* reached out to these instructors to share their achievements.

Brent Trankler: A Model of Lifelong Learning

Brent Trankler's foray into the industry as a welding instructor began in the U.S. Army, where he enrolled after graduating high school in 2000.

"I started out in the Army as a mechanic for an Engineering Battalion. A lot of the equipment we worked on was heavy equipment that was field used," Trankler said. "We had a welding, machining, and maintenance crew that I learned a lot from. Sometimes we had to fabricate parts, make structural repairs, hard surface blades, make custom tools, torch stubborn bolts, whatever it took to get the job done."

The Army veteran worked nearly four years in industrial maintenance before he decided to get his industrial education teaching license. He has earned two bachelor's degrees and two master's degrees, along with becoming a National Occupational Competency Testing Institute welding technology subject matter expert. He was hired at Sikeston Career and Technology Center (SCTC) in 2009 as the welding technology I and II instructor, but he continues to sharpen his welding skills to give his students an upper hand on how to navigate the welding industry. During the summers, he works as part of a welder/maintenance crew and operates an industrial training business throughout the year. The success of his students drives him to never stop welding.

"I take a personal interest in each student that crosses my path. My students come out of this [welding] program doing some big things," he said.

He boosts his students' confidence and pushes their limits by taking on large projects and allowing them to experiment, problem solve, and learn from mistakes to great success — Fig. 1.

"I don't give busy work. My classroom includes hands-on lab activities with over \$400,000 worth of current industrial cutting-edge equipment," said Trankler. "Everything I do comes from an industrial standard. We train to that, I go over all the technical knowledge behind each process, give personal demonstrations, and allow them time to work on perfecting it."

Additionally, the curriculum is aligned with the American Welding Society's (AWS's) National Skill Standards for the Training and Qualification of Welding Personnel. His students have the opportunity to receive

nationally recognized credentials. First-year students adhere to the AWS D1.1, *Structural Welding Code — Steel*, and second-year students work to the API 1104 standards. The weld tests students take are identical to the ones they get in the industry.

Due to Trankler's efforts, the welding program has seen student success rate rise annually. Upon graduation, almost all of his students pursue post-secondary education or receive job offers from businesses. According to Trankler, the SCTC welding program has a 95%-direct placement rate.

"I have students that go on to work as boilermakers, ironworkers, pipe/steam fitters, pipeliners, sheet metal workers in manufacturing systems, and many other related careers . . . I am an advocate for my students and am always looking for industry connections to help provide placement and opportunities for my graduates. My students continue to amaze me, and I couldn't be more proud of each of them," said Trankler.

Trankler was one of the three first-place winners. He learned about Harbor Freight's program three years ago and applied every year consecutively, being named a semi-finalist in 2018 and winning first place in 2019. Applying for the award allowed him to reflect on how to make his welding program stronger and implementing those changes.

"Early on, I included my advisory

board members and sent them out a list of equipment I was considering purchasing for the program. I wanted to make sure everything I was looking at aligned with area business and current industrial standards," he said.

With the prize reward, the SCTC welding program was able to purchase a band saw, a computer numerical control (CNC) plasma cutting table, pipe bevellers, a plasma cutting machine, an industrial rack for material storage, a milling machine, pipe stands, a welding table, and other needed equipment.

"Having a large financial burst like this has allowed me to update some large ticket items that I simply couldn't have done without this award," he said.

However, Trankler is continuing to look for ways to better the program.

"There are always areas in need of improvement. I am fortunate to be a part of a school district, community, and industry that is so supportive," he said. "Doing this is ultimately going to make my students better trained and industry ready."

He believes the program's greatest achievement is providing a workforce of craftsmen, and winning the Harbor Freight Tools for Schools Prize for Teaching Excellence will have a lasting effect on the community and welding technology program.

"I will forever be grateful and couldn't be more honored to be a part of the process," Trankler concluded.



Fig. 1 — Brent Trankler explains a blueprint to his students. (Photo courtesy of Aaron Eisenhauer for Harbor Freight Tools for Schools.)

Jacob Leair: The Welding Instructor to Call

Jacob Leair (Fig. 2) has been a welding instructor at Grants Pass High School (GPHS), his alma mater, for six years, after working in the plumbing, groundwater, and welding industries. He also served as a substitute teacher for several years, when he became known as the substitute to call for high schools that needed an educator to fill in for skilled trades classes. Today, he is also a 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence winner. But he did not originally set out for a career teaching welding. Leair's story began after graduating from GPHS in 1999, earning a scholarship for wrestling to the University of Oregon (UO).

"To be honest, I went to college to pursue my dreams of wrestling for a Division 1 program. I have always been a very hands-on person, and when jewelry making was the only option at UO, I jumped all over it. At the time, and I believe it to be the same now, there were no college programs offering teaching endorsements in welding or any CTE welding certifications . . . I graduated from the UO in 2004 with a bachelor of arts [degree], with an emphasis on history," said Leair.

From there, he worked at Ferguson Corp. in Tigard, Ore., then went on to build pumps for Western Hydro Corp. in Clackamas, Ore. After working in the industry for a while, Leair enrolled at the University of Phoenix, where he received his master's degree in education in 2007. After completing the master's program, he moved to southern Oregon. Then, the housing market crashed.

"I don't think I could have picked a worse time to move. The economy was awful, and teaching jobs were extremely hard to get. I had to combat teacher cuts as well as teachers hanging on for a few more years because they just couldn't afford to retire," he recalled. "I ended up working two to three jobs at a time and picking up a fourth wherever I could. From 2007 to 2013, I tried to substitute teach as much as possible. I also painted houses, worked a little construction, and officiated four different sports."

During the summers, Leair worked for Oregon Coach Crafters, where he learned to customize and repair recreational vehicles. Despite the hardships, he looks back on those years as a blessing in disguise.

"Early in my substitute career, I developed a reputation in the Douglas County and Roseburg School District as being the substitute to call if you

needed someone who could successfully and safely run CTE classrooms," Leair said. "I drew on my background from my teens and early 20s when I worked with my dad in the well water repair tech, as well as my AWS certified welding program at Grants Pass High School. With the budget cuts, they would often put teachers with little to no training in a shop class, and tell them to learn on the fly."

Anytime Leair was offered an opportunity to substitute for CTE teachers, whether long or short term, he would jump on it. Soon thereafter, he developed a love for teaching welding, and could often help teachers who were in those positions to better teach their welding classes.

"I started reading and learning as much as I could about the trade, and before long, I knew that this was my calling, and I wanted to be the best I could be as a welding and fabrication teacher," he said.

Finally, he was offered the welding instructor position at GPHS.

"For the first couple of years, I spent a lot of time learning, growing, and updating our old shop. I knew that I wanted to put an emphasis on theory as well as application, but I needed some help," Leair said.

Leair attended several professional development workshops, including the Lincoln Electric educator workshop, to take his knowledge and ability to the next level. He also reached out to a close friend and mentor, Ryan Eubanks, to help GPHS's welding education program grow within the region.

After a year of getting instruction from Eubanks, Leair saw the skill level of his students skyrocket. Today, his class combines industrial welding, fabrication, CNC plasma, foundry, and blueprint reading. His curriculum matches the needs of the regional welding industry and prepares students for jobs all over the country. According to Leair, students enrolled in the welding program have higher high school completion rates and higher attendance than the overall student body.

Since becoming the welding instructor, the welding program has earned many accomplishments. The program has won several events at the Rogue Community College STEM-tathalon/Weldathon and swept the Linn-Benton welding competitions last year. The program has also won several state-only individual events at Oregon State SkillsUSA, including

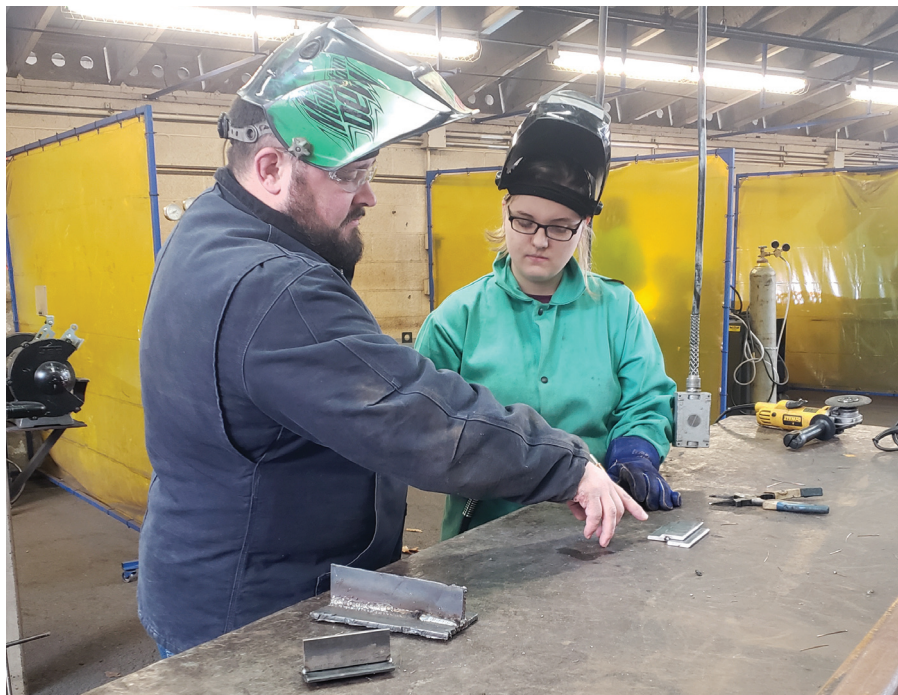


Fig. 2 — Grants Pass High School Welding Instructor Jacob Leair (left), a 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence winner, explains gas metal arc welding to his student.

state championship in team fabrication in 2015, welding and team fabrication in 2019, as well as placing sixth in welding and tenth in team fabrication at nationals.

"We have been recognized by our local news stations and newspapers for many community actions projects that we have been a part of," Leair added.

Leair acknowledges his students' accomplishments inspire him.

"I teach in an area with an extremely high-poverty level," he said. "When they latch on to this program . . . you physically see the change in them. I hear it all the time, and I'm sure other CTE teachers do, too, but every year kids tell me this is the only reason they are in school. Some even end up enjoying some other classes when they can draw real-life connections to other courses through welding . . . To see them have options for the first time in their lives, or to be able to help out with bills at home; sometimes even changing the trajectory of their family's future."

Leair is also inspired when a student leaves the program certified, or ready to be certified, and lands a great job or career in the industry.

"We have several AWS Certified Welders that have graduated this program. We have alumni welding in six different states currently," he said.

With the prize's earnings, Leair plans on purchasing a hydraulic shear or ironworker as well as a 5 × 10 ft CNC plasma cutting table for the welding program. He also plans on using the winnings for professional development and hopes the program will be able to attend the FABTECH show next year.

Leair has come a long way in his career as a welding instructor. Even with his hard work and determination, he humbly recognizes the support of his community and networks to lift him and his students.

"I know that there is no way I will ever learn everything there is to know about this stuff, but I do know that I am not afraid to be wrong, and I will always seek out those who can help myself and my students grow," said Leair. "In my life, I have always found a great deal of success through networking and creating meaningful relationships with people . . . I hope to learn more and give more knowledge to the students at GPHS. We are very community involved, and we will be able to give more back to Grants Pass."

Jodi Lancaster: Bringing a Trailblazing Spirit to the Classroom

"It actually had never crossed my mind to become a welding instructor," said Jodi Lancaster, Livingston Area Career Center (LACC) welding instructor. Now, she is the first female welding teacher to be recognized as a winner of the 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence.

Before deciding to go into the welding industry, Lancaster had been a cosmetologist as well as worked several years in different capacities in offices. She was only the second woman to attend Midwest Technical Institute's welding certification program in the early '90s to become a welder.

"Brian Hoffman, one of the founders of the school, actually met me at a store to help me buy my first pair of steel-toed shoes . . . I had no idea what a steel-toed shoe was let alone where to buy them at," she said. "I was also told I would need to wear long sleeves when welding because the ultraviolet [UV] light produced would burn my skin. My first day welding, I took off my long sleeves because I thought it would be like the UV rays of the sun and I would tan. I learned very

quickly that the two are not quite the same!"

In the '90s, it was rare to see a woman behind a welding mask. Lancaster had to prove herself to be considered equal, if not better, to her male counterparts.

"Once I was hired into my first welding position, I found I was the only female welder on my shift and again only one of two currently working for the company. It took close to a month to prove myself and become accepted as 'one of the guys' by the men I worked with," said Lancaster. "My foreman, who became a close friend, would walk by my station nightly those first few weeks shaking his head and loudly saying, 'She ain't gonna make it, she just ain't gonna make it!' but I did, and I couldn't have asked for a better career than the pathways welding has led me."

Welding gave Lancaster the financial independence to care for her family as a single parent. However, after meeting her husband and having two more children, the hours made it difficult for her to have a consistent schedule, so she decided to go back to school and become a special education teacher.

She was hired as a special education teacher at Pontiac Township High



Fig. 3 — Jodi Lancaster, Livingston Area Career Center welding instructor and a 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence award recipient, encourages her students to weld with materials of their choice. (Photo courtesy of Eric Ginnard for Harbor Freight Tools for Schools.)

School (PTHS), which is associated with LACC. Three years later, the director of LACC approached Lancaster about teaching a welding class. She immediately said yes.

"I spent the first couple of years learning what worked and what didn't, and over the next few years, a couple more welding classes were added to my load until I looked up one day and found I was the full-time welding technology I and II instructor for the LACC and the introduction to welding instructor for PTHS," Lancaster recounted.

Lancaster has been a welding instructor for 12 years — Fig. 3. She brings a trailblazing spirit to her classroom. She encourages her students to pursue their intellectual curiosity by welding with materials of their choice; for example, when one student wanted to use keys, the entire class studied metallurgy as it applied to making, melting, and welding keys.

"I am inspired by my students. They make me passionate about being an instructor and pursuing all avenues that will make me a better instructor or help me to make my curriculum the best it can be," she said.

Additionally, Lancaster tries to instill good habits early on in the learning process. She understands this will ensure her welding students are well prepared not only to create quality welds, but also to contribute positively to the overall welding operation.

"My students need to learn to weld, but just as importantly, they need to learn to work in teams proficiently and effectively. They also need to be able to work individually and be able to think ahead in the process, so they do not need someone giving them directions every step of the way. They need to show up every day and they need to be punctual. Forty percent of their grade in my class is attributed to these invaluable soft skills," she said.

Her students have also inspired her to start a local welding teacher roundtable to align on curriculum and a business roundtable to discuss industry needs.

"My director and I started a manufacturing roundtable and a welding instructor roundtable," said Lancaster. "Each of these have been developed to help me make sure I am teaching the skills that our industry needs and that I am teaching at the same standard or higher than other instructors in the same discipline. I am always trying to improve myself, so I can make my stu-

dents their very best . . . I just want to make my students as successful as possible, which means making myself as successful as possible."

With the prize earnings, Lancaster hopes to purchase new equipment for her students.

"A few years ago, I won a grant through the American Welding Society, which I used to buy welding machines that would provide my students the opportunities to work with exotic metals like stainless steel and aluminum effectively and with the same processes as the businesses in the area are in demand for. At this point, we are in need of more fabrication equipment," she explained.

She is aiming to provide the welding program with a fabrication table, bender and roller, track torch, English wheel, and a forger, amongst other equipment.

"I want to get more materials and would like to keep a cushion in my activity account for the next few years, because the welding program takes a lot of money to run, and I usually run out before the end of the year," said Lancaster.

The announcement of the Teaching for Excellence prize has allowed Lancaster and the LACC welding program to contribute more to the city. The city of Pontiac has requested the welding program to build light sculptures for the Festival of Lights. Lancaster and

her students have built an 8 × 8 ft Christmas present and an 8 × 5 ft Santa sled, which were part of the city's tree lighting ceremony. They have also been asked by the natural preserve park to renovate a canoe trailer.

"The money will allow my students to learn more skills and fabrication techniques that we have not had the ability to teach in the past," said Lancaster. "This will make my students better-rounded as employees, which in turn will make it easier for them to gain employment."

Michael Schweinsberg: Demonstrates the Business of Welding

Carroll County Career and Technology Center (CCCTC) Welding Instructor Michael Schweinsberg (Fig. 4) began his welding career as a farmhand after graduating from CCCTC himself.

"My interest in welding began at a young age while working on a farm. I was amazed at how many applications there were for welding on a farm," he said. "I discovered the welding program at the very technology center that I teach at now, enrolled, and my welding career began."

After graduating from CCCTC, Schweinsberg landed his first job in the welding industry with a bridge manufacturing company, working his



Fig. 4 — Carroll County Career and Technology Center Welding Instructor Michael Schweinsberg, who is a 2019 Harbor Freight's Prize for Teaching Excellence award recipient, hopes to modernize the welding shop to give his students a heads up in the real world. (Photo courtesy of Joseph M. Giordano for Harbor Freight Tools for Schools.)



Fig. 5 — Michael Schweinsberg (left) observes a student welding to ensure the correct procedure is used.

way up to shop foreman. From there, he branched out and started his own welding fabrication business. Soon after, he was contacted by CCCTC and offered a welding instructor position.

“Since I really enjoyed leadership roles and mentoring up-and-coming welders, I knew it would be a great fit,” said Schweinsberg. He has now been teaching welding for 16 years.

Schweinsberg brings his class to life by operating the program like a business, getting students to work with equipment, blueprints, and materials, just as they would on a job — Fig. 5. Business partners visit his classrooms to work with students, even interviewing them and offering jobs during school hours, which he attributes to the success of the welding program and his students.

“One reason that the program stands out and is successful is because of the large number of industry partners who mentor, hire, and engage with the students . . .” he said. “I encourage my students to be active members of the community. As such, they often do projects for organizations such as 4-H, Scouts, churches, etc. I try to instill the importance of being professional, productive, and to always try to achieve their best.”

Additionally, Schweinsberg encourages his students to enter into compe-

titions to push them out of their comfort zones and to pursue scholarship opportunities.

He finds inspiration through his work and enjoys molding entry-level students into welding professionals.

“This profession inspires me because I enjoy working with my hands,” said Schweinsberg. “I enjoy seeing the excitement in a student’s eyes the first time he or she strikes that first arc or lights the oxyacetylene torch, and watching that excitement grow as they progress . . . I’m proud to say that alumni keep in touch and even return to help mentor students.”

As a 2019 Harbor Freight Tools for Schools Prize for Teaching Excellence winner, Schweinsberg hopes to use the prize earnings to modernize the welding shop to give the students a heads up when entering the real world. He would also like to do the same with other programs that partner with the welding program.

“One of the big things that winning this prize has accomplished is that it brought visibility to the program via the publicity that generated. This money will allow me to ‘pay it forward’ in the form of procuring materials needed for things like practice tests or to build projects, thereby giving them real-world experience. When students get this experience, it gives them the

skills to prepare them for the welding industry,” he concluded.

Conclusion

With a deep respect for the skilled trades fields and for the intelligence and creativity of people who work with their hands, Harbor Freight Tools for Schools has aimed to drive a greater understanding of and investment in skilled trades education, believing that access to quality skilled trades education gives high school students pathways to graduation, opportunities, and good jobs.

Through its Harbor Freight Tools for Schools Prize for Teaching Excellence award, the organization shines a spotlight on excellent skilled trades teaching and attracts investment in these classes so a strong skilled trades education can once again be available to public high school students across America.

Applications for the 2020 Harbor Freight Tools for Schools Prize for Teaching Excellence are now open and will close in May. To receive information on how to apply, go to harborfreighttoolsforschools.org. 

ROLINE PASCAL (rpascal@aws.org) is education editor of the Welding Journal.

Tips for Qualifying to AWS D1.1

A journeyman instructor provides strategies to avoid pitfalls on the Welder Performance Qualification Test

BY HALINSON CAMPOS AND
JASON CHADEE

When it comes to passing the qualification test for AWS D1.1, *Structural Welding Code — Steel*, there's no substitute for spending time in the welding booth and the guidance of good instructors.

The Joint Apprentice Committee (JAC) of Iron Workers Locals 40 & 361, Astoria, N.Y., provide both the training time and guidance necessary for passing the exam. Its 12,000-sq-ft Iron Workers Training Facility is an American Welding Society (AWS) Accredited Test Facility serving the greater New York City area. The center features 35 welding stations and can administer welding tests to provide same-day certifications for contractors. The Locals have more than 1100 certified welders and 2500 journeymen who continually return to the school to sharpen their skills.

This article collects a JAC instructor's advice to help readers pass the Welder Performance Qualification Test. It focuses on areas that tend to cause the most weld failures, while illustrating how to correct them.



Holding the electrode perpendicular at the end of the plate minimizes arc blow.

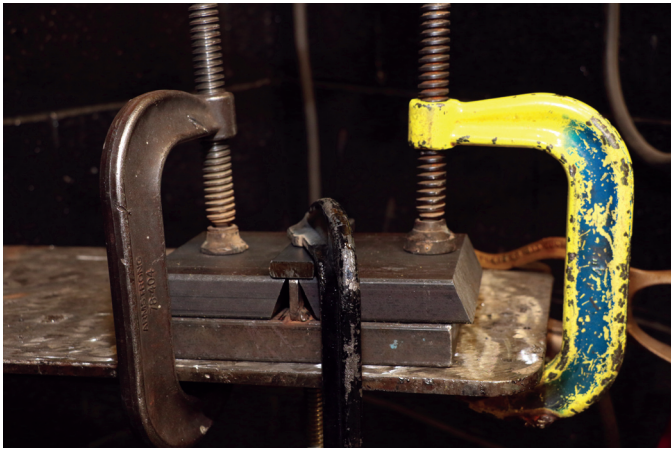


Fig. 1 — Clamp the backing bar firmly to prevent gaps that could trap slag.



Fig. 2 — AWS D1.1 requires 7018 electrodes to be used fresh from hermetically sealed packages or stored in a rod oven.

Brief Overview

The specifications for the welder qualification test include the following:

- Process: shielded metal arc welding, direct current electrode positive
- Electrode: AWS E7018, $\frac{1}{8}$ in.
- Base metal: ASTM A36 plate
- Plate thickness: 1.0 in. with 22.5-deg bevel
- Backing plate: $\frac{1}{4}$ or $\frac{3}{8}$ in.
- Root opening: $\frac{1}{8}$ in.
- Test position: 3G (vertical — up-hill progression), 4G (overhead).

The test requires making a complete joint penetration groove weld that extends completely through the thickness of components joined, transmitting the full load-carrying capacity of the structural components they join.

“The fundamental principles for making a good weld in the 3G and 4G positions are no different from welding flat,” advised Allister Lawrence, AWS Certified Welding Inspector (CWI) and Certified Welding Educator (CWE), as well as journeyman instructor, Iron Workers Locals 40 & 361. “The more you do it, the more you’ll get a feel for it. Practice the right way until it all becomes muscle memory.”

Preparation

Passing the AWS D1.1 qualification exam starts with good plate setup.

1) Use three clamps, one for each piece of metal, to prevent distortion from drawing the joint shut and to keep the backing bar solidly against the other two pieces — Fig. 1. If distortion twists the backing bar, it creates a void between the plates that can trap slag.

2) Select fresh electrodes. AWS D1.1, 7.3.2.1 Low-Hydrogen Electrode Storage Conditions, states, “All electrodes having low-hydrogen coverings conforming to AWS A5.1 and AWS A5.5 shall be purchased in hermetically sealed containers or shall be baked by the user in conformance with 7.3.2.4 prior to use. After opening the hermetically sealed container, electrodes not immediately issued for use shall be stored in ovens held at a temperature of at least 250°F [120°C] — Fig. 2. Because “electrodes shall be rebaked no more than once [and] electrodes that have been wet shall not be used,” smaller hermetically sealed packages can prevent wasting electrodes, especially on a jobsite (see side bar for more details).

3) Before creating any test welds, make practice welds to set amperage and any additional controls, such as electrode selection, hot start, and arc force control — Fig. 3. Every operator welds differently, as do different machines, so these settings will need to be fine tuned.

Setting Up for Success

Operators physically control four factors: arc length, electrode angle, electrode manipulation, and travel speed.

With a power source in constant current mode, remember that the operator sets amperage but the machine sets voltage according to its volt/amp curve. That said, operators can somewhat affect voltage by increasing or decreasing the arc length. Instructors invariably tell beginners to “hold a tight arc,” which would be about half the electrode

diameter to no more than an electrode diameter. A “long” arc would be 1.5 times the electrode diameter.

According to Lawrence, because the 4G position intimidates welders, they hold a long arc and move too fast, both of which increase the spatter and sparks they want to avoid.

“With a long arc, you lose control over the puddle [weld pool]. When you move too quickly, the puddle [weld pool] doesn’t have enough time to fuse to the base metal, so it droops. Slow down and hold a tight arc for good control,” he said.

It is recommended that prior to welding, you practice “air moves” to ensure unhindered movement. Tuck your elbows into your body to stabilize your hands and position your head adjacent to the joint so you can see the weld pool — Fig. 4.

“You don’t want to get in a position where you drag the electrode directly toward or away from you, because it’s like welding blind,” said Lawrence. “Get comfortable so you can maintain arc length, angle, or travel speed. It also helps if you come up with your shoulder, not your elbow.”

Arc Start

Keep every strike within the joint, as any outside strike marks disqualify the joint. E7018 electrodes require a specific arc start process:

1) Strike the arc about 1.5 electrode diameters in front of where the weld begins, e.g., $\frac{3}{8}$ in. from the edge of the plate or in front of the previous weld for a tie-in.

2) During arc start, hold a longer

arc (about $\frac{3}{16}$ in.) to prevent the electrode from sticking while the arc becomes established.

3) When the arc stabilizes, tighten arc length and move the electrode back to melt the edge of the joint or tie-in with the previous weld.

4) Move forward so the fully established arc welds over the spot of the arc strike.

Angles

For the 3G position, hold the electrode so it has a slight push angle (e.g., tilted back from the direction of travel) to nearly perpendicular to the plate. For the 4G position, tilt (drag) the rod about 15 deg in the direction of welding. However, as the electrode approaches the end of the joint, this guideline changes.

"The magnetic fields start going crazy because of arc blow," said Lawrence. "Changing to a more perpendicular position can minimize the distortion of the magnetic field and prevent blowing out the edge of the plate."

Arc blow occurs in direct current welding when the material being welded has residual magnetism that interacts with the magnetic field of the welding arc. While individual items may have relatively low residual magnetism, the magnetic field across the root opening can increase significantly when they are brought together for welding. When the electrode is near the edge of the plate, the normally circular lines of magnetic force can become distorted and concentrated, pushing the arc forward or backward.

Manipulation and Speed

On the root pass, the operator needs to incorporate the backing plate and side plates — Fig. 5. Some operators can completely fuse all elements with a straight stringer bead. Others find they need to use a slight side-to-side motion to ensure good sidewall fusion, especially for the 4G position.

"To prevent undercut, hold to the sides and speed across the middle," said Lawrence. "Avoiding undercut is the biggest challenge apprentices face. You don't want to leave 'wagon tracks' on the sides of the bead, especially since they can trap slag." As noted in AWS D1.1, 6.10.1.1 Visual Inspection of Groove Welds, fourth requirement,



Fig. 3 — Professional-grade inverter power sources have controls for setting "crisp" or "soft" arc characteristics.



Fig. 5 — On the root pass (shown here) and hot pass, hold to the sides of the joint to prevent undercut.

undercut shall not exceed $\frac{1}{2}$ in.

The duration of the "hold" is as long as it takes for the weld pool to flow to that side of the joint and melt and incorporate the beveled edge. The flux electrode touching the side will start to burn off first as well.

"The other reason people fail D1.1 on the root pass is because they move too quickly. Slow down so you incorporate the backing bar," explained Lawrence.

The hot pass will require more of a weave. Again, hold the sides but speed



Fig. 4 — Position your head adjacent to the joint to see the electrode and its relationship to the weld pool.



Fig. 6 — Alternate travel directions. Starting the new pass where the previous one ended fills in the "bowl" that tends to form at the end of the joint.

across the middle to keep the bead flat. Forward motion of the electrode should be about $\frac{1}{8}$ in.

"Small movements make tighter bead ripples," said Lawrence. "To me, tight ripples indicate the electrode stayed at the front of the puddle [weld pool], so the chance of trapping slag is much less compared to larger ripples."

After the hot pass, the groove will be wide enough to accommodate stringer beads, which is what Lawrence uses for all the remaining passes. He feels stringers make a

stronger weld because weaving necessitates a slower travel speed and increases total heat input. Furthermore, a hotter plate makes the weld pool more likely to sag out of position.

“Remember that the plate gets hotter as you progress, so you may need to reduce amperage. Better yet, allow the plate to cool between passes,” said Lawrence.

When making stringers, do not butt them up against each other. Instead, make sure each new bead overlaps a previous one. Also, switch directions between passes — Fig. 6. Starting on alternating ends fills the groove all the way to the end.

Final Advice

“Practice in the welding booth like you weld in the field,” stressed Lawrence. For example, do not stabilize the electrode between the fingers of the off-hand or drape the electrode cable over a shoulder. Both get hot during welding and could lead to a flinch and a weld defect.

Finally, there is no substitute for

hard work. Lawrence encourages apprentices by telling them that, “With training, anything is possible.” **WJ**

Acknowledgments

The authors would like to thank the JAC for its support. To bring the experience to life, we worked in the welding booth with Allister Lawrence, CWI, CWE, and journeyman instructor, and

Memesha Davis, a third-year apprentice, both with Iron Workers Locals 40 & 361.

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Keeping Hydrogen Low

E7018, or low-hydrogen electrodes, minimize the possibility of hydrogen cracking. These electrodes may also have additional related designations. An “H4R” designation indicates less than 4 mL of diffusible hydrogen per 100 g of deposited weld. Designed for moisture resistances, H4R electrodes have less than 0.4% moisture absorption after 12 h of exposure at 80°F and 80% relative humidity. These electrodes can be used straight out of their hermetically sealed package without the need to bake or store them in holding ovens or quivers to meet low-hydrogen requirements.

“As Iron Workers, we work in situations where rain can come through the deck and electrodes can get contaminated, so we’re very conscious of using fresh electrodes,” said Instructor Allister Lawrence. “Smaller electrode packages are easier for us because we already have a lot of other tools we need to carry on a jobsite. They also save trips to the rod oven, which is on the first floor.”



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National Welding Month: Highlighting Industry Pros

Gain insight from three early-to-mid-career welders

BY COREY STULCE

We're looking at a 2.4 million worker shortage of manufacturing professionals by 2028 (Ref. 1), which is one of the reasons why recognizing National Welding Month is more meaningful than ever.

Now is the time to examine why the percentage of qualified welders is shrinking and what can be done. The manufacturing industry isn't going anywhere. Its practices evolve with emerging technologies, and it remains an essential component of most other enterprises.

Let's look to the present to offer hope and protection for the future.

Educating on the Possibilities

Three early-to-mid-career welders, Tom Hammer, Ernest Coolong, and Brian Thessen, are a testament to what welding can do for you. The trio make up the core team who solve problems with difficult-to-achieve welds at Axenics, a more than 40-year-old contract manufacturer in New England — Fig. 1. They focus on high-accuracy weldments using gas tungsten arc welding (GTAW). This process is considered to yield welds of the highest quality and purity, while also being one of the most challenging to master due to its intricate nature.

When asked why younger generations are not entering the trades, Hammer centered on pay. "Often, the big thing for them is the money isn't always there. Why be a welder if you get really good only to make 70 grand per year and can make way more than that sitting at a computer? It's hard to take that differential."

But this perception isn't entirely correct. There are welding jobs out there with great benefits and pay, but sometimes you have to chase the



Fig. 1 — From left, Brian Thessen, Tom Hammer, and Ernest Coolong are journeyman metal welders for Axenics, a contract manufacturer in New England.

work. There's also the option of becoming an independent contractor, although that requires its own discipline to find success.

Coolong pointed at the work environment when asked why less kids are joining the welding industry.

"We're lucky that, at Axenics, we have a good environment, it's climate-controlled, and we are not micromanaged...there are different atmospheres in different shops. It is important to address the concerns of people not wanting to get into welding. Sure, you can go work in an office and that might be a better environment for you — and it might not. It all comes back to the culture of the company and where your priorities lie," Coolong said.

Enticing Generation Z

The generation entering the workforce today, born after 1996 and

dubbed Gen Z, has always known digital technology, has spent a larger percentage of their life in front of a screen, and is, therefore, hardwired to expect to make a living in front of a screen.

"The biggest problem we have in filling the trades is that kids want to be on a computer all the time, and don't want to aim for physical jobs," Welder Tom Hammer said.

Another characteristic associated with Gen Z is they expect instant gratification, which generally goes against manufacturing principles, and especially the intricate and gained-through-experience skills needed to master GTAW — Fig. 2. However, with hard work and know-how come additional opportunities.

"We paid our dues, did our time chasing jobs, sometimes going to one, a shut down (a big plant that temporarily closes so repairs or additions can be made), then going after another

[job],” Thessen said. “As we got more experience, our skill level got higher, and now we can do high-tolerance welds with minimal room for error. Some people see this and don’t realize they have to put the work in.”

Defying Stereotypes

There’s a longtime stereotype that students who are attracted to shop class and later trade schools do so because they’re not as intellectually savvy as others and are settling for what they can get. This is simply not true.

The melding of old-school manufacturing techniques with smarter machinery means tomorrow’s workforce needs to have those hands-on skills as well as digital technology know-how. For example, newer welding machines integrate artificial intelligence, so the machine can sense if you have the right angle and can correct it. If you’re traveling at the wrong speed, it can also notify you. If the distance from the workpiece to the torch is off, it will pick up the voltage that dropped or alert the welder to get closer.

Be Aware of Your Opportunities

Perhaps the biggest challenge is a lack of knowledge about the options students have today. For example, only 27% of parents consider manufacturing a viable career option for their school-age children (Ref. 2).

By visiting careersinwelding.com, a wealth of information can be found, from why you should become a welder to available scholarships.

Coolong summed it up: “Just watch that movie, *Office Space*; that dude was miserable in his cubicle. At the end, he loves being outside, working with his hands.”

Youthful Revelations

All three welders discovered their love for the art as students. For example, Hammer was motivated by his relatable high school welding teacher.

“My favorite teacher in high school was Anthony Hanna, who taught metals. He’s really down to earth, and had his own welding business on the side. He ended up teaching at Manchester Community College (MCC), so I got to follow him there,” Hammer said. “Welding always clicked with me. Ex-

perimenting with it in high school classes made me want to understand it better. Halfway through school, my first job was working on aircraft parts.”

Coincidentally, Thessen also teaches welding at MCC in Manchester, N.H., where Hanna still instructs. At 18, Thessen landed in a program for future manufacturers, and quickly worked to pass a structural welding certification test, giving him opportunities to advance his career and make more money. He earned a degree at MCC, and the educators there were so impressed, he was asked to stay as an adjunct welding instructor.

Coolong was drawn to welding as a kid because he saw how it allowed him to merge his different interests.

“I always enjoyed art class and shop,” Coolong said. “I grew up in a mill town. Someone donated a 4-foot saw blade to the school, and a student was going to use that piece of metal to cut out the school’s mascot to display on the football field. He didn’t end up doing it, so I traced it and played with a cutting torch to make it. It married two things I love, working with my hands and making art. I quickly discovered that welding could fix some of the mistakes made while working with metal.”

Coolong added, “There’s something to be said for building something that’s tangible.”

The Value of Hands-On Work

All three welders agreed students would benefit from exposure to hands-on work, as many have not had the op-

portunity to discover a talent and potential passion for it.

“It’s very fulfilling to produce high-quality welds that can only be complete when done correctly,” Coolong added. “Sometimes it takes a bit of ‘magic’ to fix it.”

“There’s a sense of pride, too,” Hammer said. “Think of people who weld on bridges, then get to cross over that bridge. I was the one that welded a third of this bridge, and hundreds of thousands of people cross this bridge every month.’ Those welds are completed to the maximum scrutinizing detail, and are not being performed by a machine.”

Welding’s Artistic Attributes

Thessen utilizes the “cool factor” of welding to entice students to take classes — Fig. 3. He has also inspired more young women to take an interest in the craft.

“You get to manipulate lightning with welding and play with fire when working with metal and really see the sparks fly,” he said. “Metal is also very malleable. You can really transform it with heat and electricity, and take metal and turn it into whatever you imagine. You can change its color, its hardness, shape, create fulcrums and levers — the possibilities are endless.”

Motivation Matters

Coolong said there are opportunities for young welders to learn exactly



Fig. 2 — GTAW is possibly the most physically challenging manual welding process to perfect, as it requires the constant use of all four of the welder’s extremities.

what drives their passion while starting out in entry-level roles.

"It does depend on the kind of leeway a company gives you. Maybe you work for a company that lets you tinker on some personal work during your lunch break. You can save up, get a welder [welding machine], and do stuff at home. Make some art and sell it on Etsy," he said. "The artistic side I found was to make my weld bead look perfect every time."

Abstract GTAW

Also on the artistic side, Thessen said he prefers abstract GTAW because it allows the welder and inner artist to come together to create something that is one-of-a-kind and mind-expanding.

"One hundred different people can see 100 different things," Thessen said of the favorite art pieces he's created.

He does nonabstract work, too.

"I made a bird. The feathers are little knives welded onto a bigger knife that is the wing, to give it dimension. I [also] did a very icky-looking mosquito with a drill bit for a needle. In my mind, if it was alive, it could punch holes in your gas tank and suck out the fuel," Thessen added.

Parting Thoughts

Whether welding for art, technology,



Fig. 3 — Welder Tom Hammer assists Welder Brian Thessen as he performs GTAW on a large stainless steel tube. The art of GTAW produces exceptionally high-quality, refined, and superior welds.

problem solving, or more hands-on purposes, the trade takes a variety of competencies and challenges you to always be learning and advancing your skills. For example, intricate weldments performed by GTAW on stainless steel help complete components that go into life-saving devices in a variety of health fields. And when opportunities begin to run out in other industries, students can still look to manufacturing as a viable option for a lifelong career.

Journeyman Welders Coolong, Hammer, and Thessen fuse the points that protecting the future of welding is learning from what has worked well in the past: education, mentorship, and appreciation.

Happy National Welding Month. To check out American Welding Society discounts, see the below sidebar. [WJ](#)

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AWS Special Offerings for National Welding Month



National Welding Month takes place in April and not only recognizes but also reflects on the impact welding has on our daily life.

To mark this month in 2020, the American Welding Society (AWS), Miami, Fla., is providing additional promotions, as outlined below.

Foundation. The Foundation will again offer 50% off job postings at jobsinwelding.com during the months of April and May.

Membership. Join AWS between now and the end of National Welding Month, and the \$12 initiation fee will be waived. You will also be eligible to receive a free hat. To participate in this offer, do the following:

1. Join AWS as a new member by submitting an online application at my.aws.org, or downloading and sending a completed application available through aws.org/about/page/national-welding-month with payment made to AWS World Headquarters. You may also call AWS at (800) 443-9353 to join, and mention this offer to have the initiation fee waived.

2. Go to surveymonkey.com/r/NewAWS_April2020 and sign up to receive your hat.

At the end of April, all entries will be verified, and gifts will be shipped. Gifts will be sent on a first-come, first-served basis while supplies last. New members outside of the United States may be asked to pay shipping fees.

In addition, to learn more about National Welding Month, be sure to visit aws.org/about/page/national-welding-month. A host of important information is there, including key resources, ways to get involved, and much more.



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Welding Programs Thrive in the Lone Star State

Explore how the hands-on trade is taught at two Texas-based institutions

BY CODY MORGAN



Fig. 1 — In the entry-level and advanced pipe welding courses at Blinn College, students learn the fundamentals as well as fabrication and pipe theory. Students weld on pipe set up outside the lab's garage door, welding in the sun and wind as they would on a jobsite.

As the industry looks to replace thousands of retiring welders, it raises the question: What is the best way to recruit and train new welders?

Successful welding education programs share several common denominators: Experienced instructors, a strong job market in that region, a thorough curriculum covering welding fundamentals, and flexibility for students.

Welders can learn the craft in many ways, including on the job, in a trade school, or in college. This article takes a look inside two thriving welding education programs in Texas — Figs. 1, 2. One is part of the largest welding school in the country, and the other is a new welding degree program that has a wait list after only four years in operation.

Tulsa Welding School

At Tulsa Welding School and Technology Center (TWSTC) (welding.school.com) Houston, Tex., campus, the culture of graduation starts on a student's first day.

When students get their photos taken for ID badges, the school also snaps a picture of them in caps and gowns, holding diplomas. These photos are framed and displayed in the hallway between classrooms. Students take that memento when they graduate.

"It's so they can envision themselves being a graduate," said Casey Stafford, regional director of facilities for TWSTC. "We're here to change these students' lives and help them any way we can. We want them to be successful."

Tulsa Welding School (TWS) launched in 1949 in Tulsa, Okla., and in the past 20 years has added campuses in Houston and Jacksonville, Fla. The school enrolls thousands of students, with the Houston campus alone averaging about 1100 students at any given time.

The Houston campus runs morning, afternoon, and evening sessions that span 7 a.m. to 11:30 p.m. every weekday. With 316 welding booths, 36 instructors, and an overflowing parking lot, the school is a hub of activity from morning to night.

A Career-Focused Program

Many of the school's instructors are TWS graduates. They bring a range of welding backgrounds, from pipe to structural to inspection, and often



Fig. 2 — Students at Tulsa Welding School practice GTAW with the Miller® Dynasty® 280 DX multiprocess welding machines. Both schools try to choose welding equipment the students will be using when they get out on the job.

decades of experience.

“We’re the largest welding school in the nation, and I truly believe that’s because of the passion of our instructors,” Stafford said.

School leaders also attribute growth to the strong job market in the Houston region, where oil and gas have a big presence. The school takes a career-focused approach and partners with local employers — Fig. 3.

Every six months, representatives from local companies meet and provide feedback on welding trends and needs. Are they using more robotic welding? Are they changing processes or filler metals? What skills do they want in new hires? Those insights help inform what TWS teaches.

“We try to have a real industrial standpoint on why we teach certain things,” said Casey Conrad, lead welding instructor at TWSTC. “We really are strict on fundamentals, because fundamentals are extremely important to be successful.”

Seven Months to a Welding Certificate

Students typically complete the certificate program in about seven to eight months, taking six courses covering shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and flux cored arc welding (FCAW). Electives on stainless steel, aluminum, and downhill pipeline are also offered, as is an optional ten-week

pipe fitting course — Fig. 4. Students spend one day each week in the classroom and the remaining four days in the welding lab.

Some students start with no welding experience. For the instructors, shepherding students from novice to employable welder is part of why they love the job.

“It’s amazing to me how students develop their skills, some in a short period of time, starting from scratch,” said Doug Watkins, welding specialist instructor at TWSTC. “At the end of my pipe class, I tell those students

‘You’re a pipe welder. You can go anywhere and take a pipe welding test and be qualified and make money.’”

Such students can complete the program in a relatively short time. The flexibility of the morning, afternoon, and evening class sessions was also important to many of them. The majority of TWS students, especially those in the evening session, work full time.

Cameron Troutman was new to welding when he started classes. He works as a night security guard for a river dredging company, so he chose the afternoon session.

“Spending a lot of time in the welding lab was really beneficial for me since I’d never done it before,” he said. “Taking the pipe welding certificate here is important to me so I can get a job and go immediately into the workforce.”

Pipeline welding is the plan for many of the students. They see it as a strong market where they can earn good money.

Mitch Brandel will take the pipe fitting course after he finishes the welding certificate because he sees so much opportunity in pipe welding in the region. He came to TWSTC with four years of welding experience in the Navy, mostly SMAW and GTAW.

“It was great training because I got to do all sorts of welding in weird positions and with different metals,” he said. “I like welding because I have a sense of pride that I’ve put A and B together; that I created it.”



Fig. 3 — School leaders at TWSTC attribute growth to the strong job market in the Houston region, where oil and gas have a big presence. The school takes a career-focused approach and partners with local employers.



Fig. 4 — Students at Tulsa Welding School, like Phillip Welch, take six courses covering SMAW, GTAW, GMAW, and FCAW. Electives on stainless steel, aluminum, and downhill pipeline are also offered, as is an optional ten-week pipe fitting course.

Support Beyond the Classroom

Tulsa Welding School also provides additional support outside of the classroom, including help with transportation, a food pantry that offers bagged meals, and a GED program that even non-TWS students can attend.

The Career Services office also helps identify jobs and employers depending on the skills and interest of students. Some employers come to the school seeking to hire a dozen or more welders at a time.

“Our job placement rate is very high, about 90 percent,” Conrad said. “We are really all about getting students jobs.”

Blinn College

Not far from Houston, the Blinn College District offered noncredit, continuing education courses in welding for many years. However, leaders at the two-year college wanted to take the next step and establish an associate degree in welding. This meant designing a curriculum, hiring qualified



Fig. 5 — Blinn College’s two-year welding degree program launched in January 2016 on the Brenham and Bryan campuses with 23 students. Four years later, enrollment is nearly 140 students.

instructors, and establishing a dual-credit program with local high schools.

Blinn’s two-year welding degree program launched in January 2016 on the Brenham and Bryan campuses with 23 students (blinn.edu/welding/index.html). Four years later, enrollment is nearly 140 students — Fig. 5. To meet the growing demand, Blinn is partnering with the Texas A&M University System and Texas A&M University at a soon-to-be-opened facility on a new shared campus that will double Blinn’s welding booths.

“Our future’s very bright,” said Welding Program Manager Dickie Jones. “We want to be number one in the state of Texas for welding.”

Starting a Welding Degree

To produce test-ready graduates, Blinn wanted the new program to meet rigorous standards. The curriculum was designed to meet National Center for Construction Education & Research (NCCER) standards, so graduates leave with a degree and NCCER certification.

Students must learn the range of processes, including SMAW, GTAW, FCAW, and GMAW, as well as blueprint reading, weld testing and inspection, and uphill and downhill pipe welding. Students are tested in code welding to meet American Welding Society (AWS) and American Society of Mechanical Engineers (ASME) standards.

“Welders are tested and held to a standard that very few people are,”

Jones said. “We build a level of confidence that makes our students feel good about what they’re doing.”

Students must also complete a one-semester welding internship. Many continue to work for those employers, even when the internship is done, with companies eager to keep them on.

While the degree plan is about 75% welding lab work, it also requires courses in math, English, history, creative arts, and other general studies. Blinn instructors believe a welding degree provides a broad base of skills that can expand career opportunities down the road.

“It’s going to give them a piece of paper where they can grow,” said Instructor Andy Isles. “A lot of companies like to have people with degrees that they can promote into jobs.”

Training Successful Welders

At Blinn, the philosophy of helping welding students succeed involves several factors: experienced instructors who get into the booth and demonstrate the necessary skills; a curriculum that’s accurate and relevant to the industry; and reliable welding machines, consumables, and equipment that are easy for students to use.

“We do a lot of legwork with companies to make sure that the things we’re teaching are what the companies need,” said Instructor John McGee. “Most of my students are employed before they graduate.”

One local manufacturer hires many



Outfitting a Welding School

Training new welders requires selecting welding equipment and consumables that are easy for students to learn and use. Schools also try to choose welding equipment the students will actually be using when they get out on the job.

Tulsa Welding School and Blinn College use Miller® welding equipment, Hobart® filler metals, and Bernard® semiautomatic GMAW guns — Fig. 6.

“We’ve got to keep our equipment up with the latest in technology. We’ve got to know that we’re meeting industry standards,” said Jones. “I can’t use ten-year-old technology to train with when they walk out into the field or go to a fabrication shop after graduation and everything is new.”

Welding schools often choose multiprocess welding machines that deliver versatility and can save space in the labs compared to using separate machines for different processes. They look for simplified interfaces that offer fast process changeover with the push of a button. Durability and consistent performance are also factors in selecting welding power sources, filler metals, and consumables. Some machines might run 10 to 15 h/day in the labs.

“I have 316 welding booths out there and 316 students welding,” said Stafford. “I cannot have a welding machine go down. I depend on reliable products.”

Successful Welding Education

While Tulsa Welding School and Blinn College offer students different models of welding education, the programs share plenty of similarities, including experienced instructors with a desire to pass on welding knowledge to the next generation; plenty of hands-on training time in the lab; and reliable, easy-to-use equipment. These factors are fundamental for both programs in training the next generation of welders. **WJ**

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Blinn students to work weekend shifts as welders and fitters.

In the entry-level and advanced pipe welding courses, students learn the fundamentals of cleaning and fitting, as well as fabrication and pipe theory. Students weld on pipe set up outside the lab’s garage door, welding in the sun and wind as they would on a jobsite. The college also has a Certified Welding Inspector on staff, so students in advanced pipe welding can test for AWS certification.

“We try to give them not only the tools and education they’ll need to survive out there, but also the paper and certificates to back it up,” McGee added.

A Love of Welding

James Anderson was a high school valedictorian, but books were never really his thing. He enjoyed welding in high school, taking dual-credit courses through Blinn, and later earned a welding scholarship there. He likes that his instructors have so much industry experience.

Welding never gets boring for Anderson. If he gets tired of carbon steel, he can switch to stainless or aluminum. If he gets tired of GTAW, he can switch to GMAW.

“If you look at the weld you did and try to make the next one better, it’s always interesting,” he said. “There’s so much in the welding world. It won’t get boring if you’re one of those peo-

ple that wanted to learn everything.”

Ariana Burleson started welding by accident in high school, after she mistakenly signed up for a welding class.

“I ended up really, really loving welding. It’s almost like an art form,” she said. “I like that I can fix things without needing help from someone.”

Burleson wants to eventually teach welding at the high school level, to share her passion with other young welders.

“I’ve had these amazing welding instructors who have always encouraged me,” Burleson said. “I want to be that next person’s motivation.”

A Growing Welding Program

In five years, Jones would like to see Blinn’s 11 classes grow to 20 per semester with several more full-time instructors.

“I think our limit is what we set on ourselves,” Jones said. “We can grow as big as we want to grow.”

Blinn’s Brenham facility now has 20 welding booths, and the Bryan campus has 16. The new facility on the Texas A&M University System RELLIS Campus will have 36 state-of-the-art booths, as well as classrooms and offices. At RELLIS, Blinn will also add other trade classes like carpentry, plumbing, and HVAC.

“Everything about me jumps up and down about this,” said Isles. “It’s been all worth it to see the impact we’ve made on kids’ lives.”

Challenges and Opportunities for Welding Heavy Structural Steel

Updates to welding processes, fabrication methods, and industry standards are key to the evolution of steel construction

BY ROBERT E. SHAW JR.



Fig. 1 — ESW-NG process application at the Wilshire Grand Hotel, Los Angeles, Calif. (Photo courtesy of Schuff Steel Co.)

The last decade has seen tremendous growth in the construction of iconic steel structures. Architects have been using the ability of steel to satisfy any architectural concept and configuration, and structural engineers have been able to design the steel frames to meet the challenge. There has been increased collaboration between engineers, fabricators, erectors, and detailers to design, fabricate, and assemble the complex, multifaceted connections these structures demand.

In addition, the market is demanding more open spaces in their structures, increasing the use of jumbo shapes and thick plates to carry the load. The size of these structural members and the significant use of welding

to make and join them has put increasing demands on the materials and welding process.

This type of work produces many challenges for not only the designers but also for the fabricators, erectors, welders, inspectors, and nondestructive examination (NDE) technicians working to provide and ensure safe structures. Heavy steel structures are at greater risk of weld-related cracking, lamellar tearing, and brittle fracture. There is also an increasing demand to build these structures at a faster pace and more economically than ever before.

These challenges should be seen as opportunities for using new structural steel systems, better quality steels, ad-

vanced and more efficient welding processes, improved welding supervision and management, and new inspection and NDE technologies. The implementation of these opportunities requires not only knowledge and innovation, but also design and structural welding codes that enable and address them.

Speed of Production and Construction

Speed of construction is emphasized today. Owners and users want their structures to be in use as soon as possible, and time is money. To speed up construction, constructability



Fig. 2 — Rainier Square Tower erection using the SpeedCore system. (Photo courtesy of Magnusson Klemencic Associates.)

should be considered as part of design. In heavy welded structures, choices made in welding process and technique can have a significant effect on both speed and constructability.

Narrow Gap Electroslag Welding (ESW-NG)

Electroslag welding (ESW) offers numerous advantages when welding thick steel, including high deposition rates, fewer internal discontinuities, minimal joint preparation, minimal distortion (especially angular distortion), no in-process cleaning between passes, little or no preheat, and so on. ESW can be used for butt, T-, and corner joints, as well as in thicknesses as thin as approximately $\frac{3}{8}$ in. (19 mm). A complete discussion can be found in the American Welding Society (AWS) *Welding Handbook*, Vol. 2, Part 1, Chapter 10.

Electroslag welding had fallen out of favor in the 1970s when problems in ES welded splices were found in several steel bridges. Subsequent research into ESW resulted in an improved method termed narrow gap electroslag welding (ESW-NG), with more reliable mechanical properties, including higher notch toughness in the weld and heat-affected zone. AASHTO/AWS D1.5M/D1.5:2010, *Bridge Welding Code*, incorporated the results of this research and process development to return ESW to industry use, adding a new Part F on ESW in clause 4, Technique; a new clause 5.14 on procedure qualification; and several annexes to define ESW-NG along with its consumables and operating parameters. The AWS D1 Committee on Structural Welding has continued to improve these provisions in subsequent editions.

AWS D1.1/D1.1M, *Structural Welding Code—Steel*, has not incorporated

the specifics of ESW-NG into either its 2015 or 2020 editions. For economy, speed, and quality, fabricators and erectors should consider using ESW-NG for building applications following the provisions of the *Bridge Welding Code*, and engineers should be supportive of these efforts. The challenge to the AWS D1 Committee on Structural Welding is to incorporate provisions specific to ESW-NG into the *Structural Welding Code—Steel* and the AWS D1.8 *Structural Welding Code—Seismic Supplement* that address variations, if any, for static, cyclic, or seismic loading.

Narrow gap electroslag welding was successfully used for the welding of gusset plates to embed plates and box columns for connecting seismic buckling-restrained braces at the belt truss level of the Wilshire Grand Hotel in downtown Los Angeles, Calif. Gusset plates at the embedded plates were 2 $\frac{1}{2}$

in. (70 mm) thick and 10 ft (3 m) long and welded in a single pass. ESW-NG was used on numerous other field-welded connections, with plate and wide-flange member connections ranging from 2¼ in. (57 mm) to nearly 5 in. (125 mm) in thickness.

Automatic and Mechanized Processes and Adaptive Controls

The need for more skilled welders is well known. The use of tracks, gantries, and similar devices to move welding processes such as flux cored arc welding (FCAW) and gas metal arc welding from a semiautomatic process (handheld) to a mechanized process (with equipment requiring manual adjustment by an operator in response to visual observation, with the torch, gun, wire guide assembly, or electrode holder held by a mechanical device) or an automatic process (with equipment requiring occasional or no observation and no manual adjustment during its operation) can improve productivity and quality while reducing welder fatigue. The skilled and knowledgeable welder is still needed to serve as the welding operator, so no job is lost in the process.

One of the challenges in a fabrication shop or on a job site is the requirement for tighter tolerances on root fitup for partial joint penetration (PJP) and complete joint penetration groove welds when using mechanized or automatic welding, compared to that permitted for manual or semiautomatic welding. For fillet welds, the weld must have leg dimensions increased should the root opening between the connected parts exceed ⅙ in. (2 mm). When welding thick sections, control and correction of fitup accuracy and alignment are particularly challenging.

Vision systems and other forms of adaptive controls can be implemented to overcome such fitup issues, adjusting root pass bead width and placement as needed, and continuing to adjust as the weld progresses from root to final layer.

SpeedCore System for Steel Construction

The Rainier Square Tower in Seattle, Wash., a 58-story, 850-ft (400-m) mixed-use office building



Fig. 3 — Example of brittle fracture at the north girders of the Transbay Transit Center. (Photo courtesy of Transit Joint Powers Authority.)

with residential occupancy in the upper levels, utilized a new innovation — a concrete-filled composite steel plate shear wall core system. This system replaces the slower slip-formed reinforced concrete core previously used in tall buildings. Steel erection of the structural frame took only ten months, 43% less than the time required if using a concrete core. The typical pace for steel erection was a story every three to five days, but a pace of two tiers (four stories) per week can be achieved using the new system.

SpeedCore, as this new core system is referred to, uses shop-fabricated sandwich panels with two structural steel plates held in place with tie rods between the plates. The panels are self-supporting during construction, enabling steel erection of the surrounding steel and floor decking. The panels are filled with concrete below the steel erection level, typically four to six stories behind the steelwork, about the time the concrete is placed on the steel floor deck.

For Rainier Square, the sandwich plates were commonly ½ in. (13 mm) thick, with some ¾ in. (19 mm) thick. At the belt-truss level with buckling-restrained braces, the plate thickness was 2 in. (51 mm). In the shop, approximately 400,000 cross-ties of ½-in (13-mm) diameter rod were welded to the plates to form the panels, with fillet welds made robotically to the outside of the plate. In the field, the sand-

wich plates were joined both horizontally and vertically using PJP groove welds, with a reinforcing fillet weld against a bar welded to the outside plate surface, providing a full-strength connection. Interior steel backing was used with a bent portion beyond the weld root to serve as an alignment aid during erection. A total of 36 miles (58 km) of FCAW field welding was completed, all by hand because of joint fitup tolerances.

The SpeedCore system offers significant time savings, hence cost savings, when compared to the old reinforced concrete core system, with the benefit of steel construction that better manages construction tolerances for the entire structure. Welding plays a significant part in both shop fabrication and field erection. There is potential for adaptive welding controls to speed up the shop and field welding operations even further. Because the system is nonproprietary, it can be designed, fabricated, and erected without restrictions.

Opportunities

Welding Supervision

A well-known theme in the industry is that “you build quality in, you don’t inspect it in.” To take advantage of the opportunities to save time and money in welding, and to make high-quality welds at the same time, the in-

dustry needs educated, competent welding supervisors who manage the work and the people who do the work. Supervisors are the ones who see problems before or while they occur, and can take the necessary steps to address the issue in a timely manner. AWS Certified Welding Inspectors often make competent welding supervisors, but may need additional expertise in production aspects such as equipment and welding techniques.

This is an opportunity for fabricators and erectors to improve efficiency, reduce errors, and improve both their quality and their bottom line. AWS published two standards on welding supervision: AWS B5.9, *Specification for the Qualification of Welding Supervisors*, and AWS QC13, *Specification for the Certification of Welding Supervisors*. AWS reports that a Certified Welding Supervisor “helps reduce welding costs, helps increase productivity and profitability, and helps make a company more competitive by an average of \$17,000 per welder per year.”

Fabricator and erector certification bodies should consider the addition of competent welding supervisors to their personnel descriptions and requirements. In addition to the AWS standards, ISO 14731:2019, *Welding coordination—Tasks and responsibilities*, and CSA W47.1, *Certification of companies for fusion welding of steel*, are excellent resources.

Use of PAUT (and Other Flaw-Sizing Methods) to Its Full Potential

AWS D1.1 introduced ultrasonic testing to the *Structural Welding Code* in 1972, and it has undergone many improvements since that time. AWS D1.1/D1.1M:2020 has introduced phased array ultrasonic testing (PAUT) to the code for the first time by providing a detailed normative Annex H. The use of PAUT is permitted under subclause 8.34, Advanced Ultrasonic Systems.

Although PAUT has been used successfully since its inception, the acceptance criteria in AWS D1.1 remain driven by workmanship and detectability; are limited to scans at 45, 60, and 70 deg; and have not incorporated modern structural performance approaches. The use of PAUT presents the opportunity to establish accept or reject decisions on true engineering-based

performance requirements. With the sophistication of current engineering designs, the industry should strive to employ PAUT, using its true potential for sizing flaws and more accurate characterization of those flaws. PAUT can better ensure structural integrity, and reduce the time and expense of unnecessary repairs.

Challenges

Brittle Fracture

The increasing use of heavy shapes and thick plates, combined with complex details, has increased concerns for the possibility of brittle fracture in steel structures. Although brittle fracture is not new and such fractures have been relatively rare, the 2018 fractures in the bottom flange of two plate girders in the new Transbay Transit Center in San Francisco, Calif., have brought renewed attention to the issue. As part of the Report of the Metropolitan Transportation Commission Peer Review Panel (mtc.ca.gov/sites/default/files/PRP_Final_Report.pdf), recommendations were made for industry development of a risk assessment methodology that considers the consequences of failure and the following factors that contribute to brittle fracture:

- Susceptible material with low fracture toughness, particularly near the mid-thickness region of thick materials, as may be affected by steel compositions, steel manufacturing methods, low service temperatures, fast loading rates, or local degradation from other operations such as forming or excessive heating;
- Susceptible material at a local level, such as hard, brittle martensite, that is formed by the rapid cooling of the surface of thermal cut edges;
- Sufficient stress, which may be from applied loads and/or from residual stresses generated by weld shrinkage, thermal heating, thermal cutting, or forming;
- Geometric stress concentrations such as reentrant corners and transitions, whether square or with a radius;
- Initiating flaws such as cracks, both micro and macro, and inclusions or notches that serve as significant stress concentrations; and
- Constraint, inherent with thick material but also created by triaxial and biaxial intersecting welds, that limits or

prohibits the material from performing in a ductile manner, which is necessary for redistribution of stress.

Welding of Steels Produced Using New Methods

Current structural welding codes focus on carbon and low-alloy structural steels, with added requirements for quenched and tempered steels such as those made to ASTM A514, *Standard Specification for High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding*. Specific rules are provided for the quenched and self-tempered (QST) steels made to ASTM A913, *Standard Specification for High-Strength Low-Alloy Steel Shapes of Structural Quality, Produced by Quenching and Self-Tempering Process (QST)*. However, there are an increasing number of steels using unique rolling and heat-treating processes and special alloying compositions to achieve better structural performance, none of which are directly or indirectly addressed in existing welding codes and standards. Addressing these material innovations in prequalification provisions or developing appropriate qualification testing requirements based on desired performance will be an ongoing challenge for those who write and apply the steel and welding industry's codes and standards.

Conclusion

Welding will continue to evolve with new equipment, consumables, processes, and techniques. Steel construction will also continue to evolve with new steels, structural systems, connection types, and methods of fabrication and erection. The synergy and expansion of these two disciplines will continue to create amazing structures using welded steel. It will not come without challenges and problems, but we know from history that the industry will rise to overcome these challenges and solve any problems that emerge. Taking advantage of opportunities and meeting challenges will result in better, safer, faster-built, and more cost-efficient structures. **WJ**

ROBERT E. SHAW JR., PE, (rshaw@steelstructures.com) is president of Steel Structures Technology Center Inc., Howell, Mich.

Battling the Trades Stigma

BY STEPHEN SCHOBER

Dating back to the 1980s, the stigma associated with trade schools and careers continues today, despite the global demand for skilled trade workers. Pictured is a young trades worker measuring metal prior to cutting.

A national survey unveiled the perceptions young Americans have about trade schools and careers

It is no secret that welders help build the world around us. They play a key role in the construction of ships, automobiles, planes, and even spacecraft. Welders create the veins that run through cities and towns by building pipelines that transport drinking water, gas, oil, and more. They are crucial in the manufacturing of electronic devices, medical equipment, and many other products.

Today, much of the nation's infrastructure is aging and requires the expertise of skilled workers to rebuild bridges, highways, and underground pipelines. However, older tradespeople are nearing retirement age much faster than they can be replaced by younger counterparts. The U.S. Bureau

of Labor Statistics suggests more than half of all skilled trades workers, such as welders, are 45 years or older (Ref. 1). As a result, jobs that require trade skills vastly outnumber the available workforce. The American Welding Society predicts a shortage of more than 375,000 skilled welding professionals by 2023 (Ref. 2). This imbalance can impact America's economic competitiveness.

The reason for such a shortage? A stigma that's been placed on "blue-collar" careers, such as welding. In 2019, Metal Supermarkets commissioned a national survey (Ref. 3) to gauge young Americans' thoughts on pursuing trade careers. The survey, which polled more than 500 men and

women aged 18–24, suggests what was once seen as a perfectly acceptable and normal career path is now considered by many to be grunt work for people who are less intelligent. For example, the survey showed skilled trade jobs are perceived as low-paying jobs that are conducted in less than ideal conditions. The stigma surrounding trade careers is so ingrained in young people that many said they would rather work in a coffee shop than in a trade.

Survey Findings

Here are some of the eye-opening results from the survey:

- Nearly three out of four polled

Trade School Stigma

New Survey Reveals Negative Perception,
Lack of Awareness of Trade Schools and Careers



56% Say they're not - or never were - interested in going to trade school.

Why no interest? - **66%** said they did not know enough about trade schools.

Fact: U.S. Department of Education reports people with trade educations are more likely to be working in their fields of study than those with academic credentials.

51% Said they would rather work as a barista than as a welder.

55% Said people with office jobs earn more respect than those who work with their hands.

Fact: Some of the top welding jobs can pay more than \$100,000 per year.



73% Said traditional college gives you a better future than trade school.

65% Believed that student debt was the price you pay for a college education.

Fact: According to the National Center for Education Statistics, the average trade school degree costs \$33,000, compared to a \$127,000 bachelor's degree.



(73%) said traditional college gives you a better future than trade school.

- A quarter of those surveyed (25%) felt students who attended trade schools were not as smart as those who went to a traditional college. They also felt people attending trade schools were not as motivated as four-year college grads.

- More than half of the respondents (55%) believe people with office jobs earn more respect than those who work with their hands.

The infographic in Fig. 1 sums up some of the major findings from the survey.

Tracing the Trouble

The start of the trade school stigma can be traced to the 1980s with the release of *A Nation At Risk*, a government report that stoked concerns about the American education system (Ref. 4). Years of declining scores on international exams called into question the academic preparation of American students, and policymakers scrambled to reverse the perceived decline. This was the time when states increased the number of core academic courses, such as science, math, and foreign language, required for high school graduation. In contrast, funding for vocational programs in high schools declined. Thanks to the focus on college prep in high school and the increased negativity toward a career in the trades, participation in vocational courses dropped significantly (Ref. 5). In fact, many educators and guidance counselors stopped suggesting a career in the trades as an option for students (Ref. 3).

According to the results, more than half of the young people surveyed said they are not — or never were — interested in going to trade school, which could be due to a lack of knowledge concerning trade careers. This lack of understanding was reflected in the survey (see Fig. 1):

- Two out of every three (66%) said they did not know enough about trade schools.

- More than half (58%) admitted they do not know about the trade schools in their community.

- Sixty-two percent revealed they didn't learn about trade school options in high school.

- More than two-thirds (68%) said trade schools were never discussed by their guidance counselor.

Fig. 1 — This infographic summarizes the results of a survey that polled more than 500 people aged 18–24 to measure the stigma associated with trade schools and careers.

With decades of focus on college degrees, the impact on students can be felt financially. The amount of student loan debt has ballooned to more than \$1.5 trillion (Ref. 6). Almost 45 million Americans currently have student loan debt (Ref. 6). Tuition rates are rising, too. According to the National Center for Educational Statistics, the average bachelor's degree costs \$127,000 (Ref. 7). Comparing that to the average trade school degree, which costs about \$33,000, a trade school education can come with far less student debt. It can also enable students to enter the workforce sooner after completing their degree within two years.

College students face other obstacles as well, including high dropout rates and difficulty finding work after graduation. According to the U.S. Department of Education, about 40% of college students at public institutions who borrow money to pursue a diploma drop out or transfer schools before graduating (Ref. 8). This adds up to wasted time and money. Additionally, roughly half of those who do graduate from college can't find work in their field of study. This is probably why approximately 37% of students who do get their degree will end up working jobs that didn't require a higher level of education in the first place.

Knowledge is Power

Due to the massive amounts of debt and high dropout rates, young people should be encouraged to explore vocational careers like welding. Opportunities in the welding industry require a high school or trade school degree while also providing paid on-the-job training. Due to the demand for their services, welders often enjoy greater job security and advanced pay that can result in six-figure salaries with little, if any, college debt.

The average salary for a welder in the United States is \$42,451, but this number can skyrocket into the \$300,000 range, depending on many important factors, including education, certifications, additional skills, and the number of years spent in the profession (Ref. 9). Compare that to the average salary for a college graduate with five years of experience or less, which is \$48,400. That is not much more than the average salary of a trade school graduate, but it is far less if you factor in the time spent in



Fig. 2 — Pictured are two young Metal Supermarkets employees, Rose Britto and Bobby Shackelford, enjoying a job in the trades field.

school along with tuition and the likelihood of a student loan payment.

People who attend trade schools also enter the workforce quicker. For example, some welding certificate programs can take as little as seven months. Graduates are highly sought after by employers, and surveys show those with career and technical education are more likely to be employed than those with academic credentials (Fig. 2).

The Outlook is Changing

Now the government that once pushed college for all is recognizing the short-sightedness of that policy. In February, President Trump proposed a nearly \$900 million increase in career and technical education funding, which is perhaps the largest increase in career and technical education ever (Ref. 10). Last year, Congress reauthorized the Strengthening Career and

Technical Education Act for the 21st Century, which aims to engage a new generation of Americans and prepare them for a career in the trades.

States are also jumping in to revive the reputation of vocational education. For example, California announced a \$6-million investment in the Strong Workforce program to support and expand trade school education (Ref. 11).

The issue surrounding the skilled trades is not going unnoticed. In the past few months, there have been a host of articles published about the shortage of skilled workers and the opportunities that await those who enter the trades. Attention like this could put the balance back in our education system and help vocational education overcome the stigma of being a second-best choice. Students who have the desire to obtain a college degree should still be prepared to do so, but students with other interests, such as a trade, should be equally supported. **WJ**

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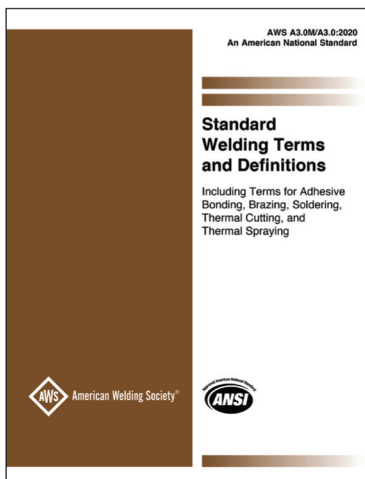
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AWS-SPONSORED EVENTS

FABTECH Mexico. May 12–14. Centro Citibanamex, Mexico City, Mexico. This event will be held jointly with AWS Weldmex, Metalform Mexico, and Coatech México. The combined event will bring together 575 exhibitors and more than 13,000 attendees from Mexico and South America to find solutions, network, learn, and experience first-hand the latest innovations in the metal forming, fabricating, welding, and finishing industries. Visit mexico.fabtechexpo.com.

Qualification of Welding Procedures Conference. June 2, 3. Lincoln Electric, Cleveland, Ohio. This workshop will guide the participants through the process of writing and qualifying a welding procedure specification (WPS) that is ASME Section IX compliant. This includes live demonstrations on the welding of the coupon; test specimen location and preparation; tension, bend, and charpy testing; evaluation of the test results; and generation of the procedure qualification record(s) and WPS. Each attendee will receive a hard copy of the 2019 edition of ASME's *Section IX Welding, Brazing, and Fusing Qualifications*. Visit aws.org.

FABTECH Canada. June 16–18. Toronto Congress Centre, Ontario, Canada. Meet with more than 300 world-class suppliers; see the latest industry products and developments; and find the tools to improve productivity, increase

profits, and discover new solutions for all of your metal forming, fabricating, welding, and finishing needs. Visit canada.fabtechexpo.com.

Aluminum Conference — Back to Basics. Sept. 16, 17. ITW Technical Center, Houston, Tex. This conference is designed to provide a basic understanding of aluminum welding and will cover various topics, including basic aluminum metallurgy; metal preparation and storage; weld discontinuities; AWS D1.2, *Structural Welding Code — Aluminum*; and more. Visit aws.org.

Sheet Metal Welding Conference XIX. Oct. 21, 22. Laurel Manor, Livonia, Mich. This technical conference brings experts together to discuss welding and joining technologies for the automotive, transportation, and light manufacturing industries. It also provides important opportunities for engineers and researchers from manufacturers, suppliers, universities, and research institutes to network and meet experts in the field of welding. The conference will be preceded by a one-day workshop on Oct. 20. Visit awsdetroit.org.

FABTECH 2020. Nov. 18–20. Las Vegas Convention Center, Las Vegas, Nev. This event provides a one-stop shop venue where attendees can meet with world-class suppliers; see the latest industry products and developments; and find the tools to improve productivity, increase profits, and discover new solutions to all of their metal forming, fabricating, welding, and finishing needs. Visit fabtechexpo.com.



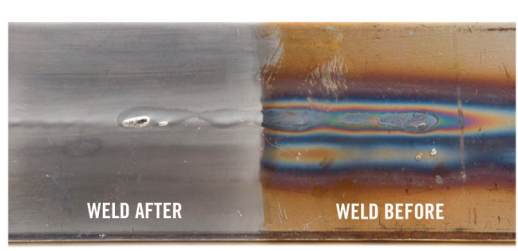
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U.S., CANADA, MEXICO EVENTS

ICPIIT 2020 — International Chemical & Petroleum Industry Inspection Technology Conference. June 17–19. Sugar Land Marriott Town Square, Sugar Land, Tex. This conference will provide a forum for the exchange of theoretical and scientific information on the nondestructive examination (NDE) of pipeline and piping, pressure vessels, storage tanks, chemical and refinery plants, and equipment for transportation. It will also cover inspector certifications, codes, standards, regulations, risk-based inspections and evaluations, and general NDE. Visit asnt.org.

INTERNATIONAL EVENTS

2020 International Conference on Defence Technology. April 20–24. International Youth Convention Hotels, Nanjing, China. This event brings together many presentations covering basic research in the fields of defense science and technology from all over the world. Theme categories include energetic materials; explosion and impact (armor and protection); novel manufacturing processes and management (additive manufacturing, 3D printing, metals with nanostructures, and casting technology); autonomous technology; application of composite materials; directed energy and pulsed power; modelling and simulation in defense science and technology; and photoelectronic information technology. Visit icdt-conf.com.

PaintExpo. April 21–24. Exhibition Center Karlsruhe, Rheinstetten, Germany. The trade fair for industrial coating technology will cover a range of topics including systems and equipment for liquid painting, powder coating, and coil coating; application systems and spray guns; wet paints and powder coatings; automation and conveyor technology; compressed air technology; accessories; measuring and test technology; and more. Visit paintexpo.de/en/.

Cutting World 2020. April 28–30. Messe Essen, Essen, Germany. The trade fair for professional cutting technology's offerings include innovative oxyacetylene cutting installations, plasma cutting installations, laser cutting systems, and water jet cutting installations, as well as shears and sawing installations, amongst other items. Apart from cutting technologies, the range of offerings will encompass the upstream and downstream working processes from operations planning and scheduling, control software, and filter systems via the straightening, deburring, and bevelling of the cut materials right up to storage and logistics. Visit cuttingworld.de.

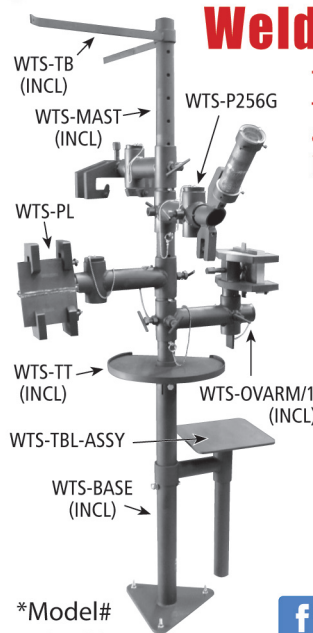
AKL'20 – International Laser Technology Congress. May 6–8. Aachen, Germany. Featuring more than 600 participants, 87 speakers, and 50 sponsors and exhibitors, this biennial forum offers laser manufacturers and users a platform to exchange ideas and experience. Moreover, it provides a comprehensive overview of current developments in laser materials processing in macro and micro areas as well as laser beam development. The conference will take place in



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73rd International Institute of Welding (IIW) Annual Assembly and International Conference. July 19–24. Marina Bay Sands Convention Centre, Singapore. With the theme of advances in joining, additive manufacturing, and surface technology, this event aims to provide a platform for knowledge exchange and networking among scientists, engineers, researchers, and industry experts in the field of welding and joining. Visit iiw2020.com.

IIW Welded Art Photographic Exhibition. July 19–24. Marina Bay Sands Convention Centre, Singapore. This exhibition will be held at the 73rd IIW Annual Assembly and International Conference. The range of exhibits will feature welded art using advanced welding methods, such as additive manufacturing, robotics, lasers, and more. Participants are invited to send photographs of his or her work, including the title of each piece, to be selected for display. Photographs can be taken on a digital camera with a resolution of 20 megapixels or more. Additional requirements include the following: 1) a photograph of the artist (eight megapixel resolution or more); 2) a short (100-word) writeup on the welded art background; and 3) a short (200-word) writeup on objectives/methods/techniques/materials/uniqueness used for the welded art. On July 22, four of the photographs in the overall display will be raffled as prizes at the IIW Banquet and presented to the winners by IIW President Doug Luciani and IIW Annual Assembly Organizer Zheng Sun. Booklets containing information on the artists, exhibits, and more will be available.

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Amada Miyachi Educational Resources/Training. Personalized training services on resistance and laser welding fundamentals, laser marking, custom programs, material selection and joint design, and more. Visit amadamiyachi.com, or call (626) 303-5676.

ASME Section IX Seminar. Learn how to use ASME Section IX quickly and cost effectively. This ASME-sponsored course is scheduled for Las Vegas, Nev., May 18–20, and Houston,

— continued on page 84

Note: The 2020 schedules for all certifications are posted online at aws.aws.org/instructor-led-seminars/seminar-exam-schedule/.

Certified Welding Inspector (CWI)

Seminar covers Parts A, B, and C of the CWI exam. Only Part B of the exam is taken following the conclusion of the seminar. Parts A and C are given at Prometric testing centers.

Location	Seminar Dates	Part B Exam Date
Mobile, AL	April 19–24	April 25
Dallas, TX	April 19–24	April 25
Las Vegas, NV	April 19–24	April 25
Bakersfield, CA	April 26–May 1	May 2
St. Louis, MO	April 26–May 1	May 2
Tulsa, OK	April 26–May 1	May 2
Miami, FL	April 26–May 1	May 2
Baton Rouge, LA	May 3–8	May 9
Detroit, MI	May 3–8	May 9
Cleveland, OH	May 17–22	May 23
Denver, CO	May 17–22	May 23
Nashville, TN	May 17–22	May 23
Birmingham, AL	May 31–June 5	June 6
Kansas City, MO	May 31–June 5	June 6
Miami, FL	June 7–12	June 13
Indianapolis, IN	June 7–12	June 13
Pittsburgh, PA	June 7–12	June 13
Spokane, WA	June 7–12	June 13
Hartford, CT	June 14–19	June 20
Beaumont, TX	June 14–19	June 20
Seattle, WA	June 14–19	June 20
Savannah, GA	June 21–26	June 27
Omaha, NE	June 21–26	June 27
Farmingdale, NJ	June 21–26	June 27
Mobile, AL	July 12–17	July 18
Phoenix, AZ	July 12–17	July 18
Miami, FL	July 12–17	July 18
Louisville, KY	July 12–17	July 18
Nashville, TN	July 12–17	July 18
Cleveland, OH	July 19–24	July 25
Oklahoma City, OK	July 19–24	July 25
Corpus Christie, TX	July 19–24	July 25

Certified Welding Inspector (CWI) Part B

Course covers only Part B of the CWI exam. The Part B exam follows the conclusion of the three-day course.

Location	Seminar Dates	Part B Exam Date
Miami, FL	April 27–29	April 30
Dallas, TX	June 17–19	June 20
Houston, TX	Aug. 5–7	Aug. 8
Minneapolis, MN	Oct. 21–23	Oct. 24
Louisville, KY	Dec. 9–11	Dec. 12

9-Year Recertification Seminar for CWI/SCWI

For current CWIs and SCWIs needing to meet education requirements without taking the exam.

Location	Seminar Dates
Seattle, WA	April 19–24
Las Vegas, NV	April 19–24
Denver, CO	May 3–8
Miami, FL	May 3–8
Salt Lake City, UT	June 7–12
Pittsburgh, PA	June 21–26

Certified Welding Educator (CWE)

Seminar and exam are given at all sites listed under Certified Welding Inspector. Seminar attendees will not attend the Code Clinic portion of the seminar (usually the first two days).

Certified Welding Sales Representative (CWSR)

CWSR exams are given at Prometric testing centers. More information at aws.aws.org/certification/detail/certified-welding-sales-representative.

Certified Welding Supervisor (CWS)

CWS exams are given at Prometric testing centers. More information at aws.aws.org/certification/detail/certified-welding-supervisor.

Location	Seminar Dates
New Orleans, LA	April 20–24
Cleveland, OH	July 12–17

Certified Radiographic Interpreter (CRI)

The CRI certification can be a stand-alone credential or can exempt you from your next 9-Year Recertification. More information at aws.aws.org/certification/detail/certified-radiographic-interpreter.

Location	Seminar Dates	Exam Date
Las Vegas, NV	June 1–5	June 6
Pittsburgh, PA	Aug. 3–7	Aug. 8
Houston, TX	Oct. 5–9	Oct. 10

Certified Robotic Arc Welding (CRAW)

OTC Daihen Inc., Tipp City, OH; (937) 667-0800, ext. 218
 Lincoln Electric Co., Cleveland, OH; (216) 383-4723
 Wolf Robotics, Fort Collins, CO; (970) 225-7667
 Milwaukee Area Technical College, Milwaukee, WI; (414) 456-5454
 College of the Canyons, Santa Clarita, CA; (661) 259-7800, ext. 3062
 Ogden-Weber Applied Technology College, Ogden, UT; (801) 627-8448
 Genesis Systems IPG Photonics Co., Davenport, IA; (563) 445-5688

IMPORTANT: This schedule is subject to change without notice. Please verify your event dates with the Certification Dept. to confirm your course status before making travel plans. Applications are to be received at least **six weeks** prior to the seminar/exam or exam. Applications received after that time will be assessed a \$395 Fast Track fee. Please verify application deadline dates by visiting our website at aws.aws.org/certification/docs/schedules.html. For information on AWS seminars and certification programs, or to register online, visit aws.aws.org/certification or call (800/305) 443-9353, ext. 273, for Certification; or ext. 455 for Seminars.

Welding Classifications: Carbon and Low-Alloy Steels

Carbon and low-alloy steels represent more than 95% of the construction and fabrication metals used worldwide. Good mechanical properties over a wide range of strengths combined with relatively low cost and ease of fabrication account for the widespread use of these steels. These attributes make carbon and low-alloy steels excellent choices for use in appliances, vehicles, bridges, buildings, machinery, pressure vessels, offshore structures, railroad equipment, ships, and a wide range of consumer products. The extensive use of these steels means that welding, brazing, and thermal cutting are essential processes of continuing importance.

Welding Classifications

From a weldability standpoint, carbon and low-alloy steels can be divided into five groups according to composition, strength, heat-treatment requirements, or high-temperature properties. Overlap exists among these groups due to the use of some steels in more than one heat-treated condition. The groups are identified as follows: 1) carbon steels, 2) high-strength low-alloy steels, 3) quenched and tempered low-alloy steels, 4) heat-treatable low-alloy steels, and 5) chromium-molybdenum steels.

The steels in these five groups are available in a variety of product forms, including sheet, strip, plate, pipe, tubing, forgings, castings, and structural shapes. Regardless of the product form, to establish satisfactory welding procedures, the composition, mechanical properties, and condition of heat treatment must be known because weldability is primarily a function of these three factors. Although most steels are used in rolled form, the same considerations for welding, brazing, and thermal cutting also apply to forgings and castings. However, with large forgings and castings, consideration should be given to the effect of size and thickness with respect to heat input, cooling rate, and restraint. Other factors to be considered with castings are the effects of residual elements and localized variations in composition, which may not occur in wrought steels.

The compositions of carbon steels typically include weight percentages of up to 1.00% carbon, 1.65% manganese, and 0.60% silicon. Steels identified as low-carbon steels contain less than about 0.15% carbon; mild steels contain 0.15–0.30% carbon; medium-carbon steels contain 0.30–0.50% carbon; and high-carbon steels contain 0.50–1.00% carbon. Although wrought carbon steels are most often used in the as-rolled condition, they are sometimes used in the normalized or annealed condition.

High-strength low-alloy steels are designed to provide better mechanical properties than conventional carbon steels. Generally, they are classified according to mechanical properties rather than chemical compositions. Their minimum yield strengths commonly fall within the range of 290 to 550 MPa. These steels usually are welded in the as-rolled, normalized, or precipitation-hardened condition.

Quenched and tempered steels are a group of carbon and low-alloy steels that are generally heat treated by the producer to provide yield strengths in the range of 340 to 1030 MPa. In addition, they are designed to be welded in the heat-treated condition. Normally, the weldments receive no postweld heat treatment, unless it is required to achieve dimensional stability or to conform to a construction code.

Many grades of heat-treatable low-alloy steels exhibit poor weldability. These steels generally have higher carbon content than high-strength low-alloy or quenched and tempered steels. Consequently, although they are capable of higher strengths, they may lack toughness in the as-welded condition and may be susceptible to cracking in the heat-affected zone. Postweld heat treatment may reduce the risk of cracking and enhance the notch toughness of heat-treatable low-alloy steel weldments.

Chromium-molybdenum steels are used primarily for service at elevated temperatures up to about 700°C (1300°F) to resist creep and corrosion for applications in power plants, chemical plants, or petroleum refineries. Chromium-molybdenum steels may be welded in various heat-treated conditions (i.e., annealed, normalized and tempered, or quenched and tempered). Postweld heat treatment is often required by fabrication codes to improve ductility, toughness, and corrosion resistance, as well as to reduce stresses caused by welding.

Metallurgy and Weldability

The versatility of steel as an engineering material can be attributed to the wide variety of microstructures that can be created through changes in composition and processing. Understanding the basic properties of these structures and the effects of changes in chemistry are essential in designing and fabricating welds that are fit for their intended purpose.

Carbon steels and low-alloy steels can be welded by arc, oxyfuel gas, resistance, electron beam, laser beam, electroslag, and solid-state welding processes. These steels also can be joined by brazing, soldering, and adhesive bonding.

Phases and Microstructures

In metals and other material systems, a phase is considered to be a physically homogeneous and distinct portion of the system. It is bound by compositional limits that vary with temperature. The term microstructure is used because virtually all of the geometric features of the phases and other structures that determine the properties of steels are observable only with the aid of microscopy. The microstructure of a type of steel is dependent on the amount of the various alloying elements that it contains, as well as on both its present temperature and thermal history. 

Excerpted from the Welding Handbook, Ninth Edition, Volume 4, Materials and Applications, Part 1.

AWS President Highlights Codes, Standards, and Talent



AWS 2020 President Robert Roth (right) and his wife, Marcy, stand next to Roth's portrait, which will be displayed on the presidential wall at AWS World Headquarters, Miami, Fla.

2020 American Welding Society (AWS) President Robert Roth underscored the importance of codes, standards, and talent during the transition ceremony held February 21 at AWS World Headquarters in Miami, Fla.

Comparing codes, standards, and talent to a house with a strong foundation, he said, "I'm a believer that you've got to have the basics right. If you've got the basics right, then you can do all kinds of wonderful things."

Roth supported his point by explaining that AWS came into existence out of the need for codes, standards, and talent during War World I. One hundred and three years later, the trio still forms the bedrock of AWS, and Roth stressed that it will continue to do so for years to come.

"As we stand here today and push ourselves forward, hopefully for another 100 years, at least, foundationally, codes, standards, and talent will be hyperly important," he affirmed.

He also praised several of AWS's publications, including *Welding Journal*, which has been published monthly for almost 100 years; the D1 standard, originally released in 1928; and more than 240 different standards, procedures, and guidelines.

"These foundational things are so important to who we are and what we need to do as we move forward," he said.

Commending AWS for reaching its centennial in 2019, Roth also empha-

sized the need for AWS staff and volunteers to continuously reflect on the Society's purpose and objectives.

"Any time you hit milestones, it's a great opportunity to reflect," he insisted. "Who are we? Why do we exist? What's the value that we bring? Who are we here to serve? Those are the types of questions we need to be asking ourselves."

Roth concluded by identifying three challenges faced by the Society today: 1) the de-

mand for instantaneous and free content, as well as the need to show the value in that content; 2) engaging more individuals by illuminating how their involvement with AWS benefits themselves and the industry as a whole; and 3) helping employers to comprehend that their employees' knowledge and skills can be bolstered through engagement in AWS, thus benefiting the company.

"This is something we need to focus on. It's at the heart of codes, standards, and talent," he asserted. "We need to drive what is the value, why we exist, and who we are here to serve."

AWS 2019 President Thomas Lienert also delivered a speech, titled *Parting Perspectives*, on his term as president. He began by acknowledging the high regard given to AWS presidents.

"It's great the tremendous respect paid to the office of president," he said. "It's been a great honor, and I'm very humbled to have served as the president of AWS for its 100th year."

Lienert then outlined some of the significant accomplishments during his presidency. This included extensive traveling, meeting AWS members, the establishment of the Future Leaders program, the new board leadership training, an improved board/committee communication initiative, American Society of Association Executives workshops, and revisions to AWS's

strategic planning process.

Providing a briefing on AWS's current status, he emphasized the organization's strong financial position, especially its Foundation department.

"It's unmatched and unparalleled in supporting welding education and training," he asserted.

Lienert concluded by summarizing some areas AWS can improve on, such as increasing participation in Section meetings, remaining relevant in a changing social and technical landscape, and understanding the diverse needs of the many demographic groups within the welding industry, which include differences in generation, gender, ethnicity, and profession. He also touched upon the shortage of qualified welding personnel.

Both incoming and outgoing presidents were given gifts. Roth was presented with his president's ring, a pen, a 1950s Cadillac emblem, and a framed piece of sheet metal engraved with images of welders and various processes, including resistance welding. Lienert received his Past President's badge, Life Member card, and Life Member pin. He was also gifted a bronze statue of a welder.

Ceremony attendees included Past President Ron Pierce; Foundation Chairman Bill Rice and his wife, Cherry; Dist. 16 Director Karl and his wife, Diane; Dist. 21 Director Samuel Lindsey and his wife, Hollaine Hopkins; Director-at-Large Walter Sperko; Director-at-Large Richard Holdren and his wife, Becky; Past President Dale Flood and his wife, Svetlana; Treasurer Carey Chen; Vice President Michael Krupnicki and his wife, Joanie; Vice President Dennis Eck and his wife, Robin; Vice President Richard Polanin and his wife, Terry; Roth's wife, Marcy, and daughter, Kayla; and AWS staff members. [WJ](#)

Article by KATIE PACHECO (kpacheco@aws.org), associate editor of the *Welding Journal*. Photo by CARLOS GUZMAN (cguzman@aws.org), editor of *Inspection Trends* and *Welding Journal en Español*.

AWS Employee of the Year



Misael Gonzalez (right) poses alongside AWS Past President Thomas Lienert after being selected as the 2019 employee of the year.

The 2019 Michael A. Rowland Exemplary Employee of the Year Award was given to Misael Gonzalez, building

maintenance technician. The peer-nominated and selected honor is bestowed yearly to an American Welding Society (AWS) employee who has provided outstanding service and made noteworthy contributions beyond the scope of normal duties, as well as possesses an attitude and behavior contributing to teamwork and the positive treatment of others in ways that exceeded job expectations.

Reading the nomination form during the presidential transition ceremony held February 21 at AWS World Headquarters, Miami, Fla., AWS Interim Executive Director Ray Shook praised Gonzalez for going beyond his daily duties while always keeping a smile on his face.

Gonzalez's job entails maintaining the AWS building and parking lot, ensuring it is painted, clean, and safe. Most recently, he took on the job of cleaning the outside fountain, allowing AWS to terminate its yearly contract with the cleaning service.

With his experience in construction, Gonzalez has also saved AWS money by supervising contractors, sometimes lending a hand when they have a limited crew. When he does not know something, he takes the initiative to learn and inform himself.

Gonzalez was further described as being proactive in seeking additional ways to lend a hand, including assisting with setups and breakdowns during AWS events and transporting visitors to their hotels.

Additionally, Gonzalez was characterized as being highly dependable and punctual. When asked to stay late or work on the weekends, Gonzalez is said to always agree — no questions asked.

"AWS is fortunate to have such a proactive, skilled, friendly employee with a go-getter attitude that makes him approachable," read Shook.

Gonzalez received \$1500, an engraved trophy, a restaurant gift certificate, and a designated parking space for one year.

TECH TOPICS

Opportunities to Contribute to AWS Technical Committees

The following committees welcome new members. Some committees are recruiting members with specific interests in regard to the committee's scope, as marked below: Producers (P), General Interest (G), Educators (E), Consultants (C), and Users (U). For more information, contact the staff member listed or visit aws.org/library/doclib/Technical-Committee-Application.pdf.

S. Borrero, sborrero@aws.org, ext. 334. **Definitions and symbols**, A2 Committee (E). **Titanium and zirconium filler metals**, A5K Subcommittee. **Piping and tubing**, D10 Committee (C, E, U). **Welding practices and procedures for austenitic steels**, D10C Subcommittee. **Aluminum piping**, D10H Subcommittee. **Chromium molybdenum steel piping**, D10I Subcommittee. **Welding of titanium piping**, D10K Subcommittee. **Purging and root pass welding**, D10S Subcommittee. **Low-carbon steel pipe**, D10T Subcommittee. **Or-**

bita pipe welding, D10U Subcommittee. **Duplex pipe welding**, D10Y Subcommittee. **Joining metals and alloys**, G2 Committee (E, G, U). **Reactive alloys**, G2D Subcommittee (G).

R. Gupta, gupta@aws.org, ext. 301. **Filler metals and allied materials**, A5 Committee (E). **Magnesium alloy filler metals**, A5L Subcommittee.

P. Portela, pportela@aws.org, ext. 311. **High energy beam welding and cutting**, C7 Committee (C, E, G). **Hybrid welding**, C7D Subcommittee (G). **Robotic and automatic welding**, D16 Committee (C, E). **Additive manufacturing**, D20 Committee (C, E, G). The D1N Subcommittee on Titanium Welding is recruiting all interest groups.

J. Molin, jmolin@aws.org, ext. 304. **Structural welding**, D1 Committee (E). **Sheet metal welding**, D9 Committee (C, G). The D1 Committee is recruiting educators. The D9 Committee is recruiting producers, consultants, and general interest members.

K. Bulger, kbulger@aws.org, ext. 306. **Methods of weld inspection**, B1 Committee (C, E). **Brazing and soldering**, C3 Committee (C, E, G).

Welding in marine construction, D3 Committee (C, E, G, U). **Welding of machinery and equipment**, D14 Committee (C, E, G, U).

M. Diaz, mdiaz@aws.org, ext. 310. **Resistance welding**, C1 Committee (C, E, G, U). **Friction welding**, C6 Committee (C, E). **Automotive welding**, D8 Committee (C, E, G, U). **Resistance welding equipment**, J1 Committee (C, E, G, U). **Welding in the aircraft and aerospace industry**, D17 Subcommittee (C, E, G).

S. Hedrick, steveh@aws.org, ext. 305. **Metric practice**, A1 Committee (C, E). **Mechanical testing of welds**, B4 Committee (E, G, P). **Joining of plastics and composites**, G1 Committee (C, E, G). **Safety and health committee**, SHC Committee (E, G). **Welding in sanitary applications**, D18 Committee.

J. Rosario, jrosario@aws.org, ext. 308. **Procedure and performance qualification**, B2 Committee (E, G). **Thermal spraying**, C2 Committee (C, E, G, U). **Oxyfuel gas welding and cutting**, C4 Committee (C, E, G). **Welding iron castings**, D11 (C, E, G, P, U). **Railroad welding**, D15 (C, E, G, U).

Technical Committee Meetings

All AWS technical committee meetings are open to the public. Contact the staff members listed or call (800/305) 443-9353 for information.

March 31–April 2. B2 Committee and Subcommittees on Procedure and Performance Qualification. San Diego, Calif. Contact: J. Rosario, ext. 308, jrosario@aws.org.

March 31–April 3. D1 Committee, Subcommittees, and Task Groups on Structural Welding. Miami, Fla. Contact: J. Molin, jmolin@aws.org, ext. 304.

April 14. D15C Subcommittee on Track Welding. Nashville, Tenn. Contact: J. Rosario, jrosario@aws.org, ext. 308.

April 14–16. D14 Committee on Machinery and Equipment. Longview, Tex. Contact: K. Bulger, ext. 306, kbulger@aws.org.

April 15. SH1 Subcommittee on Fumes and Gases. Columbus, Ohio. Contact: S. Hedrick, steveh@aws.org, ext. 305.

April 22. SH4 Subcommittee on Labeling and Safe Practices. Pittsburgh, Pa. Contact: S. Hedrick, steveh@aws.org, ext. 305.

May 18, 19. C1 Committee on Resistance Welding, D8 Committee and Subcommittees on Automotive Welding, and J1 Committee and Task Groups on Resistance Welding Equipment. Whitmore Lake, Mich. Contact: M. Diaz, mdiaz@aws.org, ext. 310.

May 27–29. D17 Committee and Subcommittees on Welding for Aircraft and Aerospace. Phoenix, Ariz. Contact: M. Diaz, mdiaz@aws.org, ext. 310.

New Standards Projects

Development work has begun on the following new or revised standards. Affected individuals are invited

to contribute to their development. Participation in AWS technical committees is open to all persons.

D1.1/D1.1M:20XX, *Structural Welding Code — Steel*. This code covers the welding requirements for any type of welded structure made from the commonly used carbon and low-alloy constructional steels. Clauses 1 through 11 constitute a body of rules for the regulation of welding in steel construction. There are eight normative and 11 informative annexes in this code. A commentary on the code is included with the document. Contact: J. Molin, jmolin@aws.org, ext. 304.

Standards for Public Review

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. This column also advises of ANSI approval of documents.

The following standards are submitted for public review. A draft copy may be obtained by contacting the listed staff secretary of the committee.

C2.19/C2.19M:20XX, *Specification for the Application of Thermal Spray Coatings to Machine Elements for OEM and Repair*. Revised Standard. \$31.50. ANSI public review expires 4/13/20. Contact: J. Rosario, jrosario@aws.org, ext. 308.

D14.6/D14.6M:20XX, *Specification for Welding of Rotating Elements of Equipment*. Revised Standard. \$48.00. ANSI public review expired 3/23/20. Contact: K. Bulger, kbulger@aws.org, ext. 306.

D14.9/D14.9M:20XX, *Specification for the Welding of Hydraulic Cylinders*. Revised Standard. \$32.00. ANSI public review expired 3/23/20. Contact: K. Bulger, ext. 306, kbulger@aws.org.

D17.3/D17.3M:20XX, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*. Revised Standard. \$38.00. ANSI public review expired 3/30/20. Contact: M. Diaz, mdiaz@aws.org, ext. 310.

ISO Draft Standards for Public Review

Copies of the following Draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43 St., Fourth Floor, New York, NY, 10036; telephone (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body.

In the United States, if you wish to participate in the development of international standards for welding, contact Andrew Davis at AWS, 8669 NW 36 St., #130, Miami, FL 33166-6672; telephone (305) 443-9353, ext. 466, email: adavis@aws.org. Otherwise, contact your national standards body.

ISO/DIS 8167 — *Resistance welding — Embossed projection welding — Projections for resistance welding*.

ISO/DIS 15615 — *Gas welding equipment — Acetylene manifold systems for welding, cutting and allied processes — Safety requirements in high-pressure devices*.

ISO/DIS 17279-3 — *Welding — Micro joining of 2nd generation high temperature superconductors — Part 3: Test methods for joints*.

New Standards Approved by ANSI

C3.14M/C3.14:2020, *Standard Method For Evaluation of Braze Joints using Visual and Metallographic Techniques*. Approval Date: 1/31/2020.

Nominate AWS Members to be Profiled

The *Welding Journal* is celebrating the diversity of its membership by profiling AWS members each month in its Society News section. Michael Gerhardt and Joe Bailey are profiled on pages 68 and 69.

To nominate an AWS member, submit a short statement

about what makes the nominee a noteworthy member, along with the nominee's contact information, to Katie Pacheco, kpacheco@aws.org.

To see member profiles from previous issues, visit aws.org/about/page/diversity-inclusion.

MEMBERSHIP ACTIVITIES

New AWS Supporters

Affiliate Corporate Members

Anytime Welding

1195 N. 5 St.
San Jose, CA 95112

Arkansas Valley Welding and Fabrication

P.O. Box 1761
Buena Vista, CO 81211

FDS Mechanical Inc.

19 Westfield Rd.
Coram, NY 11727

Industrial Welding Services

P.O. Box 51626
Casper, WV 26005

Olson Steel

1941 Davis St.
San Leandro, CA 94577

Pittsburgh Pipe

2331 Hampton Ave.
St. Louis, MO 63139

Pro Paragon Construction Co. Ltd.

17, Kyaik Waing Pagoda Rd.,
Myaing Hay Wun Housing
Yangon 11062 Myanmar

Ramcast Ornamental Supply Co. Inc.

2201 E. Firestone Blvd.
Los Angeles, CA 90002

Steel Guard Safety

16520 Vincennes Ave.
South Holland, IL 60473

Supreme Integrated Technology

12311 Cutten Rd.
Houston, TX 77066

Supporting Company Members

Strum Contracting Co. Inc.

6309 Fort Smallwood Rd.
Baltimore, MD 21226

Webb-Stiles Co.

700 Industrial Pkwy.
Gadsden, AL 35903

Sustaining Members

Freightcar America Inc.

2 N. Riverside Plaza, Ste. 1300
Chicago, IL 60606

Novarc Technologies

1225 Keith Rd. E., Unit 6
North Vancouver, BC V7J1J3
Canada

Portable Solutions Group

801 Scott St.
Worthington, KY 41183

Educational Institution Members

Bismarck State College

1500 Edwards Ave.
Bismarck, ND 58501

Colquitt County High School

P.O. Box 2708
Moultrie, GA 31776

Columbus State Community College

550 E. Spring St.
Columbus, OH 43215

Ferguson Inspection and Testing Services LLC

308 N. Main St., Ste. B
Huntsville, MO 65259

Holmes Community College — Goodman Campus

1 Hill St., P.O. Box 369
Goodman, MS 39079

Holmes Community College — Grenada Campus

1060 J. K. Avent Dr.
Grenada, MS 38901

Holmes Community College — Ridgeland Campus

412 W. Ridgeland Ave.
Ridgeland, MS 39157

Pacific Northwest Ironworkers Joint Apprenticeship Training Committees

16610 E. Euclid Ave.
Spokane, WA 99216

Pinellas Technical College — St. Petersburg Campus

901 34 St. S.
Saint Petersburg, FL 33711

Plymouth High School

1 Big Red Dr.
Plymouth, IN 46563

R & S Welding Mentors

P.O. Box 12036
Salem, OR 97309

West Virginia Northern Community College

1704 Market St.
Wheeling, WV 26003

Whitley County High School

350 Blvd. of Champions
Williamsburg, KY 40769

Woodland Park High School

P.O. Box 6820
151 Panther Way
Woodland Park, CO 80863

AWS Member Counts March 1, 2020

Sustaining.....	584
Supporting	357
Educational.....	836
Affiliate	607
Welding Distributor	63
Total Corporate	2447
Individual	57,109
Student + Transitional	10,904
Total Members.....	68,013



American Welding Society®
MEMBERSHIP



SPARKING CONNECTIONS – 2020 AWS MEMBERSHIP CHALLENGE



■ *What it is:*

Be the spark that ignites the people you know to become AWS members, and get rewards.

■ *How it works:*

Build up points throughout the year for each AWS Member you recruit: **5 Points** per Individual Membership and **1 Point** per Student Membership.

■ *What you get:*

Grand Prize Winner: \$200 gift card

2nd Place: \$100 gift card

3rd Place: \$100 gift card

4th Place: \$100 gift card

All other participants earning 10 or more points will get AWS branded merchandise based on points accrued throughout 2020.

The Fine Print: All AWS members in good standing may participate and are eligible to receive rewards based on points accrued January 1 – December 31, 2020. Participant eligibility is determined at the sole discretion of AWS program administrators. AWS staff members and administrators of commercial / corporate or educational packages that include AWS memberships in the pricing structure are not eligible to participate. For more information, visit aws.org/be-the-spark

PRIMARY CONTACT INFORMATION (Please Print)

☐ Mr. ☐ Ms. ☐ Mrs. ☐ Dr.

Last Name: _____ First Name: _____ M.I.: _____ Birthdate: _____

E-Mail: _____ Mobile Phone: () _____ Secondary Phone: () _____ ☐ Home ☐ Work

Company/School (if applicable): _____

Mailing Address: _____

City: _____ State/Province: _____ Zip/Postal Code: _____ Country: _____

☐ Check here if you would prefer to not receive email updates on AWS programs, Member benefits, savings opportunities and events.

Technical Interests (Circle All That Apply)

A Ferrous Metals	F High Energy Beam Processes	L NDT	R Automotive	X Structures
B Aluminum	G Arc Welding	M Safety and Health	S Machinery	Y Other
C Nonferrous Metals Except Aluminum	H Brazing and Soldering	N Bending and Shearing	T Marine	Z Automation
D Advanced Materials/Intermetallics	I Resistance Welding	O Roll Forming	U Piping and Tubing	1 Robotics
E Ceramics	J Thermal Spray	P Stamping and Punching	V Pressure Vessels and Tanks	2 Computerization of Welding
	K Cutting	Q Aerospace	W Sheet Metal	

STUDENT MEMBERSHIP

☐ New

☐ Renewal, Member #:

☐ 1 Year-Digital *Welding Journal* \$15

☐ 1 Year-Print and Digital *Welding Journal* \$85

☐ 1 Year-Print and Digital *Welding Journal* (US, Canada, and Mexico) \$35

(outside of US, Canada, and Mexico)

\$ _____

INDIVIDUAL MEMBERSHIP

☐ New

☐ Renewal, Member #:

Were you referred to AWS by an AWS Member? ☐ Yes ☐ No

Member's Name: _____ Member's # (if known) _____

DOMESTIC (INCLUDES US, CANADA, AND MEXICO)

New Member

☐ Initiation Fee \$12

☐ 2 Year - Print and Digital *Welding Journal* \$151

☐ 1 Year - Print and Digital *Welding Journal* \$88

\$ _____

Renewing Member

☐ 1 Year - Print and Digital *Welding Journal* \$88

☐ 2 Year - Print and Digital *Welding Journal* \$163

\$ _____

INTERNATIONAL (OUTSIDE OF US, CANADA, OR MEXICO)

New Member

☐ Initiation Fee \$12

☐ 2 Year - Digital *Welding Journal* \$151

☐ 1 Year - Digital *Welding Journal* \$88

☐ 2 Year - Print and Digital *Welding Journal* \$251

☐ 1 Year - Print and Digital *Welding Journal* \$138

\$ _____

Renewing Member

☐ 1 Year - Digital *Welding Journal* \$88

☐ 2 Year - Digital *Welding Journal* \$163

☐ 1 Year - Print and Digital *Welding Journal* \$138

☐ 2 Year - Print and Digital *Welding Journal* \$263

\$ _____

NEW MEMBER OPTIONAL BOOK SELECTION (Not available to renewals. Choose ONE option ONLY.

Includes shipping & handling.) Visit aws.org/memberships/page/new-member-book-offer to view selections and write your choice here:

☐ Domestic \$35

☐ International \$85

\$ _____

TOTAL \$

Business (Circle ONE Letter Only)

A Contract Construction	F Machinery Except Electric (Incl. Gas Welding)	J Transport Equip. — Boats, Ships	O Educational Services (Univ., Libraries, Schools)	R Government (Federal, State, Local)
B Chemicals & Allied Products	G Electrical Equipment, Supplies, Electrodes	K Transport Equip. — Railroad Utilities	P Engineering & Architectural Services (Including Assns.)	S Other
C Petroleum & Coal Industries	H Transport Equip. — Air, Aerospace	L Welding Distributors & Retail Trade	Q Misc. Business Services (Including Commercial Labs)	
D Primary Metal Industries	I Transport Equip. — Automotive	M Misc. Repair Services (Including Welding Shops)		
E Fabricated Metal Products				

Job Classification (Circle ONE Letter Only)

01 President, Owner, Partner, Officer	04 Purchasing	10 Architect Designer	08 Supervisor, Foreman	15 Educator
02 Manager, Director, Superintendent (Or Assistant)	05 Engineer — Welding	12 Metallurgist	14 Technician	17 Librarian
03 Sales	06 Engineer — Design	13 Research & Development	09 Welder, Welding or Cutting Operator	16 Student
	20 Engineer — Manufacturing	22 Quality Control	11 Consultant	18 Customer Service
	06 Engineer — Other	07 Inspector, Tester		19 Other

PAYMENT INFORMATION

Payment can be made (in U.S. dollars) by check or money order (international), payable to the American Welding Society.

☐ Check ☐ Money Order

☐ AMEX ☐ Diners Club ☐ MasterCard ☐ Visa ☐ Discover ☐ Other Application Date: _____

Name on Card: _____ CC#: _____ / _____ / _____

Expiration Date (mm/yy): _____ / _____ CVV: _____ Applicant Signature: _____

OFFICE USE ONLY Source Code: **WJ** Account #: _____ Check #: _____ Amount: _____

Date: _____ AWS Staff: _____

2020 Membership Challenge

Listed here are the members participating in the 2020 Membership Challenge — point standings as of Feb. 21. The campaign runs from Jan. 1 to Dec. 31, 2020. Members receive 5 points for each Individual Member and 1 point for every Student Member they recruit. For more information, please

see page 65 of this *Welding Journal* or call the AWS Membership Dept. at (800) 443-9353, ext. 480.

A. D. Dillon, Detroit — 38
B. J. Cain, Los Angeles/Inland Empire — 34
T. M. Molin, Illinois Valley — 30
D. P. Thompson, Southwest Virginia — 29
A. P. Duris, Northwest Ohio — 26

R. Young, Iowa — 24
H. J. Merrill II, Louisville — 20
B. A. Cheatham, Columbia — 17
O. Ortiz, Los Angeles/Inland Empire — 16
J. C. Durbin, Tri-River — 16
C. W. Gilbertson, Northern Plains — 14
V. O. Harthun, Northern Plains — 13
S. Silverstein, Milwaukee — 12

AWS A5C Subcommittee Meets in Orlando



The American Welding Society (AWS) A5C/A5.10 Subcommittee held a meeting on Jan. 23 in Orlando, Fla. Pictured (from left) are Jian Zhang; Galen White; Teresa Melfi, A5 Committee chair; Lance Vernam; Patrick Berube; Damian Kotecki; Carson Williams; Matt Underwood; Tony Anderson, A5C Subcommittee chair; Bill England; and Rakesh Gupta, AWS senior staff engineer, Standards Development.



AWS A5 Committee Chair Teresa Melfi (left) honors AWS A5C Subcommittee Chair Tony Anderson with a service pin for his ten years as a volunteer.



AWS A5 Committee Chair Teresa Melfi (left) presents a service pin to Lance Vernam for his 20 years of volunteer service to the A5C Subcommittee.

AWS Member Profile



Michael Gerhardt

For Michael Gerhardt, welding has been an academic saving grace. Prior to discovering the craft in his freshmen year at Millard North High School, Omaha, Neb., he didn't have the strongest grades. Now in his junior year of high school, and enrolled in afternoon welding classes at the Metropolitan Community College (MCC) Career Academy, Gerhardt says welding has bolstered his academic standing.

"Being in welding has improved my GPA significantly. I think that being able to do something that makes me happy has made me want to get better grades in all my classes, and I feel more engaged in those classes now," he said. "Knowing that I will be welding in the afternoon makes me feel positive and energetic from the start of the day. It also helps that I need to get good grades so I can stay in the Academy."

Looking back, Gerhardt says he enrolled in his high school's material-forming class because he wanted to work with his hands instead of sitting behind a desk. He quickly found that welding piqued his interest.

"I loved it when the metal would heat up and turn red, and the sparks would fly. I was hooked from the beginning," he recalled. "When I'm welding, I feel like I'm in my own world, and all I think about is what I'm doing and how to do a good job."

With the help of his instructor, Jonathan Olson, Gerhardt learned oxyacetylene welding (OAW), shielded metal arc welding (SMAW), gas metal

arc welding (GMAW), and gas tungsten arc welding.

"I was introduced to most of the processes of welding, and I was able to get a feel for what welding was like," he said. "Mr. Olson was able to give me practical knowledge and advice, and I was then able to help others who were just starting."

With his newfound skills, Gerhardt has built pieces he is proud of, including a square-tube park bench joined with OAW, SMAW, and GMAW. Varnished wood slates were used for the seat and backrest.

"The reason why I liked the bench was because it was a challenging project, but in the end the bench turned out really good," he affirmed. "The benches were sold to raise money for our program."

In 2018, Gerhardt's commitment to welding drove him to become an American Welding Society member. He continues to seek out opportunities that can help him further develop his knowledge.

"My dad told me about it since he knew how much I was interested in welding. The *Welding Journal* has shown me how much variety there is to welding, and how much there is to learn," he explained. "We've been talking about trying to make it to FABTECH in Las Vegas this year since there are so many opportunities to learn and be around other people passionate about welding."

Gerhardt has also challenged himself through competitions. Last year, he took part in the SkillsUSA state welding competition, earning seventh place with his team.

"What I liked about it was that we had to practice a lot for the competition. The competition was stressful. We had to work as a team in order to get done," he recollected.

Gerhardt was also involved in the Metro Omaha Trade Invitational competition as an individual welder, coming in at 16th place. He's looking forward to competing again this year.

By the end of his sophomore year, Gerhardt had completed all of the welding classes offered at his high school, so he dual-enrolled in afternoon classes at MCC, where he was able to broaden his knowledge in all

processes, as well as learn spray transfer, oxyfuel gouging, and plasma arc cutting and gouging.

"At Metro, I'm able to advance my skills beyond what I could do in high school, and I'm able to get credit toward an associate's degree in welding," he said. "I like that I can do a different type of welding every day. I keep learning new things about each welding process, and I know that I will never be done trying to learn more and get better."

Gerhardt also enjoys using the college's advanced facilities.

"The Construction Education Center at Metro is new, and the building and equipment are top-notch. We have all the trades together in one building, and we have space for our work in our trades and for classroom time," he said.

His plans for the future include earning an associate's degree in welding from MCC. He hopes to one day become a pipeline welder.

"The reason for that is most welding on pipelines is done with stick [SMAW], and stick [SMAW] is my favorite type of welding," he said. "Also pipe welding is very hard, and I want a career in welding that will be a challenge."

Gerhardt acknowledges he wouldn't be where he is now if it weren't for the guidance of several dedicated instructors as well as the comradery of his fellow classmates.

"I have been very lucky to have supportive teachers in high school and at the Academy who take the time to teach me and are always encouraging. I feel like the Industrial Arts program at Millard North and my teammates in SkillsUSA gave me a place where I felt at home. Now at the MCC Career Academy, I'm surrounded by other students like me who love welding every day. I really don't know where I would be right now if this career path hadn't been made available to me," he said.

He also credits his late grandfather, a jack-of-all-trades who worked for a general contractor, for influencing him.

"I wanted to be like him, so that is why I started getting involved with the trades," he affirmed. "I hope he would be proud of me, and I wish he would have had the chance to teach me what he knew about welding."

AWS Member Profile



Joe Bailey

Joe Bailey is a testament to the saying, “If at first you don’t succeed, try, try again.” Attempting welding for the first time in high school, he found the shielded metal arc welding process to be anything but easy.

“I was super frustrated. I remember for the first 30 minutes I stuck one rod after another and couldn’t lay a good bead,” he recalled with a laugh.

Although he didn’t initially have a knack for welding, he seized an opportunity to take a longer welding class through Vermeer Corp., Pella, Iowa, a manufacturer of industrial and agricultural equipment. He was able to master gas metal arc welding (GMAW), learn how to inspect welds, and work in the company’s metallurgy lab.

“Learning how a metallurgy lab works and how to measure materials really intrigued me and piqued my interest,” he said.

As a high schooler, Bailey also started his own successful mowing business, called Minute Men Mowers, which employed several workers. Being a business owner taught him the significance of good customer service.

“I learned how to set expectations for a customer so they know what to expect from a job, the importance of meeting and exceeding those expectations, and how to deal with unhappy customers,” he said. “Those were not easy experiences, but they helped me a lot in my professional development.”

After graduating high school, Bailey took on a job as a welder at Vermeer, where he performed GMAW and air carbon arc cutting, tacked parts from

blueprints, assembled chains for trenchers, and operated welding robots. The experience further solidified his love of welding and manufacturing processes.

In 2008, Bailey enrolled at LeTourneau University, Longview, Tex., to pursue a double major in materials joining engineering and mechanical engineering. During his college years, Bailey continued to expand on his work experience. He completed two engineering internships with John Deere and one with Vermeer. When asked what was the most interesting project he worked on as an intern, he identified his time at Vermeer’s metallurgy lab.

“We had a cylinder rod that had failed at a welded connection. In digging into it, I discovered one of the parts was made out of high-sulfur steel. I was able to then apply my metallurgical learning from school to that problem and see first hand the metallurgical phenomenon that happens when you weld on a high-sulfur steel and the cracks that it can create,” he recollected. “It’s really cool to be able to put the theoretical knowledge to a real-world problem.”

In between classes and internships, Bailey served his college as the student body president and secretary of the American Welding Society (AWS) Student Chapter.

Today, Bailey is a senior engineer at Vermeer, where he has been for more than seven years. His job entails providing welding and material-related expertise for manufacturing issues, product design, and root cause failure analysis; developing welding procedure specifications and procedure qualification records; and training engineers on welding, weld standards, and weldment design. His favorite part of the job is when something breaks.

“I get most excited when we have a failure that comes in and try to figure out why the part failed and how we can fix it moving forward,” he explained. “I just love that root cause investigation process.”

Bailey is also a professional engineer with the state of Iowa, as well as an AWS Certified Welding Engineer and Certified Welding Inspector.

Dedicated to propelling the industry, he has volunteered for AWS in

multiple capacities since becoming a member in 2010. He has served as secretary, chairman, and member-at-large of the Iowa Section; member of the AWS D14 Committee on Machinery and Equipment plus its Subcommittees (14.3, 14.4, and 14.9); member of the Chapter 5 Committee on Design and Welded Connections; and judge of Iowa SkillsUSA competitions. His dedication has earned him the Iowa Section Meritorious Award and the Dist. 16 Meritorious Award.

His volunteer work is spurred by the desire to give back to an industry that has given him a lot. A recipient of various scholarships from AWS and other societies, he is thankful he was able to complete his education debt-free. To pay it forward, he has helped the Iowa Section implement three different endowed scholarships through the AWS Foundation’s matching program.

“I am really excited to be able to reinvest what was invested in me back into the Society,” he said. “One of my favorite things I get to do occasionally is talk to students about their future education. I love to paint a picture of what they can do in the world of welding, and how they can help fund their education through AWS scholarships.”

When asked where he would like to see himself within the next few years, Bailey explained he wants to continue honing his technical skills while improving his management abilities. He also plans to continue serving AWS and its various committees.

Reflecting on his welding journey, Bailey credits the guidance he received from others, including AWS Past President Dave Landon and Dr. Duane Miller, for inspiring him to continue pursuing the craft.

“I did not get to where I am by myself. I have been incredibly blessed by other people investing in me and seeing where I can go. The fact that I am in welding is because others said, ‘This is a career that might interest you,’” he affirmed. “I’ve had great mentors along the way, and so I encourage readers to find mentors they can team up with. And if you’re already well into the industry, look for ways you can give back. Look for ways you can mentor others and help them on their journey.”

District 1

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CONNECTICUT December 30

Location: La Luna Restaurant, New London, Conn.
Presenter: Ilya Gekhman, CEO, Center of Audit and Advisory
Summary: The Section was selected to have its financial operations reviewed. The suggestions from the audit were well taken with minimal adjustments to be made to the operational system used by Connecticut Section officers. The dinner meeting lasted approximately an hour and consisted of excellent conversation and getting to know a little bit more from everyone on a personal basis.

District 2

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NEW YORK January 21

Location: Carpenter's Union Training Center, New York City, N.Y.
Presenter: Doug DeMarco, CWI and welding educator
Summary: Members and students were given a tour of the Section's library at the Carpenter's Union Training Center. Students were also instructed on the use of virtual welding machines and AWS membership benefits were discussed.

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District 4

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TRIANGLE January 23

Location: Raleigh, N.C.
Presenter: Susan Rothecker, CEO, SMT Co.
Summary: Members were treated to dinner followed by a plant tour of the SMT Co., which included a view of the company's paint/powder coat line. Attendees then spent time in the weld shop where they saw robotic welding as well as numerous manual welding stations in operation.



NEW YORK — January meeting attendees are seen at the Carpenter's Union Training Center.



NEW YORK — Doug DeMarco, CWI and welding educator, was the guest presenter at the Section's January meeting.



CONNECTICUT — Attendees of the Section's financial audit enjoyed dinner at La Luna Restaurant.



TRIANGLE — Members took a tour of the SMT Co. in Raleigh, N.C.

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District 6

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NIAGARA FRONTIER

January 30
Location: Buffalo, N.Y.
Summary: Charlie Cross, from Lincoln

Electric, spoke to Section members about becoming an AWS Certified Welding Inspector. Approximately 50 people attended the meeting, including students from local high schools and colleges.

NORTHERN NEW YORK

February 13
Presenter: Lawrence Mullins, ASNT regional director, Region 2
Summary: Section members participated in an annual joint meeting with ASM and ASNT. Mullins spoke about developments in ultrasonic equipment and codes and standards for weld inspection.

ROCHESTER

February 5
Location: Fishers, N.Y.
Summary: Members took a plant tour of Gorbel, a manufacturer of overhead material handling and fall protection products in the industrial sector, as well as gait and balance therapy products in the rehabilitation world. Members are appreciative to Tyler Brown, vice president of operations, and Max Powell, staffing specialist, for coordinating the event.



NIAGARA FRONTIER — Meeting attendees enjoyed a presentation on how to become an AWS Certified Welding Inspector.



NIAGARA FRONTIER — Guest speaker Charlie Cross (left) received a speaker award from Section Chair Kevin DeVault.



NORTHERN NEW YORK — Members of AWS, ASM, and ASNT are seen during their annual joint meeting.



ROCHESTER — February meeting attendees gathered for a photo during their plant tour of Gorbel.

District 7

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COLUMBUS

January 16

Location: Edison Joining Technology Center, Ohio State Campus
Presenters: Tom Eckardt, Keifner and Associates; Matt Boring, DNV GL; and Boris Shneyder, Worthington Industries

Summary: The Section held a scholarship recognition event at the Edison Joining Technology Center, which is the welding engineering building on Ohio State campus. The Section provided pizza, salad, and soft drinks for the students and presenters. The event started off with a presentation on AWS scholarships and an individual recognition of all AWS scholarship recipients from the Section. They were presented with certificates, an AWS pin, and a sticker. The second portion of the event included two speakers from local industry. The first speaker from Worthington Industries, who was also previously with Airgas, presented on shielding gas selection for gas metal arc welding. The second speaker was from DNV GL and spoke about current welding issues in the pipeline industry, including hot taps



COLUMBUS — Matt Boring (right) reviewed a student's résumé.



COLUMBUS — Canyon Underhill (left) received an AWS scholarship recognition certificate from Tom Eckardt.

and X70 pipe failures. The event concluded with a résumé review session for the students searching for summer internships. The speakers and Section officers worked with groups of four to five students to review and compare their draft résumés to examples provided by Ohio State Career Services as well as provide interviewing tips.

January 29

Location: Pins Mechanical, Dublin, Ohio

Presenter: Kurt Louys, professional solutions consultant, Konica Minolta Business Solutions USA Inc.

Summary: Members got together for a social gathering at Pins Mechanical. Topics discussed included engineering copier capabilities and production, weld quality and inspection, failure analysis and cracking problems, and solutions.

February 19

Location: Crowne Plaza Columbus North, Columbus, Ohio

Presenter: Jason Robbins, head of NDT sales, VisiConsult X-Ray Systems & Solutions

Summary: Robbins was the guest

speaker at the Section's February meeting. He presented several case studies to highlight the technology changes that have arrived in the rapidly evolving xray and nondestructive examination world. The three main topics discussed focused on relevant applications that use additive manufacturing, artificial intelligence, and 3D automated defect recognition (ADR).

JOHNSTOWN/ALTOONA

November 2019

Location: Johnstown, Pa.

Summary: Members toured RNDT. The tour showcased the various inspection services offered by the company, including welding inspection.

December 2019

Location: Napotnik Welding/Napotnik Welding Supplies, New Florence, Pa.

Summary: Section members were given a tour and presentation of Napotnik Welding and Napotnik Welding Supplies. The company showcased its design, welding, fabricating, machining, and painting capabilities at their manufacturing plant.



COLUMBUS — Kurt Louys, John Lawmon, and Joey Worman attended the January social gathering.



COLUMBUS — Guest Speaker Jason Robbins (left) was presented a gift by Brian Frye.



JOHNSTOWN/ALTOONA — Members are pictured after touring RNDT in Johnstown, Pa.



JOHNSTOWN/ALTOONA — Section members are seen during a tour of Napotnik Welding and Napotnik Welding Supplies.

PITTSBURGH

February 11

Location: Steamfitters Local #449
Harmony Training Center, Harmony, Pa.

Summary: The Section held its 39th Annual Student Weld-Off Awards Night. The evening was hosted by Steamfitters Local #449. The Weld-Off competition took place previously at Pittsburgh Technical College. The competition involved 46 students welding two coupons each. The 96 coupons then underwent a visual test (VT) inspection. The coupons that passed VT were then inspected by radiography. SystemOne performed the radiography of the coupons and reading of the film free of charge. The speaker for the evening, Dan Klingman of Lincoln Electric Co., gave a presentation on motorsports welding and lessons learned. Also attending were Dan McMahon, Lincoln Electric district representative and Evan McCorkel, Lincoln Electric technical sales representative.



PITTSBURGH — First-place post secondary winner Kody Turner (left) is seen with Eastern Gateway Community College Instructor Gary Coulter.



PITTSBURGH — First-place secondary winner Dylan Eckman (left) is seen with Northern Westmoreland Career & Technology Center Instructor George Kirk.



PITTSBURGH — Section Chair Ray Knobbs (far left) is seen with (from left) Guest Speakers Dan Klingman and Dan McMahon as well as with Evan McCorkel.



PITTSBURGH — Post-secondary student Weld-Off certificate winners gathered for a photo.

District 8

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CHATTANOOGA January 22

Location: Chattanooga State Community College, Chattanooga, Tenn.
Summary: Sequoyah High School Student Chapter officers presented on the office they held, how they became interested in welding, and what their plans were after graduation. Many Section members offered them industry advice.



CHATTANOOGA — Sequoyah High School officers include (from left) Shane Smith, James Thwing-Munn, Tristan Baggett, Joey Morrison, Savannah DeFur, and Julian Moore.

HOLSTON VALLEY February 11

Location: Utility Trailer, Glade Spring, Va.
Presenter: Tim McVey, human resources, and Otis Barker, plant engineer, Utility Trailer
Summary: Section meeting attendees were given a tour of the Utility Trailer manufacturing facility, which included parts processing, subassembly manufacture, final assembly, and testing of its dry box trailers. The facility spans more than five acres under one roof and the tour was split up into two groups. More than 100 welders are employed at the facility. The welding

processes utilized include gas metal arc welding, gas tungsten arc welding, gas shielded flux cored arc welding, and self shielded flux cored arc welding. An AWS CWI oversees many of the quality control aspects related to welding performed. The meeting had a great turnout and attendees found it beneficial to network with other welding professionals in the Southwest Virginia region of the Section.

District 9

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District 10

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DRAKE WELL February 11

Location: Harmony, Pa.
Summary: Every year the welding technology class from Venango Technology Center enters the Pittsburgh



HOLSTON VALLEY — Section members are seen at the tour of Utility Trailer in Glade Spring, Va.



DRAKE WELL — Attendees of the AWS Pittsburgh Section's 39th Annual Weld-Off included (from left) Travis Crate, Dakota Urey, Cole Harvey, Tyler See, and Robert Fugate.

Section's American Welding Society's Annual Weld-Off. This year, in addition to high school seniors, two night class students competed in the event. Dakota Urey (Cranberry High School) earned 2nd place in the college level competition. He received a plaque and a check for \$200. Those receiving D1.1 xray certifications included Urey for 3G vertical up and 4G overhead, Cole Harvey (Titusville) for 3G vertical up, and Tyler See (Titusville) for 3G vertical up.

District 11

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DETROIT February 13

Location: Easom Automation – Lincoln Electric, Madison Heights, Mich.

Presenter: Tim Hurley, global industry segment director — transportation;

and D. Mark Douglass, business development manager, additive solutions, Lincoln Electric

Summary: The Section held a technical meeting. The host for the event was Frank Wennberg, sales manager, Lincoln Electric. Douglass presented the latest in Lincoln Electric's additive manufacturing efforts. His presentation focused on both the progress and challenges the industry is facing as this technology moves forward. Hurley presented on the latest efforts by Lincoln Electric to decrease the amount of surface silicates left after

gas metal arc welding, with a focus on the mechanisms that cause surface silicates and the ongoing work to reduce or eliminate them.

PINCKNEY COMMUNITY HIGH SCHOOL STUDENT CHAPTER January 14

Location: Pinckney, Mich.

Summary: Welding students and Instructor Mark Stein recognized Craig Winbigler and Stan Wood of Bradhart Products Inc. for donating a coordinate measuring machine to the school's manufacturing and welding program.



DETROIT — Section Events Chair Eric Lichtfusz (left) thanked Guest Speakers D. Mark Douglass and Tim Hurley.



Pinckney Community High School Student Chapter — Welding instructor Mark Stein (far left) is seen with his students and the coordinate measuring machine donated to the school's manufacturing and welding program by Bradhart Products Inc.



BLACKHAWK — Presenters/Instructors (from left) Rob Zezniewski, Tina Clucas, George Bane, and Tommy Carpenter (back, far right) helped local Boy Scouts earn their Welding Merit Badge.

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BLACKHAWK February 1

Location: Lino's Restaurant, Rockford, Ill.

Presenter: Jay Haynes, regional automation specialist, Lincoln Electric
Summary: The Section hosted a technical dinner with Haynes as its featured presenter. The meeting was a great opportunity for members to network and learn more about automation system possibilities.

February 8

Location: Rock Valley College, Rockford, Ill.

Presenter: Rob Zezniewski, Tina Clucas, George Bane (Rock Valley College welding department chair), and Tommy Carpenter

Summary: Scouts participated in a two-day event for shielded metal arc (SMAW) and gas metal arc welding (GMAW). They first met for an evening of welding safety and understanding the basics of welding. Day two was hands-on experience at Rock Valley College's weld lab. Scouts built

a carbon steel eagle using the GMAW process and wrote their initials using the SMAW process. This is an annual Welding Merit Badge event held with the Section and instructors from Rock Valley College. The event brings Scouts in from all around Northern Illinois to participate.

CHICAGO January 29

Location: Mama Luigi's Restaurant, Bridgewater, Ill.

Summary: The Section's board members met to discuss old and new business as well as to schedule spring 2020 meetings.



BLACKHAWK — Retired instructor Larry Clevenger (left) discussed workforce development with new instructor Bill Isham and a guest.

District 14

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ST. LOUIS January 23

Location: Chesterfield, Ill.

Summary: Members visited the blacksmithing workshop of Craig Camerer. Camerer was a blacksmithing champion on Season 2, Episode 1 of the History channel's "Forged in Fire." The show tests some of the best in the field as they attempt to recreate some of history's most iconic edged weapons.

District 15

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ST. LOUIS — Blacksmith Craig Camerer demonstrates some of his skills during a tour of his home blacksmith shop.



CHICAGO — January meeting attendees included (sitting, from left) Craig Tichelar, James Greer, Elisabeth Darnell, Pete Host, Anghelina Iftimie, and Section Chair Cliff Iftimie. Standing are (from left) Jeff Koppel, Jeff Stanczak, Dave Viar, and John Hesseltine.

District 16

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MID PLAINS February 10

Summary: Michael Jorgenson, welding instructor at Hershey High School, gave members a tour of the recent upgrades made to the school's skilled and technical sciences program. Highlights included six upgraded individual welder training booths for shielded metal, gas metal, gas tungsten, and flux core arc welding as well as a space for welding fabrication and a materials processing area.

District 17

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District 18

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HOUSTON October 19

Location: Tulsa Welding School, Houston, Tex.
Presenter: Shelly Short
Summary: The Section participated in



MID PLAINS — Hershey High School Juniors Ali Vaughn and Kinley Crow are seen in front of the school's new virtual reality welding machines.



ST. LOUIS — Section members are seen at Craig Camerer's blacksmith shop.



MID PLAINS — Hershey High School students are pictured in the welding lab.

SECTION NEWS

Tulsa Welding School's "Top Welder Series 2."

SABINE December 17

Summary: District 18 presented its final first-place welding competition scholarship at the Texas Rice Festival.

District 19

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ALASKA January 29

Location: Anchorage, Alaska
Presenter: Joe Shepard, PE, owner/engineer, North Iron Engineering
Summary: North Iron Engineering (NIE) was gracious to facilitate the Section's January meeting. Besides eating and general Section announcements and discussions, NIE also gave the attendees a tour and explanation of a range of metallurgical investiga-

tions, instruments, and tools of their analysis. NIE operates Alaska's only commercial metallurgical engineering test laboratory. Alaska's unique blend of harsh weather, aging infrastructure, and delicate ecosystems create an environment where failure is not an option. In appreciation for the tour, NIE was presented with an AWS Alaska Section 125 gold pan.



SABINE — Jeff Clark (right) presented a welding competition scholarship to Bret Mock.



ALASKA — Guest Speaker Joe Sheperd (second from right) was awarded the Alaska Section 125 gold pan by (from left) Section Certification Officer Lou Alvord, Member Ace Dube, and Treasurer Creighton Moore.



HOUSTON — Teams from Jacksonville, Fla.; Tulsa, Okla.; Phoenix, Ariz.; and Houston, Tex. are pictured during the Tulsa Welding School's "Top Welder Series 2."



ALASKA — Pictured are attendees of the Section's January meeting.

SPOKANE February 20

Location: Steam Plant Kitchen & Brewery, Spokane, Wash.
Summary: The Section met for Ladies' Night at the historic Steam Plant Kitchen and Brewery, a working steam plant from 1907 to 1986 turned museum in 1996. Attendees were invited to bring their spouse or guest for dinner and were treated to a presentation by Teresa McHugh, a local commercial artist who uses metal to create sculptures inspired by nature.

District 20

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COLORADO February 20

Location: The Rusty Bucket, Westminster, Colo.
Summary: Section members got together for an informal gathering at The Rusty Bucket to meet Evelyn Andino, AWS program manager, AWS Student Chapters/Sections. Attendees were happy to meet Andino and discussed Section concerns while treating her to dinner in appreciation for taking time out of her vacation to meet with them.

HELENA HIGH SCHOOL STUDENT CHAPTER January 23

Location: Helena High School, Helena, Mont.
Summary: The Section held its 8th annual Weld-Off against Capital High

School. Students dug through scrap metal, chose pieces that would work for their project, then designed and welded the project in 4 h. The participants showed great creativity and sportsmanship. The first-place team from Helena High School included



SPOKANE — Teresa McHugh, local commercial artist, spoke to February meeting attendees about her experiences in welding and design of metal artwork.



Helena High School Student Chapter — The first-place winners of the Section's Weld-Off were (from left) Byren Stoner, Collin Neilson, Luke Ronan, and Makenna Wofford.



COLORADO — Pictured at an informal gathering of the Section are (from left) Erich Posdich, president, BDB Fabrication; Jeremy Mowry, shop supervisor, Broomfield Sheet Metal; Bob Teuscher, AWS past president and president, Ajax Industries; Evelyn Andino, AWS program manager, AWS Student Chapters/Sections; Marj Oliver, AWS Senior Certified Welding Inspector, Great Denver Iron; Kevin Dowell, instructor, Community College of Denver Advanced Manufacturing Center; and Brice Davison, president, BDB Fabrication.

SECTION NEWS

Byren Stoner, Collin Neilson, Luke Ronan, and Makenna Wofford. The second-place team was from Capital High School and included August Nelson, Mason Copeland, Matt Richards, and Jacob Engdahl. Third-place team members from Helena High school were Dillon Ostberg, Alex Ogle, Ava Ogle, and Koner Schmolke. The fourth-place team was Ezra Rojas, Mason Skains, Jacob Bartow, and David Hanson from Capital High School. The Section is appreciative to all the local businesses that supported the competition as well as to the judges.

NEW MEXICO

February 18

Location: Albuquerque, N.Mex.

Presenter: Robert Roth, AWS 2020 president

Summary: Roth visited the Section

and spoke about water-cooled, high-current, low-voltage power sources manufactured by RoMan Mfg.

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purviswelds@gmail.com

SACRAMENTO VALLEY

December 3

Location: Shasta College, Redding, Calif.

Summary: District 17 Director Chelsey Morris flew out to the Section to present Jack Fife with his 25-Year AWS Silver Member Award. Morris was a student of Fife and surprised him with the presentation under the guise of being a guest speaker for his welding class.



SACRAMENTO VALLEY — Jack Fife (left) received his AWS 25-Year Member Award from former student/current District 17 Deputy Director Chelsey Morris.



NEW MEXICO — Section Chair Matt Johnson and AWS President Robert Roth are seen with Section members.



SACRAMENTO VALLEY — Instructor Jack Fife (center with award plaque) is surrounded by his blueprint reading students at Shasta College.

GUIDE TO AWS SERVICES

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American Welding Society

Change of Address? Moving?

Make sure delivery of your *Welding Journal* is not interrupted. Contact Kim Hugley in the Membership Department with your new address at (800) 443-9353, ext. 262, or by email to khugley@aws.org.

National Tooling and Machining Adds President



R. Atkins

The National Tooling and Machining Association (NTMA), Cleveland, Ohio, representative of the custom precision manufacturing industry, has appointed Roger Atkins as president. Atkins joined the association in 1979. He has since held

every officer position at the national level, including chairman in 2012, and served in every officer position in the Houston, Tex., NTMA chapter. He began his career at his family's contract manufacturing business. Over the years, he spearheaded growth in multiple contract manufacturing companies, including growing a Texas-based company from \$22 to \$156 million, which included acquisitions and international greenfield startups. For the past several years, he has operated RJ3 Enterprise, an executive advisory company, guiding small- to medium-sized contract manufacturing companies through growth and change.

Wall Colmonoy Chooses Managing Director of European Headquarters



R. Davies

Wall Colmonoy, Pontardawe, Swansea, Wales, UK, a global materials engineering group, has selected Rob Davies as managing director of its European headquarters. Davies joined the company in March 2015, bringing with him 14 years of experience in strategic, opera-

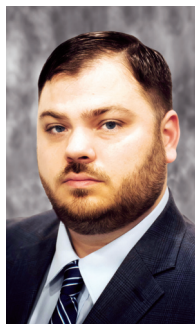
tional, and engineering management. He has worked predominantly in the automotive industry with more than

five years of profit and loss responsibility as plant manager. His experience covers assembly, precision machining, and extrusion processes for safety critical steering systems, engines, and seating components. In his role, he will focus on growing the company and reaching into new markets through product solutions and business acquisitions.

Solar Atmospheres Announces Plant Hires



G. Scheuring



T. Gundic

Solar Atmospheres has added Gregory Scheuring as plant metallurgist to the Western PA, Hermitage, Pa., facility and Tom Gundic as plant manager to the Greenville, S.C., facility. Scheuring has extensive metallurgical experience from his time with A&T Stainless, AK Steel, and the Ellwood Group. Along with assisting on daily metallurgical questions, he will be responsible for expanding the company's materials testing laboratory. Gundic brings more than 14 years of vacuum heat-treating and brazing experience, with time spent leading teams in Nadcap and AS9100 quality systems.

Member Changes at Hobart Institute Board of Directors

Hobart Institute of Welding Technology, Troy, Ohio, has welcomed Steve Staub, the president of Staub Manufacturing Solutions in Dayton, Ohio, as a member of the college's board of directors. He is also a member of the executive committee of the National Association of Manufacturers in Washington, D.C. Staub began his career at the age of 14, working at his



S. Staub



G. Schaffer

father's tool and die shop. He has served on regional, state-wide, and national boards promoting the manufacturing industry and science, technology, engineering, and mathematics careers. Additionally, long-time member Greg Schaffer has retired from the board of directors. Schaffer was elected to the board in 2004 as a trustee of the Institute. His history with the school dated back to his 17-year career with Hobart Brothers as a business controller. He left the company in 2005 and moved to North Carolina to accept a position with Duke Energy until 2018 when he started working for Ernst and Young. He officially retired in 2019.

Lincoln Electric Board Directors Named Influential Corporate Directors



K. J. Lincoln



H. S. Runtagh

WomenInc. magazine, a magazine dedicated to women's achievement in business, has named Lincoln Electric, Cleveland, Ohio, Board Directors Kathryn J. Lincoln and Hellene S. Runtagh amongst the 2019 Most Influential Corporate Directors. The list features top women executives and influ-

encers who represent corporate board leadership, diversity, and excellence. Lincoln serves as the board chair and chief investment officer of the Lincoln Institute of Land Policy. She has served on the company's board since 1995, chairs the nominating and corporate governance committee, and serves on the compensation and execu-

utive development committee. She is also a member of the board of directors of the HonorHealth Network and chairs the Claremont Lincoln University board. Runtagh is the former president and CEO of the Berwind Group, served as executive vice president of Universal Studios, and previously held a variety of leadership positions at

General Electric Co. She has served on the Board of Directors of Lincoln Electric since 2001 and is a member of the compensation and executive development committee as well as the nominating and corporate governance committee. **WJ**



American Welding Society

AWS, Weld-Ed Website Promotes Welding Careers

The American Welding Society (AWS) and National Center for Welding Education & Training (Weld-Ed) website at *CareersInWelding.com* offers the following details: people and companies in the welding industry; fun facts; salary information; industry news; videos; articles; and upcoming training opportunities, seminars, and events.

Additionally, the site features pages geared directly for students with scholarship information and a welding school locator; for welding professionals to build a résumé,

find welding-related jobs, and learn about AWS certifications; and for educators to discover tips for teachers and guidance counselors, information about curricula, professional development, and other resources.

This website serves as a valuable tool for students, parents, educators, counselors, and welding professionals. It also allows visitors to send questions, comments, or ideas for people profiles.



American Welding Society

Can We Talk?

The *Welding Journal* staff encourages an exchange of ideas with you, our readers. If you'd like to ask a question, share an idea, or voice an opinion, you can call, write, email, or fax. Staff email addresses are listed below, along with a guide to help you interact with the right person.

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COMING EVENTS

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Tex., June 15–17. Contact Marion Hess, hessm@asme.org, (212) 591-7161, or register at asme.org/products/courses/bpv-code-section-ix-welding-brazing-fusing.

Business Electronics Soldering Technology. Certification and training classes held in Rolling Meadows, Ill.; Auburn Hills, Mich.; Rosemount, Minn.; and Cleveland, Ohio, or can be coordinated onsite at your facility. Training schedule is available at solder.net. Contact BEST at (847) 797-9250.

CWB Online/Classroom Courses. Courses in NDE disciplines to meet certifications to the Canadian General Standards Board or Canadian Nuclear Safety Commission. The Canadian Welding Bureau; (800) 844-6790; cwbgroup.org; info@cwbgroup.org.

CWI Exam Prep Course. American Institute of Nondestructive Testing offers a 40-h online CWI exam prep course. Part A covers the fundamentals of welding technology; part B consists of extensive practical hands-on techniques and will be held at the Houston Marriott North in Houston, Tex.; and part C provides in-depth training to the welding code portion of the exam. Contact Jeff LeTourneau, instructor@trainingndt.com, (855) 313-0325, or visit trainingndt.com.

E-Courses in Destructive and Nondestructive Testing of Welds and Other Welding-Related Topics. Online video courses taken at one's own pace offer certificates of completion and continuing education units. Contact Hobart Institute of Welding Technology; (800) 332-9448; welding.org/product-category/online-courses/.

ESAB Welding and Cutting Instructor-Led Training. Year-round training at Denton, Tex.; West Lebanon, N.H.; Traverse City, Mich.; Hanover, Pa.; and Salt Lake City, Utah. Online e-Learning training is available. Email trainingteam@esab.com or visit training.victortechologies.com.

Gas Tungsten Arc Welding Aerospace Course. Hobart Institute of Welding Technology, Troy, Ohio. This 70-h course will develop the skills necessary for entrance into the aerospace industry, including working with typical materials, weld joint configurations, and tools involved in production and testing within aerospace manufacturing and repair. For information, contact (937) 332-9500 or visit welding.org.

Hypertherm Cutting Institute Online. Includes video tutorials, interactive e-Learning courses, discussion forums, webinars, and blogs. Visit hypertherm.com; hyperthermcuttinginstitute.com.

Industrial Laser Training. Technical training and support offered for users of industrial lasers in manufacturing, education, and research. Regularly scheduled classes in laser welding, laser cutting, and drilling. HDE Technologies Inc.; (916) 714-4944; laserweldtraining.com.

Laser Safety Training Courses. Laser training courses for personnel in research, industrial, and medical laser facilities. Courses based on ANSI Z136.1, *Safe Use of Lasers*. Orlando,

Fla., or customer's site. Laser Institute of America; (800) 345-2737; lia.org.

Laser Vision Training Seminars. Two-day classes, offered monthly and on request, include tutorials and practical training. Presented at Servo-Robot Inc., St. Bruno, QC, Canada. For schedule, cost, and availability, email info@servorobot.com.

Machine Safeguarding Seminar. Rockford, Ill. Two-and-a-half-day seminar teaches how to properly safeguard machinery for OSHA/ANSI standards. Added will be discussion of the upcoming release of ANSI B11.0-2020 and ANSI B11.19-201X standards. Go to rockfordsystems.com/seminar.

Modern Furnace Brazing School. Wall Colmonoy presents a three-day seminar offering knowledge and practical application on brazing design, metallurgical aspects/brazing operation, brazing atmosphere and furnace equipment, brazing material and applications, and quality control. United States seminar: May 12–14, Cincinnati, Ohio, contact Jim Nicoll, (248) 585-6400, ext. 233, wallcolmonoy.com/brazingschool, brazingschool@wallcolmonoy.com. European seminar: Oct. 6–8, Pontardawe, Wales, UK, contact Jordan Brace, +44 (0) 1792 860622, wallcolmonoy.co.uk/brazingschool, brazingschool@wallcolmonoy.co.uk.

NDE Classes. Moraine Valley Community College, Palos Hills, Ill., offers NDE classes in PT, MT, UT, RT, radiation safety, and eddy current, as well as API 510 exam prep and weld inspection. (708) 974-5735; ccce@morainevalley.edu; morainevalley.edu.

NDT Classroom Training and e-Learning Course. Offers courses in UT, RT, MT, PT, eddy current, and remote visual inspection. Onsite training also available. (855) 232-7470; geinspectionacademy.com; inspection.academy@ge.com.

NDT Courses and Exams. Brea, Calif., and customers' locations. Level I, II, and III refresher courses in PA, UT, MP, radiation safety, radiography, visual, and more. Test NDT LLC; (714) 255-1500; testndt.com.

Preparation for AWS® — CWI®/CWE® Examination. Troy, Ohio. This two-week class offers nine days of instruction with the test being administered on the tenth day. Includes a backpack for the convenience of carrying books and other study materials. Contact Hobart Institute of Welding Technology; (800) 332-9448; welding.org.

Professional Development Workshop. Five-day workshop equips welding educators and industrial trainers with the latest in training techniques, technology, and best practices. Seven training modules include welding metallurgy; joining and cutting processes; design, assembly, and robotic welding; welding codes, specifications, and safety; instructional design and teaching strategies; nondestructive examination; and additional welding and allied processes. Location and dates available at weld-ed.org, or contact Michael Fox, (440) 366-4927, mfox@lorainccc.edu.

Protective Coatings Training and Certification Courses. At various locations and online. The Society for Protective Coatings; (877) 281-7772; sspc.org.

Resistance Welding Seminar. T. J. Snow Co. Subjects covered include basics of resistance welding, resistance welding terms, pneumatic systems and troubleshooting, welding transformer operation and troubleshooting, basic resistance welder setup and weld lobe development, electrode selection and maintenance, quality assurance, operator safety, and identifying problems and solutions. The dates and locations are as follows: April 8, East Mich.; April 22, Cleveland, Ohio; May 6, Frankfort, Ky.; June 24, Charlotte, N.C.; July 22, Montgomery, Ala.; Aug. 12, Dallas, Tex.; Aug. 26, Nashville, Tenn.; Sept. 9, Omaha, Neb.; Sept. 23, Grand Rapids, Mich.; and Oct. 14, Phoenix, Ariz. To sign up, contact Cheryl McDonald, (423) 308-3214, CherylMcDonald@tjsnow.com.

Veterans Goodwill Weld Training Program. South Burlington, Vt., and Eagle River, Wis. AWI and Veterans of

Foreign Wars (VFW) have partnered to offer veterans a complimentary two-day training at AWI facilities. Contact (802) 660-0600, (715) 337-0122, or awi.edu.

WJM Technologies Welding Training Courses. Courses include Resistance (Spot) Welding, Laser Welding and Materials Processing (now being offered on a quarterly basis), and Metallurgy and Welding. Classes can be combined with hands-on training at your location and can be customized to suit your needs. For more information, contact Girish P. Kelkar, WJM Technologies, (562) 743-7576, or go to welding-consultant.com. 

NEWS OF THE INDUSTRY

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result in the development of joining applications to benefit electronic and consumer product manufacturers.

- **Peabody Energy**, St. Louis, Mo., has donated \$3000 to **Eastern Wyoming College's** welding technology program. The funds were used to purchase flux cored guns, liners, and $\frac{1}{16}$ -in. wire for the college's power sources. This will en-

able students to use equipment they would find in a working environment.

- **Xiris Automation**, Ontario, Canada, has appointed **Weld Australia** as its exclusive distributor of weld camera products for Australia. "We are excited to work with an excellent partner who has many years of experience in the welding industry at all levels in Australia, combining training and certification experience with extensive welding equipment knowledge," said David Garrard, the company's sales director of Asia Pacific. 

PRODUCT & PRINT SPOTLIGHT

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less steel and high tensile alloys. The 30-grit wheel comes in sizes $4\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8}$ and $4\frac{1}{2} \times \frac{1}{2} \times \frac{1}{4}$ —11 in. The $\frac{1}{4}$ -in.-thick Velocity Grinding Wheel is for general fabrication applications, such as heavy weld grinding, beveling hard steels, grinding casting parting lines, or removing weld deposits. It has a maximum stock removal rate with an extended wheel life on stainless steel and ferrous metals, such as structural steel and iron. The 24-grit grinding wheel

comes in sizes $4\frac{1}{2} \times \frac{1}{4} \times \frac{1}{8}$ and $4\frac{1}{2} \times \frac{1}{4} \times \frac{1}{4}$ —11 in.

Rex-Cut Abrasives
rexcut.com
(800) 225-8182

Report Evaluates the Global Carbon Steel Market

Carbon Steel Market by End-User and Geography — Forecast and Analysis 2020–2024 predicts the global carbon steel market will expand at a compound annual growth rate of 8% due to the demand for high-strength and cost-effective construction materials. The 153-page report posits the con-

struction segment had a significant market share in the carbon steel industry, and this trend is expected to continue. The development of high-rise buildings, tech parks, roads, highways, and other residential and commercial infrastructure is predicted to play a significant role in the construction segment's leading position. However, the report states, the volatile prices of raw materials, the threat of substitutes, and stringent government regulations on reducing carbon emissions from steel production may hamper this market's growth over the coming years.

Research and Markets
researchandmarkets.com
(800) 526-8630



SCHOOL PROFILES

Employers
Are you in need of
good welders?

Students
Are you searching for a way to
hone your skills?

Welders
Is it time to expand your
talents and knowledge?

Below are welding schools across the country that have taken this advertising opportunity to promote their resources both to industry in need of welders and to those searching for a solid career path to employment.

The National Center for Welding Education and Training (dba **Weld-Ed**) is a partnership of community colleges, universities, business and industry, and the American Welding Society and it is funded by the National Science Foundation. The Center's primary mission is to increase the quantity and quality of welding and materials joining technicians to meet industry demand through curriculum reform and educator professional development. Additional information is available at www.weld-ed.org.



National Center for Welding Education and Training

Alfred State College SUNY College of Technology Founded 1908

Alfred State College offers welding training on its Wellsville, NY campus. Earn an associate in occupational studies degree. Employer-driven curriculum teaches the skills needed in today's workforce: oxyfuel, SMAW, GTAW, GMAW, and pipe welding. Program includes key support courses such as metallurgy, blueprint reading, and quality control. Benefit from AWS Level I and II certification. Enjoy small classes, tutoring and personal attention. Customized courses available for employers.

Hit the ground running!



10 Upper College Drive
Alfred, NY 14802
(800) 4-ALFRED
admissions@alfredstate.edu
alfredstate.edu

All-State Career School Essington, PA

Are you interested in gaining the skills needed to enter the rewarding field of welding? If so, choose All-State Career School in Essington, Pa. Our welding instructors take pride in providing our students with essential education and training to create the well-rounded welding professional – one who is skillful with today's welding processes. The welding curriculum at All-State Career School is structured to provide focus on the design, production, performance, and maintenance of welding materials. Learn how you can enroll at All-State today and train to be able to earn your certificate in welding.



All-State Career School
Essington Trades Campus
50 W. Powhattan Avenue
Essington, PA 19029
(610) 521-1818

For consumer info visit
allstatecareer.edu



Advanced Technology Institute

ATI provides diploma and AOS degree programs in the practical aspects of construction and repair of equipment and structures built with steel and aluminum. Our staff is AWS, CWI and CWE certified and we are an AWS Accredited Test Facility. We instruct all position welding in the four most common processes: SMAW, GMAW, GTAW and FCAW. Students will train in the use of modern welding equipment and tools, and learn weld symbols and blueprint reading. Students may test for their 6G pipe qualification in accordance with AWS D1.1-2020. ATI offers financial assistance for those who qualify, and graduate employment services. Certified to operate by SCHEV in Virginia.



Advanced Technology Institute (ATI)
5700 Southern Blvd.
Virginia Beach, VA 23462
(757) 490-1241
auto.edu

All-State Career School Pittsburgh, PA

Did you know that welders are capable of gaining employment in a variety of industries, including car racing and manufacturing? At All-State Career School's welding program you will be provided with a foundation in industrial welding techniques, crafting skills, and welding mathematics to prepare you for a rewarding welding career. Fulfill your dream of becoming specialized in welding, cutting, soldering, or brazing with training from All-State Career School.



All-State Career School
Pittsburgh Trades Campus
1200 Lebanon Rd., Suite 101
West Mifflin, PA 15122
(412) 823-1818

For consumer info visit
allstatecareer.edu

Austin Community College

The Welding Technology Program at Austin Community College offers seven certificates and four Associate of Applied Science degrees. Areas of specialty include welding inspection, ultrasonic testing, structural welding, and inert gas welding. Additional topics include orbital tube welding; metallurgy; and pipe welding. Our architectural and ornamental metal programs include blacksmithing, power hammer, and metal sculpture. Classes totaling over 600 seats are offered at two campuses.



Austin Community College
(512) 223-6220
austinctc.edu/welding



SCHOOL PROFILES

Bellingham Technical College Welding Technology Program Founded 1957

Bellingham Technical College's welding program is an AWS Accredited Test Facility that offers students an Associate of Applied Science or the opportunity to transfer to a four-year school. BTC welding graduates have high job placement rates, as we serve a thriving community of refineries, pipelines, shipbuilders, fabrication shops, contractors and more. Our award-winning program is housed in an 80,000-square-foot, state-of-the-art facility, where students can learn welding and fabrication for alloys, structural steel or pipe welding. Students in the program take part in a week-long welding competition in which they create sculptures from scrap metal, with proceeds from sales funding welding scholarships. The program also hosts a yearly High School Skills Challenge that draws young welders from throughout the region.



3028 Lindbergh Ave.
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(360) 752-8301
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crush@btc.edu
rwright@btc.edu
btc.edu



Butte-Glenn Comm. College

Recipients of NASDCTEc 2015 Excellence in Action award for the best CTE program in the nation. CITEA 2015 Community College Program of the Year. The Welding Technology program is designed to produce qualified personnel for certified welding jobs. Butte has modern and well-equipped welding facilities. Program standards are in accordance with the AWS SENSE program and follows NCCER curriculum, ASME, and API codes. Produces entry-level welding technicians qualified in the 6-G pipe position. Large emphasis on SMAW, FCAW, GMAW, GTAW, OAW, OFC, PAC and AAC processes, in all positions using various metals and alloys. Qualifications earned in AWS, ASME, and API according to personal skill. **PG&E Power Pathway Gas Pipeline Welding Capstone Program:** The Pathway specifically trains welders for potential careers within the petrochemical/natural gas pipeline industry.

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CDA Technical Institute Commercial Diving Program with Underwater Welding

CDA Technical Institute is the only fully accredited diver training program with IMCA-recognized training, on-campus housing, and a full meal plan. CDA offers a comprehensive and rigorous (20 weeks) program. CDA's graduates earn certifications from the Association of Commercial Diving Educators, Association of Diving Contractors International, Diver Certification Board of Canada (a truly internationally recognized certification), National Center for Construction Education and Research, and Haz-Woper Environmental Training. They can also earn certifications from the American Welding Society, National Board of Diving and Hyperbaric Medical Technicians, National Academy of Scuba Educators, and National Registry Emergency Medical Technicians. Call or visit our website for more details.



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Jacksonville, FL 32208
(888) 974-2232 toll free • (904) 766-7736
CDA.EDU

Brigham Young University Idaho

The BYU-Idaho B.S. degree in Welding Engineering Technology draws students from across the United States. The degree provides qualified graduates with a balance of welding engineering savvy and hands-on welding skill. The program is preparing graduates to be successful in a variety of welding industry segments with graduates currently in manufacturing, automation, inspection, codes and standards, technical sales, design, tooling, processes and planning.



Welding Engineering
Technology

525 S. Center St., AUS 159
Rexburg, ID 83460-1010
(208) 496-7654
byuiweld.com

Cal-Trade Welding School of Modesto Founded 1975

Cal-Trade Welding School of Modesto has been operating since 1975. Using the industry employers as a guide, we teach SMAW, GMAW, GTAW, FCAW and pipeline welding. Welding technique training is primary and students are given one-on-one instruction. In the 18 week Combination Welding Course students have the opportunity to earn multiple certifications. Welding theory, mathematics for welders, and blue print reading are also offered. Lifetime job placement assistance is available to students after graduation.



424 Kansas Ave.
Modesto, CA 95351
(209) 523-0753
Fax: (209) 523-8826
caltradeweldingschool.com

Central Carolina Technical College Founded 1961

The welding program at CCTC provides a thorough knowledge of the techniques of SMAW, GTAW, GMAW, FCAW, oxyacetylene cutting and plasma cutting. Graduates can further develop their skills in CCTC's Advanced Pipe Welding program where students pass welding tests using the shielded metal arc welding process, as well as gas tungsten arc pipe welds, gas metal arc pipe welds and combination pipe welds. Established in 1961 and located in Sumter, SC. CCTC is a fully accredited technical college.



CENTRAL CAROLINA TECHNICAL COLLEGE

506 N. Guignard Drive
Sumter, SC 29150
(803) 778-1961

Axel Reis, Welding Program Manager
(803) 778-7863
reisah@cctech.edu
cctech.edu



SCHOOL PROFILES

Central Lakes College

In the Central Lakes College Welding and Fabrication Program, students get advanced training in the shop, which is home to 50 power units. They will develop a skill-set above the average student. Those skills include welding processes, cutting processes, metallurgy, fabrication, blueprint reading and math. Choose from the 11-month diploma or 2-year AAS degree options, and then easily join the high-demand workforce. Or through the AWS SENSE Program, earn a Level I certificate. Learn and live in the Brainerd Lakes area, which is the premier recreational region in the upper midwest. Central Lakes College, with campuses in Brainerd and Staples, Minnesota, offers over 50 career programs and liberal arts transfer education.



David Otto – david.otto@clcmn.edu
Josh Carter – joshua.carter@clcmn.edu
501 West College Drive
Brainerd, MN 56401
(218) 855-8086
clcmn.edu

Columbus State Community College

Columbus State Community College, located in Columbus, Ohio, offers individuals an opportunity to learn welding and complete a Welding Associate Degree or an Intermediate Welder Certificate. The certificate provides the necessary credentials for entering the workforce as an intermediate level welder. Our Skilled Trades program proudly participates as a Level II S.E.N.S.E. school, teaching SMAW, GMAW, FCAW, GTAW, PAC, and oxy-fuel processes. Certificate studies can be completed in one year. Financial aid and veteran's benefits are available.

COLUMBUS STATE

COMMUNITY COLLEGE

Scott Laslo,
Program Coordinator
(614) 287-2653
slaslo1@csc.edu
550 E. Spring St.
Columbus, OH 43215
csc.edu

Cuesta College Welding Technology

Located on the central coast of California, the Cuesta College Welding Technology program has a strong history of preparing students for work in industry. Students are afforded the opportunity to obtain certificates of specialization, certificates of achievement and an Associative Science Degree in welding technology. Our curriculum is well rounded with courses ranging from basic welding through certification, as well as courses in metallurgy, blueprint reading and welding power. The shop facility includes twenty multiprocess welding stations with current power supply technology. There are a total of six part-time instructors and two full-time instructors. Four of our instructors are CWIs. Welder qualifications are offered in structural steel and pipe welding to AWS D1.1, ASME Section IX, and API 1104.



P.O. Box 8106
San Luis Obispo, CA 93403-8106
(805) 546-3100 ext. 2737
Rob Thoresen, rthorese@cuesta.edu



Central Wyoming College

Industry driven, affordable, hands-on! Central Wyoming College, located in the beautiful Wind River Valley, is an AWS Educational Institution with curriculum that aligns with AWS's SENSE program. CWC is also an Accredited Test Facility with the AWS. Students are trained to weld according to AWS prequalified welding procedures as well as the American Petroleum Institute's 1104 Pipeline Code. There is a large emphasis on blueprint reading, welding symbols, metallurgy and weld inspection. Training includes Shield Metal Arc Welding, Gas Tungsten Arc Welding, Gas Metal Arc Welding, Flux Core Arc Welding and Oxyacetylene Welding. Students have a choice of earning a credential, a certificate or an associate of applied science degree. Our welding lab has the most up-to-date welding equipment and a state of the art air moving system.



Darryl Steeds, CWI
dsteads@cw.edu
(307) 855-2138
Admissions: (800) 865-0193
cw.edu

Cosumnes River College

Cosumnes River College Welding Technology Department is a competitive trade program located in Sacramento, California. Students can earn certificates in welding code and fabrication or an associate science degree. The shop is fully equipped with Hypertherm, Miller Electric and Lincoln Electric power supplies. The welding stations are equipped with FCAW, SMAW, GMAW and GTAW processes. Material handling of plate, sheet-metal and pipe are accomplished by a 1/2" thick by 6' long capacity shear, two 1" plate capacity iron workers, two track cutting torches, three band-saws and three belt sanders. Students can perform plate and pipe certifications to ASME, API and AWS standards. Graduate students can enter the work force with a class 5 industrial truck license, a 10 hour OSHA safety card, overhead crane and rigging skills and AWS welder certifications.



8401 Center Parkway
Sacramento, CA 95823
Jason Roberts
(916) 691-7386
robertj@crc.losrios.edu

Dunwoody College of Technology

Founded 1914

For more than 100 years Dunwoody has been a national leader in welding education. Current academic offerings include a one-year Welding Certificate and two-year AAS Degree in Welding & Metal Fabrication. Dunwoody strives to change lives by building opportunities for graduates to have successful careers and develop into leaders and entrepreneurs. With 99% placement, an average class size of 11, and 15.7 job requests per student, Dunwoody provides students with the education needed to excel in today's workforce.

DUNWOODY

COLLEGE OF TECHNOLOGY

818 Dunwoody Boulevard
Minneapolis, MN 55403
(612) 374-5800
info@dunwoody.edu
dunwoody.edu



SCHOOL PROFILES

Earlbeck Technical Center

The Earlbeck Technical Center offers a complete curriculum of welding classes. Our Fundamentals course instructs in the basics of oxyfuel, GTAW, GMAW, and SMAW. Students may then progress through intermediate level classes, offering certification testing in plate, and advanced level classes, offering certification testing in pipe. Visual Welding Inspection, Symbols for Blueprint Reading, and customized and mobile training are also available. The Earlbeck Technical Center, winner of the 2017 AWS & WEMCO "Excellence in Welding Award" in the Educational Facility category, is an AWS Accredited Test Facility, as well.



Baltimore, MD
York, PA
Scranton, PA
(410) 687-8400
dhodges@earlbeck.com
earlbeck.com/weldertraining.html

Ferris State University

Ferris State University's nationally recognized ETAC-ABET Welding Engineering Technology program is the largest of its kind in the United States. Since its inception in 1984, the program is designed to produce plant-level welding engineering technology graduates who are involved in the concept, design and engineering of weldments and implementation of welding processes.



Welding Engineering Technology
915 Campus Drive, SWN 220
Big Rapids, MI 49307
(231) 591-2511
Jeffrey Carney,
Associate Professor/Program Coord.
carneyj@ferris.edu
ferris.edu/welding
facebook.com/FSUWelding

Fortis College Cuyahoga Falls, OH

Fortis College Cuyahoga Falls, formerly known as National Institute of Technology, was founded in Cuyahoga Falls, Ohio, in 1966. The Welding Technician program teaches students the principles of welding technology. In the program, students are introduced to basic air carbon arc, oxyfuel, and plasma arc cutting processes. The fundamental concepts of shielded metal arc welding and gas metal arc welding as well as flux core arc welding are taught. Pipe welding and gas tungsten arc welding applications are also included in the curriculum.



2545 Bailey Road
Cuyahoga Falls, OH 44221
(330) 923-9959
For consumer info visit fortis.edu

Eastern Florida State College Founded 1960

Eastern Florida State College, located in the heart of the nation's space coast, offers a one year Welding Technology certificate program. The program provides the theoretical and practical experience necessary to develop a basic foundation in the skills of welding, and is designed to train students to become certified welders in pipe and structural steel. SMAW, FCAW, GMAW, GTAW and cutting processes along with AWS, ASME, API and ANSI welding codes apply. Graduates of the program will be prepared for entry-level positions as welders and are eligible to take the AWS weld certification exam.



1519 Clearlake Road
Cocoa, FL 32922

Phil Sweeney, Student Advisor
sweeney@easternflorida.edu
(321) 433-5771

Kenneth Cox, Asst Professor
coxke@easternflorida.edu
(321) 433-7175
easternflorida.edu

Fortis College Smyrna, GA

Kick-start your welding career with a Fortis College education. In our Welding Technology program you can get the training and hands-on expertise needed to enter the growing welding industry in various careers, including industrial welders, check welders, welding apprentices and more. Our courses offer instruction on the intricacies of welding and all its phases including the use of destructive and nondestructive testing to ensure our students have a thorough understanding of quality welding. Contact us today to learn more about our program and schedule a campus visit.



2140 South Cobb Drive
Smyrna, GA 30080
(770) 980-0002
For consumer info visit fortis.edu

Fortis College Cincinnati, OH

Enjoy using your hands and finding practical solutions to complex problems? If so, a career in welding could be for you! The first step is to gain the essential training to be successful in the field. At Fortis we have the training, guidance, and resources to help you succeed. Our Welding Technology program offers instruction in fundamental math applications, introduction to oxyfuel cutting, and various welding processes to make you skillful in this skilled trade with a future. Give Fortis a call today to learn more and to schedule a campus visit.



11499 Chester Road, Suite 200
Cincinnati, OH 45246
(513) 771-2795
For consumer info visit fortis.edu



SCHOOL PROFILES

Fox Valley Technical College

FVTC has been a college of choice in Northeast Wisconsin for over 100 years. Offerings include more than 200 associate degree, technical diploma and certificate programs, and apprenticeship instruction for eighteen skilled trades. Additionally, FVTC delivers customized training to 35,000 business and industry clients each year. In total, the college serves approximately 50,000 people annually. Welding and Metal Fabrication offerings include 2 certificates, 3 technical diplomas and 1 associate degree. Classes are taught at our state-of-the-art facilities in Appleton, Oshkosh and Wautoma, Wisconsin, by 14 Certified Welding Inspectors.



Craig Schmidt
(920) 232-6056
schmidtcfv@fvtc.edu

Appleton Main Campus
1825 N. Bluemound Drive
Appleton, WI 54912

Advanced Manufacturing Tech. Center
4200 Poberezny Road
Oshkosh, WI 54902

Wautoma Regional Center
556 S. Cambridge Street
Wautoma, WI 54982

Guilford Technical Community College

GTCC Welding graduates are employed in a variety of industries, including Nuclear, Aircraft, Mechanical and Artistic. Students are highly qualified and prepared for Welder Performance Qualification tests. Our focus is welding performance on structural plate and pipe in compliance with AWS D1.1 and ASME Section IX. The new Center for Advanced Manufacturing has 76 welding booths. GTCC offers Certificate 1 – Structural Plate/Pipe; Certificate 2 – Welding Technology in Manufacturing; and Diploma, which consists of both certificates together.



6012 W. Gate City Boulevard
Greensboro, NC 27407
(336) 334-4822

Donald Ellington, Associate Professor
djellington@gtcc.edu
gtcc.edu

Hobart Institute of Welding Technology

Founded 1930

Hobart Institute of Welding Technology offers a wide range of welding skill and technical training classes and certifications. The catalog lists the skill training programs, over 25 individual courses, corporate training, and a listing of the AWS® certified testing services provided. Corporate training may be done at our facility or yours. The HIWT bookstore offers complete training curriculum that include DVDs, Instructor Guides, and Student Workbooks along with other weld education-related items.



HOBART INSTITUTE
OF WELDING TECHNOLOGY
400 Trade Square East
Troy, OH 45363
(937) 332-9500
Fax: (937) 332-9550
welding.org

Georgia Trade School

Founded 2012

Georgia Trade School graduates have worked on iconic stadiums from Mercedes Benz to Truist Park, iconic music venues from the Roxy to Ameris Bank Amphitheatre, iconic film and television sets from Stranger Things to The Walking Dead, Fast and Furious and Tyler Perry Studios and on the most important acres of America building ships for the Navy, Coast Guard and Marines. With 800 graduates across 20 states our welders are truly "Rebuilding America."



GEORGIA TRADE SCHOOL
REBUILDING AMERICA

Joanna Vinson, President
4231 Southside Drive
Acworth, GA 30101
(770) 590-9353

jvinson@georgiatradeschool.com
georgiatradeschool.com

Harper College

Harper College offers AAS degrees in Welding Technology and in Advanced Manufacturing with an emphasis in metal fabrication. Home to the FMA Metal Fabrication Lab, Harper now offers press brake, laser and robotic welding training, along with certificates in basic and advanced welding, basic pipe welding and welding fabrication. The program prepares students to pass American Welding Society Level I and Level II testing. Harper also provides custom training in welding and fabrication for employees of area businesses.



Kurt J. Billsten
Coordinator of Manufacturing
Technology
1200 West Algonquin Rd.
Palatine, IL 60067
(847) 925-6149
kbillste@harpercollege.edu
harpercollege.edu

Illinois Valley Community College

Founded 1924

Illinois Valley Community College offers classes in all of the major welding process (SMAW, GMAW, GTAW, FCAW, and oxy-acetylene). Blueprint reading, metallurgy, and fabrication are also available. Certificates and AAS degrees may be earned by taking morning, afternoon, or evening classes. IVCC is an AWS Accredited Test Facility. Local partnerships with business and industry ensure that students are prepared for high wage in-demand careers available to our graduates. Customized training is available to area employers.



Anthony Sondgeroth
Welding Program Coordinator
815 N. Orlando Smith Road
Oglesby, IL 61348
(815) 224-0319
Anthony_Sondgeroth@ivcc.edu
ivcc.edu



SCHOOL PROFILES



Lakeshore Technical College

Located between Milwaukee and Green Bay, Wisconsin, on the eastern shore of Lake Michigan, Lakeshore Technical College is a nationally recognized college that can have you work-ready in 27 weeks. From our innovative programs and experienced faculty to our high-tech classrooms and labs, affordability, and graduate placement rates, LTC ranks among the best. Our state-of-the-art KOHLER Center for Manufacturing Excellence serves as the only AWS certified testing facility in the area; it's also where we offer multiple entry points for our welding fabrication and welding industrial programs. Learn more today at gotoltc.edu.



#2 IN THE U.S.
TWO-YEAR COLLEGE

1290 North Avenue
Cleveland, WI 53015
1.888.GO TO LTC
gotoltc.edu

Lone Star College

Founded 1972

Lone Star College, founded in 1972, provides high-quality, low-cost academic transfer and career training education to 99,000 students each semester in the greater Houston area. LSC offers AAS degrees in Welding Technology to prepare individuals for a career as a welding technician in the fabrication, construction and manufacturing industries. The LSC Welding Technology certificate program prepares students for entry-level employment as a structural welder. LSC also offers a BAS in Energy, Manufacturing and Trades Management, which is designed for students seeking to advance their professional qualifications.



(832) 813-6500
LoneStar.edu

Mid-Plains Community College

Mid-Plains Community College's Welding Technology program is offered at both North Platte and McCook campuses. The program is an open-entry, open-exit program that leads to a diploma or associate of applied science degree and employment in the welding field. Students will progress according to his/her abilities and efforts. Upon completion of a set of prescribed technical competencies, students will be able to perform skills necessary to be successfully employed at the entry level.



1101 Halligan Dr.
North Platte, NE 69101
(800) 658-4308
info@mpcc.edu
mpcc.edu

Locklin Technical College

Locklin Tech has been serving students with career/technical training opportunities for over 35 years. All programs offer certificates of completion, industry certifications and/or state and national licensure. Partnerships with business and industry help ensure programs prepare students for high skill, high wage, and high demand occupations. Locklin's Welding Technology and Advanced Welding programs equip students using current industry driven curriculum providing instruction in the necessary skills needed by industry employers including: oxyfuel, SMAW, GMAW, FCAW, GTAW and pipe welding. We prepare you to meet the current workforce demands.



5330 Berryhill Road
Milton, FL 32570
(850) 983-5700
Fax: (850) 983-5715

Long Beach City College

Long Beach City College offers welding and metal fabrication training on its PCC Campus in Long Beach, Calif. Earn either an A.S. Welding degree or a A.S. Metal Fabrication Technology degree and up to (6) different certificates in SMAW, GTAW, FCAW, Robotic Welding and Metal Fabrication with a curriculum that is aligned with the AWS SENSE program. Our facility conducts welder's structural performance qualifications for the city of Los Angeles Dept. of Building and Safety (LADBS) with (2) CWI/CWE faculty on staff. The program is supported by (2) shops with the weld shop containing 65 welding booths, along with the best equipped metal fabrication shop in California. Courses are offered in most welding processes along with support courses in robotic welding, blueprint reading, layout, metallurgy, CNC metal fabrication, and CNC plasma cutting. Day and night courses are offered with program completion possible in one year.



Long Beach, CA 90806

(562) 938-3042
(562) 938-3051
dskinner@lbcc.edu
tshoemaker@lbcc.edu

Mitchell Technical Institute

Mitchell Technical Institute offers an industry-driven Welding & Manufacturing Technology program providing skills for graduates to excel in welding, machining, drafting, laser/plasma cutting systems, robotics and lean manufacturing techniques. Instruction is American Welding Society code based. During the second year, students learn clearly defined and communicated welding quality standards and learn to test welds by various methods including dye penetrant, radiographic, visual, tensile load testing and bend-and-break testing conducted by a CWI within an ATE.



Mitchell Technical Institute

1800 E. Spruce St.
Mitchell, SD 57301
(800) 684-1969
mitchelltech.edu



SCHOOL PROFILES

Modern Welding School

Founded 1936

Modern Welding School is an ACCSC School of Excellence award recipient. Students receive training in OAW, SMAW, pipe, GTAW, and GMAW/FCAW. The school's full-time program is 900 hours and the evening part time program is 665 hours. Job placement assistance is available for students of the career programs. Training is also available to companies looking for specialized welding training, welding certification testing, or consulting for their personnel.



Schenectady, NY 12304

(800) 396-6810

(518) 374-1216

Learn2weld@modernwelding.com
modernwelding.com

Moraine Park Technical College

Moraine Park Technical College offers a one-year Welding diploma program focusing on GMAW, FCAW, SMAW and GTAW in all positions. Instruction includes AWS and ASME welding codes, Print Reading and Fabrication courses. Moraine Park also offers a one-year Metal Fabrication diploma and two-year Fabrication Technologies AAS degree. These programs emphasize the manufacturing process from conception to final product using lasers, plasma tables, rollers, press brakes and welding equipment.



700 Gould St.
Beaver Dam, WI 53916

235 N. National Ave.
Fond du Lac, WI 54935

NI73 W21150 N.W. Passage Way
Jackson, WI 53037

Larry Clark
(800) 472-4554, ext. 3509
lclark@morainepark.edu
morainepark.edu

Pueblo Community College Southwest

The welding program at Pueblo Community College Southwest prepares you for a career in construction and manufacturing settings, small job shops, city and government welding centers and related sites. Earn your Associate of Applied Science degree in welding, as well as four certificates. Learn Basic Structural Welding in addition to the more advanced Coded Pipe Welding.



33057 Hwy. 160
Mancos, CO 81328

Robert Reed
Robert.Reed@pueblocc.edu

Cody Hager
Cody.Hager@pueblocc.edu

General Enrollment Information
(970) 564-6201

Monroe County Community College

Founded 1964

Monroe County Community College, located in Monroe, Michigan, offers welding technology education, which includes training in SMAW, GMAW, FCAW, GTAW structural and steel pipe welding applications. Thermal and mechanical cutting techniques and processes are also emphasized in our state-of-the-art, hands-on training facility. Welder certification can be earned through our American Welding Society QC-10 (entry level) and QC-11 (advanced level) SENSE program in an accelerated, 10-week format. MCCC also offers an associate degree in welding technology, a nondestructive testing certificate program, and an articulation agreement with Ferris State University. Apprenticeship training is available to companies with registered apprenticeship programs.



MONROE COUNTY
COMMUNITY COLLEGE

Steve Hasselbach, CWI/CWE
(734) 384-4118

shasselbach@monroeccc.edu

Cameron Albring, M.Ed.
(734) 384-4112

calbring@monroeccc.edu
monroeccc.edu

Pennsylvania College of Technology

Penn State affiliate since 1989

Penn College's 55,000 sq. ft. welding lab is one of the largest facilities in U.S. higher education. The lab includes an electron beam welder, CNC plasma cutters, laser welding, automation and robotics, and 124 individual welding booths. In addition to associate-degree and certificate programs, a B.S. degree in Welding & Fabrication Engineering Technology prepares graduates to work as welding, design, or automation engineers. Penn College is an AWS Accredited Test Facility and Sustaining Company member.



Pennsylvania
College of Technology
A Penn State Affiliate

One College Avenue
Williamsport, PA 17701
(800) 367-9222
admissions@pct.edu
pct.edu/welding



Rochester Arc + Flame Center

Rochester Arc + Flame Center is a privately owned training facility that offers welding training to the public. The business has partnered with Monroe Community College to offer "The Welding and Fabrication Certificate," a 20-week, 450-hour intensive program designed to produce entry-level fabricators. Also available is a 10-month night class version of this same industry certificate program. Customized training, inspection, metallurgy and NDE are also specialties. Arc + Flame Center received the 2016 Excellence in Welding Award in the Educational Facility category.

ARC+ *flame*
CENTER

ROCHESTER

125 Fedex Way
Rochester, NY 14624
(585) 349-7110
rocafc.com



SCHOOL PROFILES

San Jacinto College Serving East Harris County, Texas Founded 1961

San Jacinto College provides students the Welding and Inspection training skills for jobs in industrial, Petro-Chem and maritime enterprises found along the Houston Ship Channel and Gulf Coast region.

Come train at San Jacinto College for your future in one of the region's largest and best equipped facilities, where you can earn your Certificate or Degree in Welding or Inspection Technology (Non-Destructive Testing). Our accredited programs are taught to AWS, API, NACE and NCCER standards.



INDUSTRIAL TECHNOLOGY

Welding Central (281) 476-1814
Welding North (281) 998-6150 ext. 7373
sanjac.edu/Welding

Inspection (281) 478-2799
sanjac.edu/NDT

Tri-County Technical College Founded 1965

The Welding program at Tri-County Technical College has trained welders for industry since 1965. Training is provided in structural, pipe, and fabrication welding using SMAW, GMAW and GTAW processes. Students have the option of an associate degree program, or certificate programs with varying skill sets. 72 modern weld stations to accommodate training needs. Three Certified Welding Inspectors/Educators are on staff to provide welder certification testing and customized company training.



7900 Highway 76
P.O. Box 587
Pendleton, SC 29670
(864) 646-1405
Paul Phelps
pphelps@tctc.edu
tctc.edu

United Technical, Inc.

Train, test, and become an AWS Certified Welder at our facility in Whitmore Lake, Michigan. With the ability to train in all common processes (GMAW, GTAW, SMAW, FCAW, etc.) on any material (steel, stainless, aluminum, titanium, copper, etc.), United Technical is the go-to place for all your welding training needs. Our classes have a large emphasis on hands on training, so students spend most of the time actually welding. Focusing on corporate weld training, we know what it takes to create a true welding professional. Our CWIs/CWEs on staff give us the advantage to be able to support manufacturing companies.



1081 E. North Territorial Road
Whitmore Lake, MI 48189
Robert Dines
(248) 667-9185
rdines@unitedtech1.com

Schoolcraft College

Located in one of the largest manufacturing areas of the USA, Schoolcraft College offers certificates and Associates Degrees in an AWS Accredited Test Facility. The college provides state of the art welding and fabrication equipment in an innovative, dynamic and productive environment. Small class size give easy access for students to knowledgeable industry trained experts and CWI instructors who strive to educate students for real life, on the job scenarios. Schoolcraft College offers classes in all major welding processes as well as specialized classes in blueprint reading, inspection, metallurgy, OSHA 30, CAD, CNC manufacturing and metal sculpture. Schoolcraft College also offers courses for AWS certifications in Aerospace, ASME, D1.1, B2.1 and several other codes and standards to enrolled students as well as local skilled tradesmen and tradeswomen.



Schoolcraft College

18600 Haggerty Road
Livonia, MI 48152
(734) 462-4400 ext. 5176
Coley McLean
cmclean@schoolcraft.edu

Tyler Junior College

Tyler Junior College (TJC) is a comprehensive community college in Tyler, Texas, recognized as one of the top colleges in Texas! Its one-year certificate and two-year associate degree pathways in welding technology prepare students for entry-level code welding for industry. Training is provided in Blueprint Reading and Layout as well as SMAW, GMAW, FCAW, GTAW and pipe welding. In addition, the welding program follows the AWS SENSE entry level guidelines for welder training. Many TJC welding graduates secure a great job before graduation. Let us help you prepare for a rewarding career in a high-demand field. Call 1-800-687-5680 or visit our website.



P.O. Box 9020
Tyler, TX 75711
(903) 510-2390
or (800) 687-5680
tjc.edu

Wall Colmonoy Modern Furnace Brazing School

Engineers, technicians, quality, production, and others involved in the brazing process! Wall Colmonoy offers a spring session of its Modern Furnace Brazing School on May 12-14, 2020 in Cincinnati, Ohio. Preserving the tradition originated by the late Robert Peaslee, a brazing pioneer who invented the first nickel-based brazing filler metal, attendees will participate in "hands-on" practical applications while learning about brazing technology from the industry's leading brazing engineers. Register today to take part in the only hands-on brazing seminar! Visit us at wallcolmonoy.com/brazingschool.



WALLCOLMONOY

Brazing Engineering Center
Cincinnati, OH
(248) 585-6400 ext. 233
brazingschool@wallcolmonoy.com
wallcolmonoy.com/brazingschool



SCHOOL PROFILES

Waubonsee Community College

The Welding Technology program at Waubonsee Community College offers students options of two certificates, as well as an Associate in Applied Science Degree. Class sizes are small to ensure students get focused and individualized attention. Waubonsee's welding program includes classes in each of the basic processes including: OFW, TB, OFC-A, PAC, SMAW, GMAW, FCAW, and GTAW. Additionally, the curriculum includes two courses specifically devoted to pipe welding with GTAW and SMAW in all positions.



WAUBONSEE
COMMUNITY COLLEGE

Where futures take shape

Rt. 47 @ Waubonsee Drive
Sugar Grove, IL 60554
(630) 466-7900, ext. 2263
Fax: (630) 466-5795
waubonsee.edu

Wilson Community College

Welding Technology Diploma & Certificate Program

Established in 1958, Wilson Community College is one of the system's oldest institutions. The College offers associate degrees, diplomas, and certificates. The Welding Technology curriculum provides students with an understanding of the science, technology, and applications essential for successful employment in the industry. Instruction includes electrode welding and cutting processes, blueprint reading, metallurgy, welding inspection, and destructive and nondestructive testing to provide the student with industry standard skills. Enrollment is approximately 17 to 25 students.



902 Herring Avenue
Wilson, NC 27893
(252) 246-1210
wilsoncc.edu

Margie Norfleet, Dean of Industrial Tech.
(252) 246-1210
mnorfleet@wilsoncc.edu

Orange County Inspections, Inc.



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Sandra Jorgensen at 305-443-9353 ext: 254

Lea Owen at 305-443-9353 ext: 220

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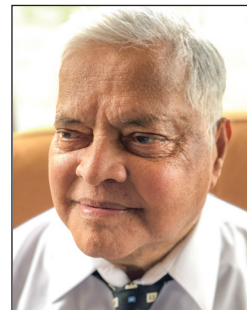
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Evaluation of Hydrogen-Assisted Cracking Susceptibility in Grade T24 Steel

The susceptibility to hydrogen-assisted cracking of Grade T24 steel base metal and the simulated CGHAZ was evaluated using a delayed hydrogen cracking test

BY X. FENG, J. M. STEINER, B. T. ALEXANDROV, AND J. C. LIPPOLD

ABSTRACT

The delayed hydrogen cracking test was performed to evaluate the hydrogen-assisted cracking (HAC) susceptibility of Grade T24 steel base metal and the simulated coarse-grained heat-affected zone (CGHAZ). The base metal did not fail after testing for up to 672 h. In contrast, the CGHAZ sample failed after about 2 h when charged from all four sides, and 4 h when charged only from the internal diameter (ID) surface. The higher HAC resistance of the base metal compared to the CGHAZ was due to the microstructure difference. The tempered bainitic-martensitic microstructure in the base metal was more resistant to HAC compared to the untempered martensite microstructure in the CGHAZ. Fractography analysis indicated the decarburized zone on the ID surface delayed the development of the critical hydrogen concentration in the CGHAZ, thus improving the HAC resistance. The HAC cracking initiated with an intergranular fracture, then transitioned to quasi-cleavage and microvoid coalescence. The fracture behavior was explained using Beachem's model.

KEYWORDS

- Delayed Hydrogen Cracking Test • Grade T24 Steel
- Hydrogen-Assisted Cracking • Fracture Analysis
- Microstructure

Introduction

Grade T24 steel has been developed as a material that can be used without preheat and postweld heat treatment in thin-wall structures (Ref. 1). It was developed based on a modification in the chemical composition of Grade 22 steel (Ref. 2). It has wide applications in ultra-supercritical boilers (Ref. 3). Many researchers have investigated the welding process and properties of this steel (Refs. 4–8).

Compared to the conventional Grade 22 steel, Grade T24 steel has a reduced carbon content for improved weldability and is microalloyed with vanadium, titanium, and boron for precipitation strengthening with fine MX-type ($M = V, Ti$; $X = C, N$) carbides and/or carbonitrides.

Grade T24 steel is usually delivered in the normalized and tempered condition with a tempered bainitic-martensitic microstructure (Ref. 9). Hardness values lower than 350 HV are required for power generation applications with Grade T24 steel welds (Ref. 10). Recently, cracking in the welds of the water-wall panels made of Grade T24 steel has been reported in a number of newly constructed power plants in Europe after a few hundreds of hours of operation. The nature of cracking in these instances is not yet clear, but it has been speculated to be a form of stress corrosion cracking (SCC) (Refs. 11–14). Meanwhile, the presence of magnetite on the crack surface was confirmed. Therefore, hydrogen-assisted cracking (HAC) initiated by the Schikorr reaction could also be a contributing factor. This kind of failure mechanism operates with the simultaneous presence of a susceptible microstructure, high residual stress, and exposure to an aqueous and/or corrosive environment where hydrogen can be concentrated. The occurrence of HAC is not uncommon in high-strength steels (Refs. 15–19). Researchers have reported Grade T24 steel is susceptible to SCC (Ref. 20), but its susceptibility to HAC has not yet been fully understood.

As a result, in this study, the delayed hydrogen cracking test (DHCT) was used to evaluate the Grade T24 steel HAC susceptibility, which is caused by the Schikorr reaction during service. This test consisted of simultaneous electrolytical charging with hydrogen and loading with a constant tensile stress (below the steel yield strength) on the tested sample (Ref. 21). The time to failure was used as a criterion to evaluate the HAC susceptibility. Both the Grade T24 base metal and simulated coarse grain heat-affected zone (CGHAZ) were tested.

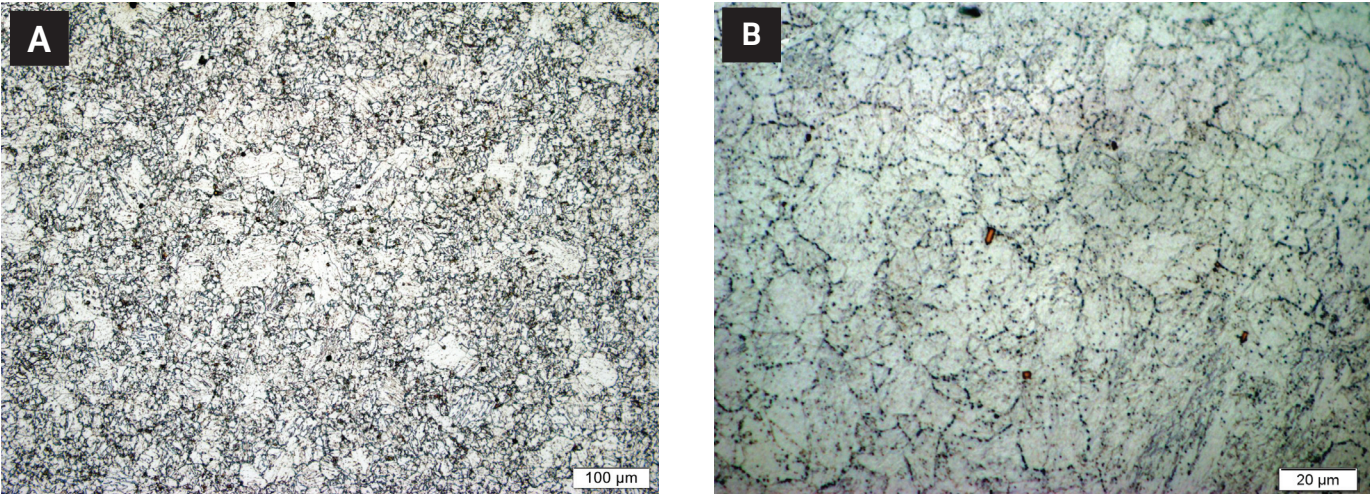


Fig. 1 — Microstructure of the Grade T24 steel base metal: A — Tempered bainite and martensite; B — Ti(C, N) in the base metal.

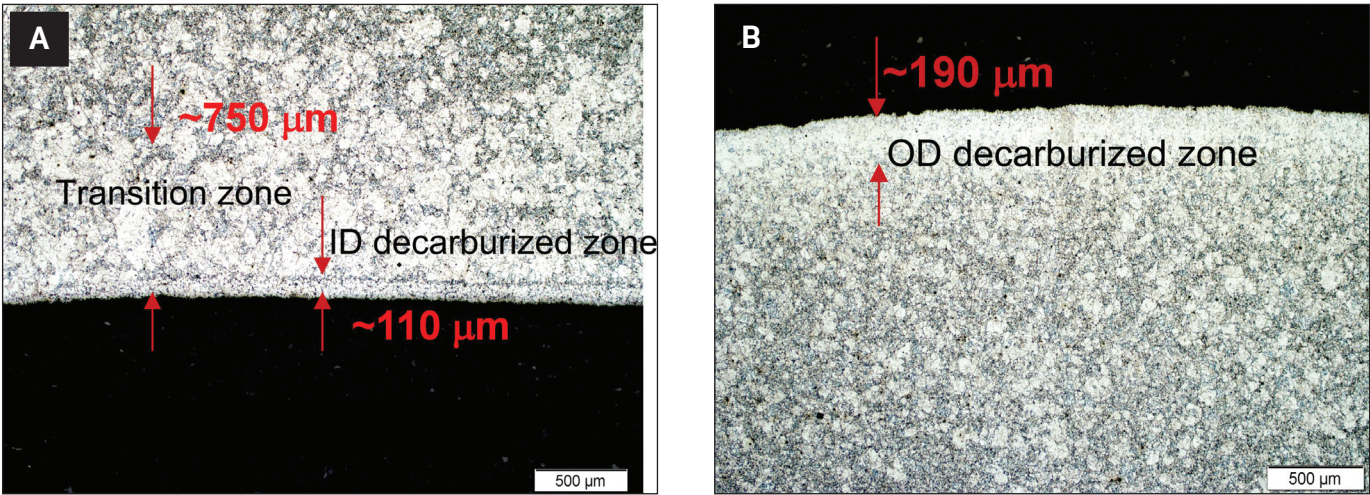


Fig. 2 — Decarbonized zones on the ID and OD surfaces of the Grade T24 tube: A — ID side; B — OD side.

Materials and Experimental Procedures

Base Metal

The Grade T24 steel base metal used in this study was a hot-rolled tube with an outside diameter (OD) of 44.5 mm and a wall thickness of 7.1 mm. The chemical composition and mechanical properties of the Grade T24 steel are shown in Table 1. The tube was in the as-delivered condition with a

tempered bainitic-martensitic microstructure (Fig. 1A) and a microhardness of 215 HV_{0.1}. The gold-colored cuboidal particles (Fig. 1B) observed in the base metal were identified as Ti(C, N) using the energy dispersive spectroscopy in the scanning electron microscope (SEM).

Narrow decarburized layers were present at the tube OD and internal diameter (ID) surfaces. Figure 2 shows the OD and ID decarburized layers, which were measured to be ~ 190 and ~ 110 μm, respectively. A transition zone, which is the light-etched area extending beyond the decarburized

Table 1 — Chemical Composition and Mechanical Properties of the Grade T24 Steel

Chemical Composition (wt-%)											
C	Mn	P	S	Si	Cr	Mo	Ti	V	B	N	Al
0.08	0.56	0.012	0.004	0.26	2.47	0.98	0.09	0.24	0.0056	0.009	0.015
Mechanical Properties											
Yield strength (MPa)				Ultimate tensile strength (MPa)				Elongation (%)			
521				645				21.3			

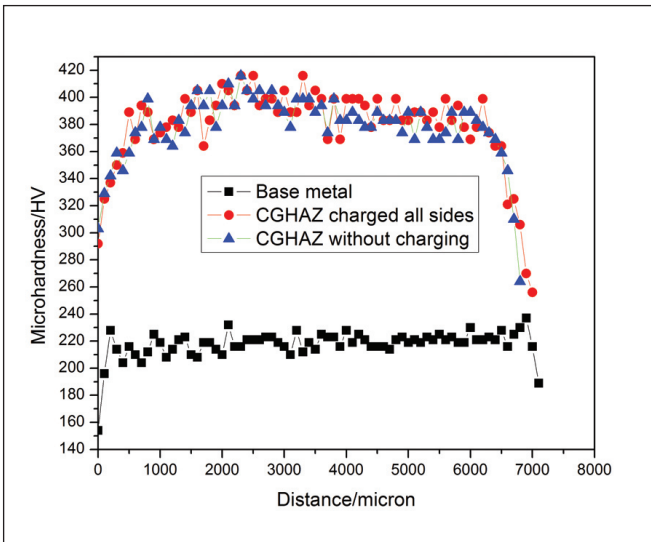


Fig. 3 — Microhardness of the cross section of the base metal and simulated CGHAZ.

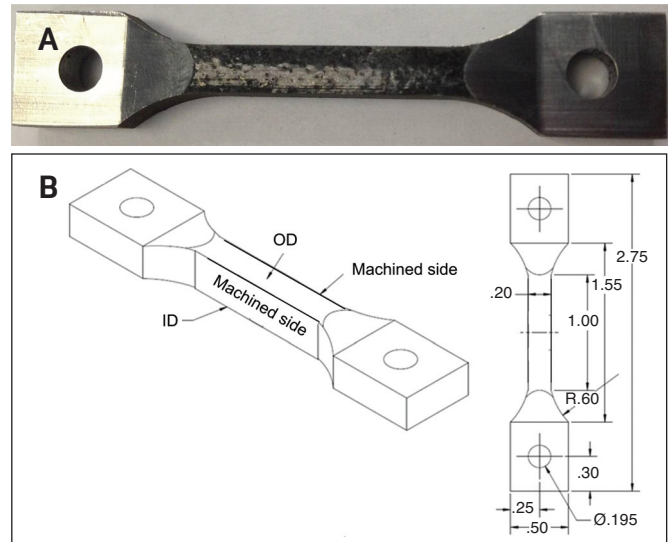


Fig. 4 — Geometry of the DHCT sample: A — Machined sample; B — schematic drawing of the sample.

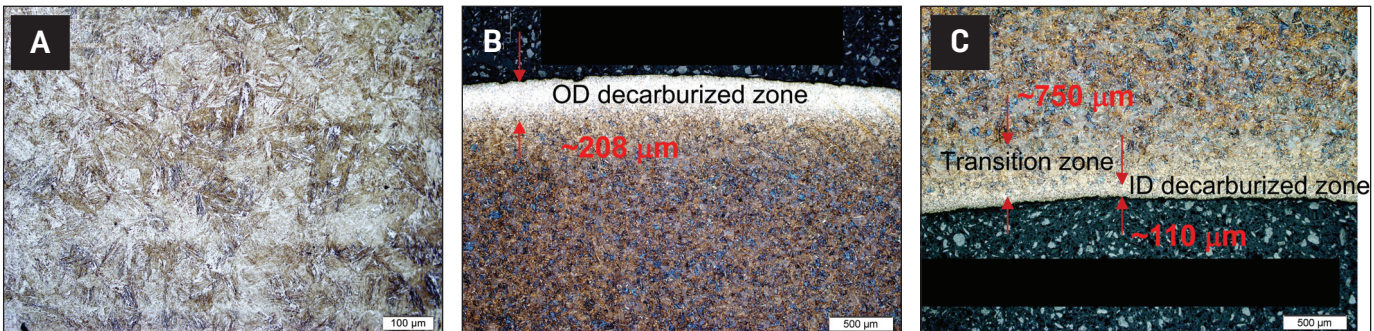


Fig. 5 — Microstructure of the simulated CGHAZ: A — Bulk; B — OD side; C — ID side.

zone, was revealed at the ID side. The transition zone was measured to be $\sim 750 \mu\text{m}$. Figure 3 shows the microhardness along the traverse direction. The microhardness in the CGHAZ was much higher than that in the base metal because of the formation of martensite.

Dog-bone-shaped test samples were extracted from the tested tube. Figure 4 shows the geometry of the test samples. The longitudinal axis of the samples was parallel to the tube axis. The gauge section had a decarburized microstructure at the OD and ID surfaces, as well as a normalized and tempered microstructure at the other two machined-side surfaces.

Simulated CGHAZ

Dog-bone samples with simulated CGHAZ were produced using the Gleeble™ 3800 thermal-mechanical simulator. The temperature was controlled with a type-K thermocouple, which was welded to the sample at the midsection. The samples were heated to a peak temperature of 1350°C at a linear rate of 100°C/s and then free-cooled to room temperature. The cooling time from 800° to 500°C ($t_{8/5}$) in these samples varied between 13.4 and 13.9 s. The simulations were conducted in a vacuum of 10^{-3} torr to limit surface oxidation and avoid thermocouple detachment. The CGHAZ mi-

crostructure was a mixture of bainite and martensite (Fig. 5A) with a microhardness in the range of 370 and $420 \text{ HV}_{0.1}$ in the bulk of the tube wall. The OD and ID decarburized layers were measured to be ~ 208 and $\sim 110 \mu\text{m}$, respectively — Fig. 5B, C. A transition zone that had a width of $\sim 750 \mu\text{m}$ was revealed at the ID.

DHCT Sample Preparation

The gauge section was lightly ground with 400- then 800-grit sandpaper to remove any surface contamination and oxides. After grinding, the samples were further cleaned in an ultrasonic cleaning bath. Following this, the area intended for electrolytic charging with hydrogen was marked on the sample, and fingernail polish was applied to cover all remaining surfaces adjacent to this area. When the fingernail polish completely dried, the sample was inserted into the extension rods, and all surfaces not intended to be charged were coated in Plasti Dip® — Fig. 6.

DHCT

The DHCT applied a constant tensile load to the test sample, which was simultaneously subjected to electrolytic charging with hydrogen. The time to failure under these

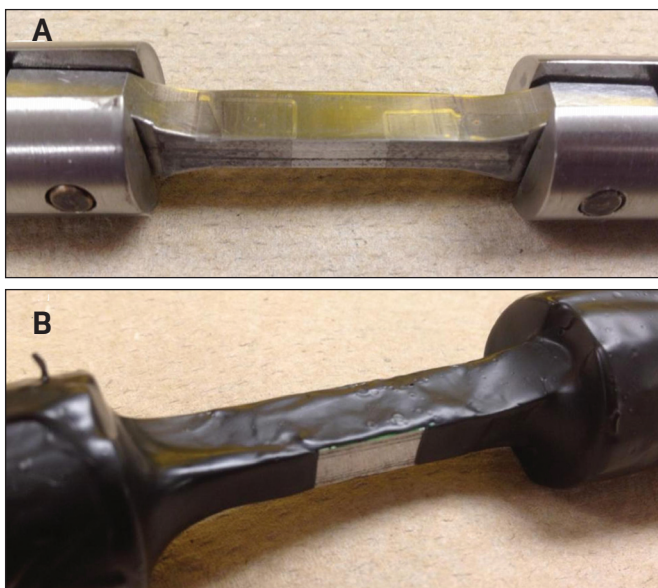


Fig. 6 — Samples prepared for the DHCT: A — Before coating with Plasti Dip; B — after coating with Plasti Dip.

testing conditions was used as a criterion for ranking susceptibility to HAC. A longer time to failure indicated a greater resistance to HAC. The test conditions used in this study included the following: 1) The tensile loading stress was 90% of the base metal yield strength; 2) the charging current density was 10 mA/cm²; and 3) the electrolyte was made of 27.5 mL H₂SO₄ in 9500-mL distilled water with the addition of 0.5-g Na₂S₂O₃. The solution's pH was approximately 1.22. The sodium thiosulfate acted as a barrier to recombination of the atomic hydrogen into hydrogen gas. Figure 7A shows the DHCT frame. The arm gave a 10:1 ratio for the hanging weights. The linear variable displacement transducer was positioned at the end of the arm to measure the sample displacement and detect failure. The polypropylene cell is shown in Fig. 7B. The alligator clip at the top connect-

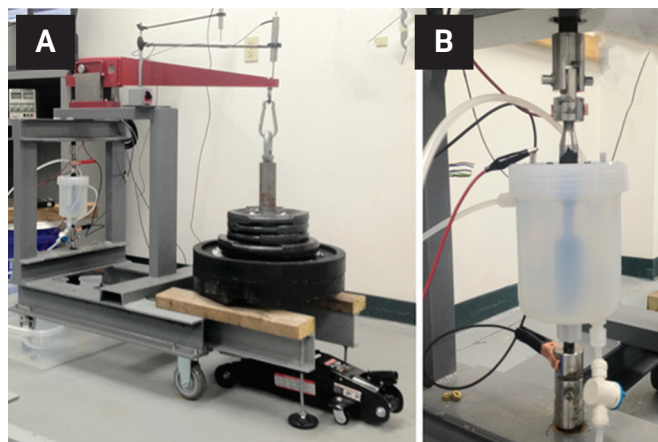


Fig. 7 — The DHCT equipment: A — Test frame; B — polypropylene cell.

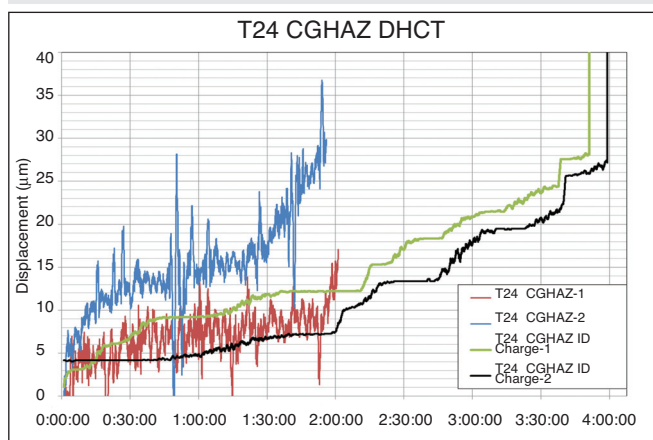


Fig. 8 — The displacement of the tested samples as a function of time.

ed the power supply to the platinum coil surrounding the sample. The two clamps attached to the clevises completed

Table 2 — Summary of the DHCT Results

Sample	Time to Failure, h:min	Note
T24 CGHAZ 1	2:01	Circumferentially charged, 10-mm-wide charged area
T24 CGHAZ 2	1:56	Circumferentially charged, 10-mm-wide charged area
T24 CGHAZ ID 1	3:51	ID charged, 10-mm-wide charged area
T24 CGHAZ ID 2	3:59	ID charged, 10-mm-wide charged area
T24 CGHAZ no tensile load	Cracks found after 48 h charging	ID charged, 10-mm-wide charged area, no tensile load
T24 CGHAZ no hydrogen charging	—	Did not fail in 264 h, tensile load without hydrogen charging
T24 base metal 1	—	Did not fail in 672 h, circumferentially charged, 5-mm-wide charged area
T24 base metal 2	—	Did not fail in 266 h, ID charged, 10-mm-wide charged area

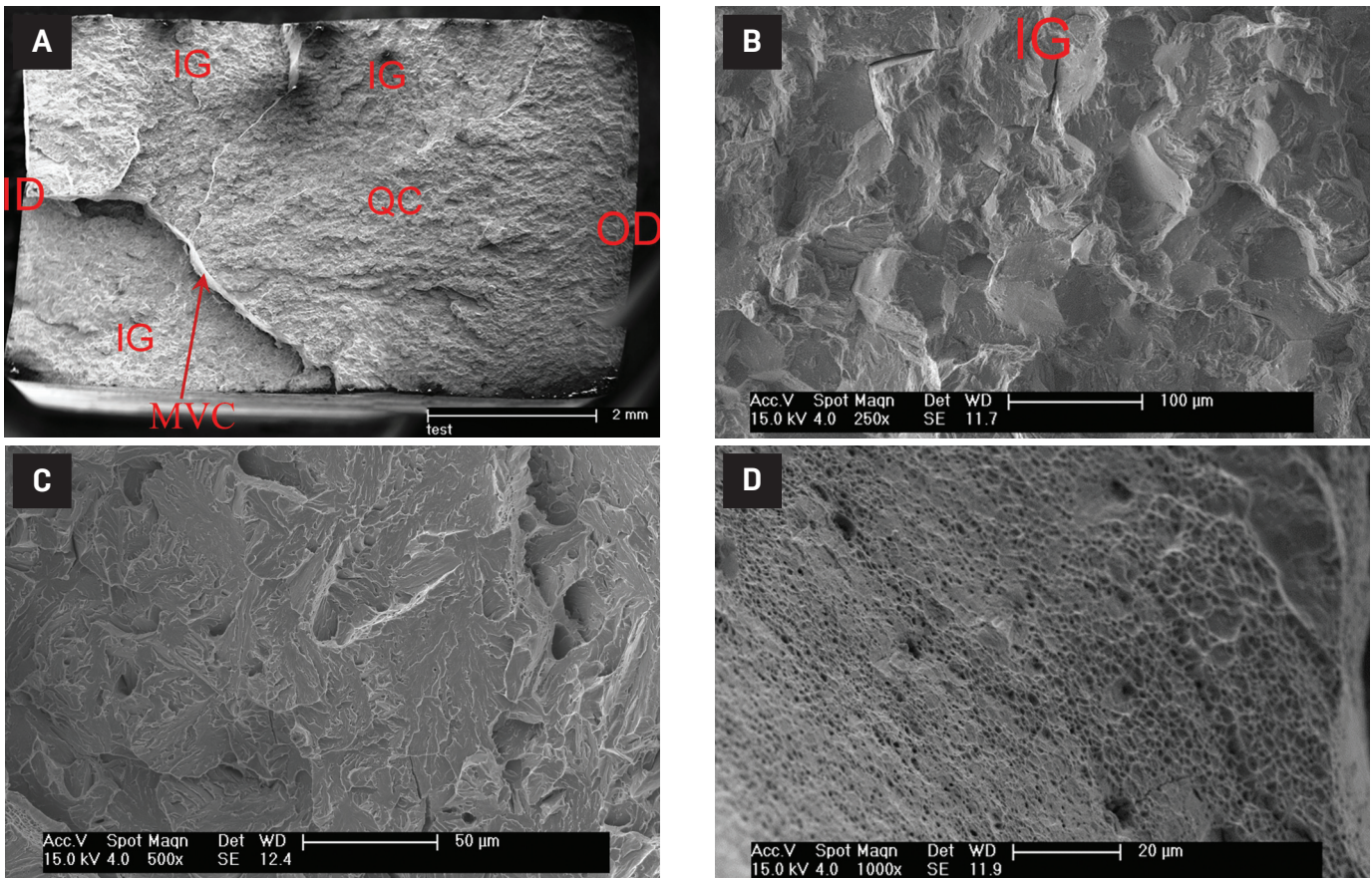


Fig. 9 — Fractography analysis of the simulated CGHAZ charged from all four sides: A — Macro image; B — intergranular failure mode close to the machined side; C — quasi-cleavage failure mode in the middle of the sample; D — microvoid coalescence on the ridge between cracks.

the circuit back to the power supply. The tubes running into the top and side of the cell were used to circulate the charging solution, and the tube running out of the bottom allowed for evacuation of the fluid at the end of a test.

The Grade T24 base metal and its simulated CGHAZ samples were tested using the DHCT. The samples were charged through only the gauge-section ID surface or the full-gauge-section circumference (all four sides). The samples that were charged only through the ID simulated the actual service condition for the tube (only the ID surface was exposed to the hydrogen-containing environment), while charging through the full circumference exposed the microstructure in the bulk of the tube wall to the hydrogen-containing environment. This was done to simulate the direct exposure of the CGHAZ microstructure to the tube environment in case the decarburized layer at the ID was removed during the preweld groove preparation. This approach allowed for comparison of the HAC susceptibility of the T24 steel base metal and simulated CGHAZ, as well as evaluation of the effect of the decarburized zone at the tube ID on the HAC susceptibility.

A simulated CGHAZ sample was charged with hydrogen from the ID for 48 h without mechanical loading to identify the preferential crack initiation locations. Another simulated CGHAZ sample was loaded at 90% of the steel yield strength for 264 h without hydrogen charging to provide a base line.

Fractography Analysis and Microstructure Characterization

The fracture surface of the failed test samples was analyzed using a Philips ESEM FEG-30 SEM. An optical microscope was used for metallurgical analysis of the samples. The samples were cut parallel to the loading direction, showing both the fracture surface (if present) and the OD and ID surfaces. They were then mounted in conductive Bakelite, ground, polished, and etched with 5% nital.

For the nonfailure samples, the charged area was cut from the sample and mounted on a stub for SEM examination. These samples were also cross sectioned in the charged area and mounted, ground, polished, and etched using 5% nital. They were then examined using an optical microscope and SEM to evaluate the effect of hydrogen charging on the microstructure. Microhardness measurement was performed on the cross sections of the base metal and simulated CGHAZ using a 100-g load.

Results and Discussion

DHCT Results

The DHCT results are summarized in Table 2. The base metal samples that were charged only through the ID and



Fig. 10 — Cross section of the simulated CGHAZ charged from all four sides with loading: A — Low-magnification image; B — higher-magnification image of region A; C — higher-magnification image of region B.

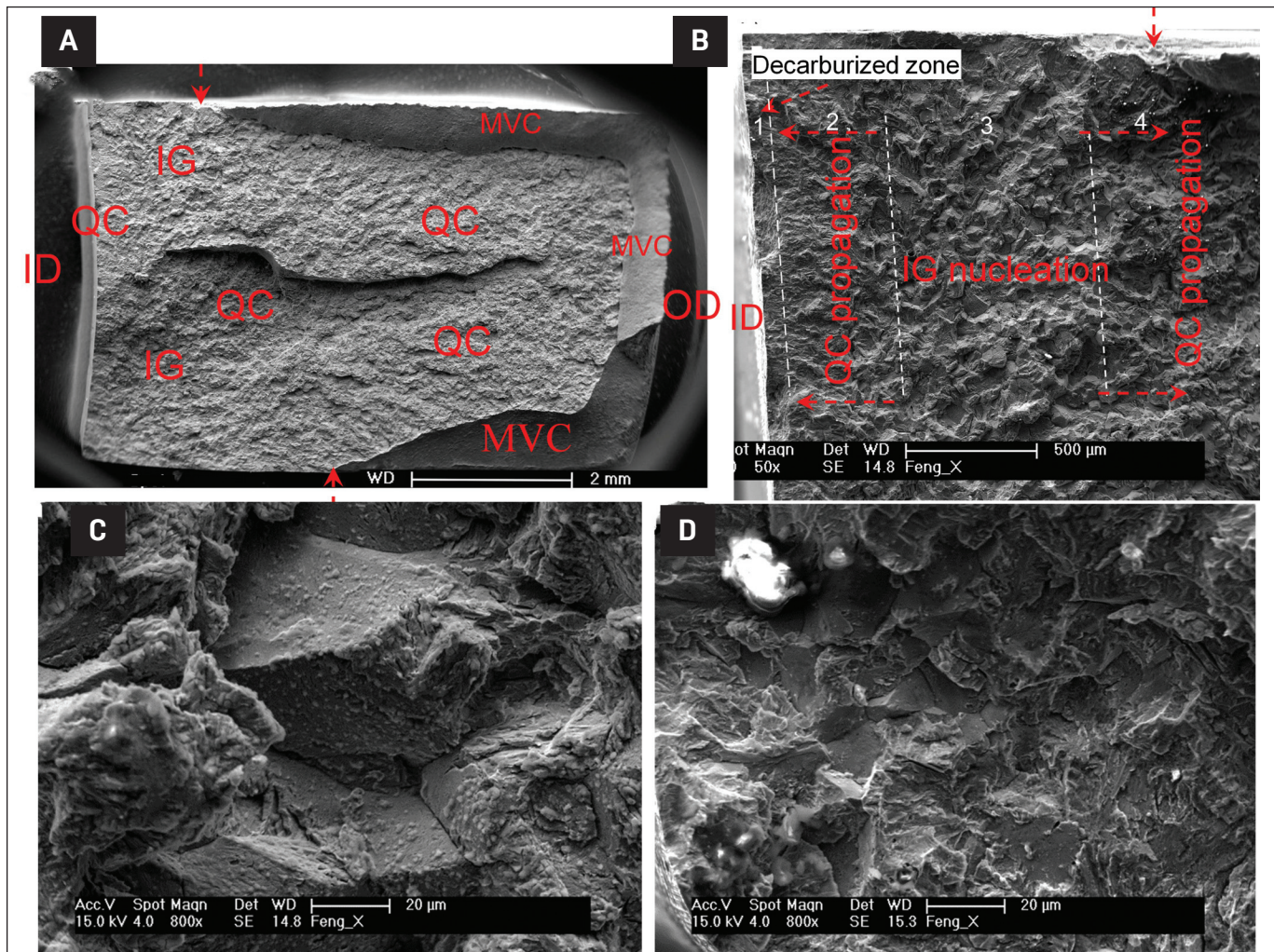


Fig. 11 — Fractography analysis of the simulated CGHAZ charged from the ID: A — Macro image; B — higher-magnification image on the ID side; C — higher-magnification image of IG; D — higher-magnification image of QC in the decarbonized zone.

through all four sides did not fail after 266 and 672 h, respectively. The CGHAZ only with charging did not fail but showed cracks after 48-h charging. The CGHAZ only with loading did not fail after 264 h. However, all the charged-simulated CGHAZ samples with loading failed. The chart of time to failure for these samples are shown in Fig. 8. It was found that the decarburized layer on the ID tube surface had a significant effect on the time to failure in Grade T24 steel

samples. Samples charged only through the ID surface failed in about 4 h, while samples charged through the whole circumference of the gauge section (ID, OD, and two machined sides) failed in about 2 h.

Fractography Analysis

Figure 9 shows the fractography analysis result of the

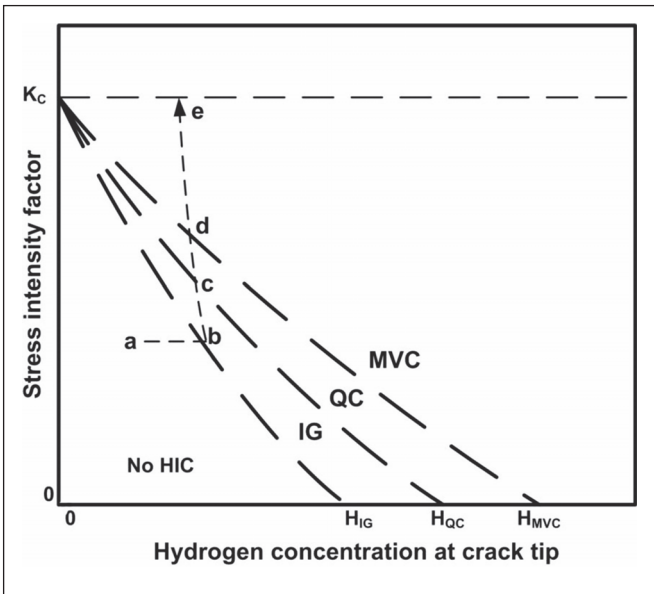


Fig. 12 — Beachem's hydrogen-induced cracking model (Ref. 22).

simulated CGHAZ sample charged from all sides with loading. Because the two samples show similar fracture surface features, fractography analysis of only one of the two samples (sample T24 CGHAZ 2) is shown here. Intergranular (IG) failure was observed on the two machined sides of the sample. These locations should be the crack initiation in this sample. The cracks propagated in a quasi-cleavage (QC) mode. Where these cracks met, microvoid coalescence (MVC) was found. Because the sample was charged from all sides, more hydrogen could get into the sample in the same time compared to the sample that was only ID charged. Therefore, the time to failure of the all-sides-charged samples (~ 2 h) was shorter than that of the only-ID-charged samples (~ 4 h).

Figure 10 shows the longitudinal direction of the failed sample, which was charged from all sides with loading. Secondary cracks were found along the fracture surface. Ti(C, N) particles were adjacent to the cracks. Multiple crack nucleations were observed in the CGHAZ. These cracks showed typical HAC features. This further proved the crack initiated from the two machined sides of the sample.

Figure 11 shows the fractography analysis of the simulated CGHAZ sample charged only from the ID. Because the two samples showed similar fracture surface features, fractography analysis of only one of the two samples (sample T24 CGHAZ ID 2) is shown here. In this sample, MVC was observed at the OD side and the two machined sides of the sample. A ductile ridge was present in the middle of the sample — Fig. 11A. An additional detailed analysis on the ID side is shown in Fig. 11B. This area can be divided into four regions — Fig. 11B. The very left region (region 1) was the ID decarburized zone, and the failure mode was QC. The second region (region 2) and fourth region (region 4) showed the QC mode. In between regions 2 and 4 was region 3, which was the crack nucleation region exhibiting the IG mode. Higher magnification images of the IG mode in region 3 and the QC mode in region 1 are shown in Fig. 11C and D, respectively.

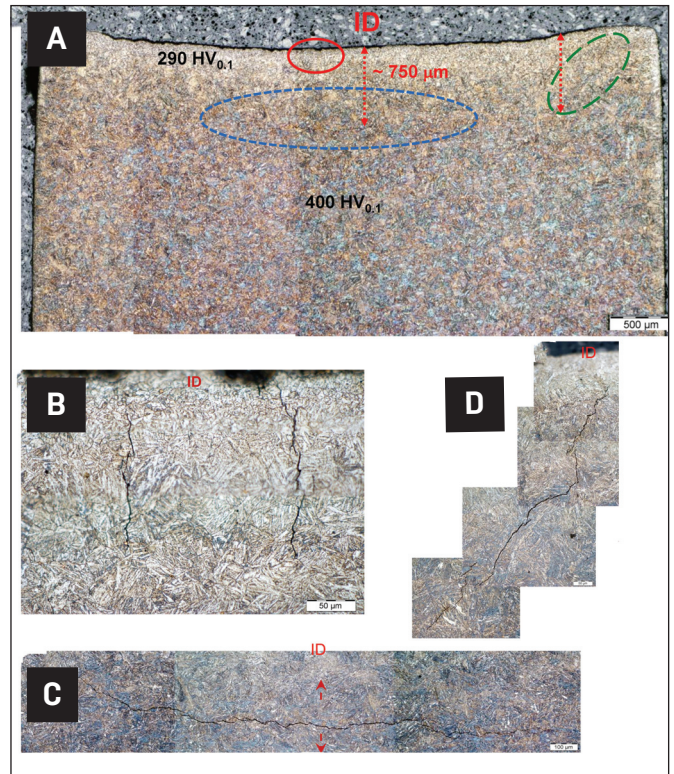


Fig. 13 — Microstructure of the charged-simulated CGHAZ without loading: A — Macro image; B — cracks in the decarburized zone; C — cracks parallel to the ID surface; D — cracks diagonal from the ID surface.

Based on the fractography analysis, the HAC mechanism was explained with Beachem's model (Ref. 22) — Fig. 12. The microstructure in the decarburized zone was ferrite, which was resistant to HAC. Because the diffusion rate of hydrogen in ferrite is high, but the solubility of hydrogen in ferrite is low, the hydrogen diffused into the martensite (region 3 in Fig. 11B) very fast through the decarburized zone. When hydrogen accumulates to a critical level in the martensitic microstructure, an IG crack will initiate (point b in Fig. 12). After the crack initiates, the stress intensity in front of the crack sharply increases and less hydrogen is needed for the crack to propagate. The failure propagated in the IG mode through region 3, which had a relatively high hydrogen concentration (line b–c in Fig. 12). With the crack propagating, the stress intensity further increased to a level that an even lower hydrogen concentration was needed for the crack to continue growing (point c in Fig. 12). The hydrogen concentration in regions 1 and 4 was decreased due to the lower hydrogen solubility in region 1 and the insufficient charging time in region 4. The combination of lower hydrogen concentration and higher stress intensity in regions 1 and 4 resulted in cleavage crack propagation (line c–d in Fig. 12).

With further increase of the stress intensity, the failure mode transitioned to ductile failure (MVC mode), which was observed in the two machined sides and OD side (line d–e in Fig. 12). The reason for the ductile ridge in the middle of the tested sample could be that two main cracks nucleated and propagated separately and connected by a shear mechanism at the final stage of failure.

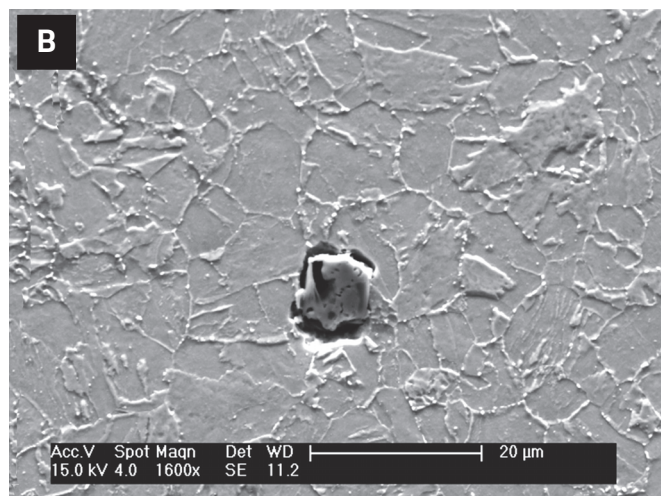
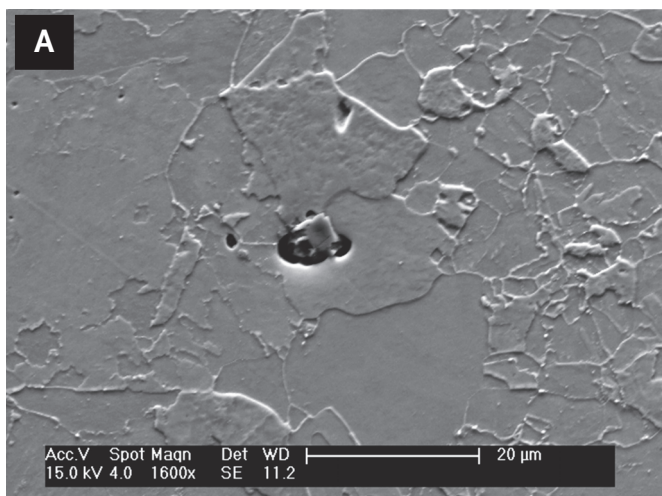


Fig. 14 — Microstructure of the decarbonized zone and bulk material of the base metal (charged from ID): A — Decarbonized zone; B — bulk material.

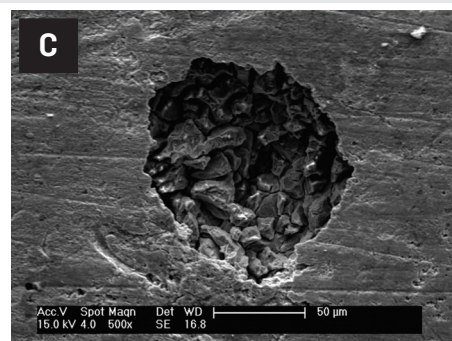
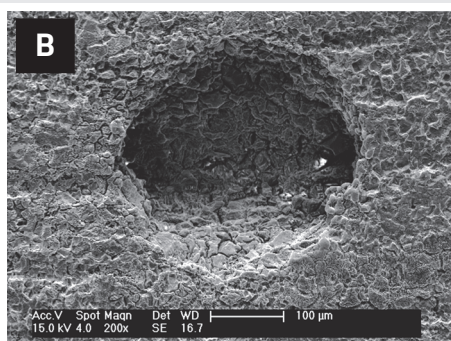
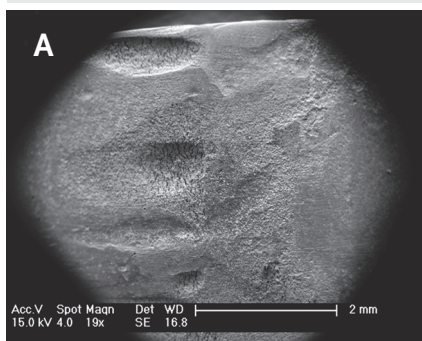


Fig. 15 — SEM image of the OD, ID, and machine side of the base metal (charged from all four sides): A — OD surface; B — ID surface; C — machined side.

Microstructure of the Nonfailed Samples

Figure 13A–D shows the cross section of the charged, simulated CGHAZ sample without loading. Three cracks were found at different locations. The first one (Fig. 13B) was perpendicular to the ID surface and through the decarburized zone to the simulated CGHAZ. Compared with the CGHAZ, the hydrogen diffusion rate in the decarburized zone was higher, but the hydrogen solubility was lower. Therefore, it is possible that the crack nucleated in the CGHAZ and propagated back into the decarburized zone. The second crack (Fig. 13C) was in the CGHAZ and parallel to the ID surface. This crack propagated in a combination of intergranular, transgranular interlath, and branching modes. The third crack (Fig. 13D) was diagonal from the ID surface and propagated through the decarburized zone and simulated the CGHAZ. It showed similar propagation features as the second one. This confirmed the crack-initiation location in the DHCT samples.

Figure 14 shows the microstructure in the decarburized zone and the bulk of the DHCT base metal, which was charged from the ID and did not fail during the test. The decarburized zone had a larger grain size compared to the bulk material. Ti(C, N) particle surrounded by voids was observed in both the decarburized zone and the bulk material. No cracking was found in the decarburized zone or the bulk material. This indicated the base metal was more resistant to

HAC than the CGHAZ.

Figure 15 shows the SEM images of OD, ID, and one machined side of the base metal, which was charged from all four sides. Cavities were present on the ID surface and machined side but not on the OD surface. These could be hydrogen blisters, which could be caused by hydrogen accumulation around inclusions.

Conclusions

The susceptibility to HAC of the Grade T24 steel base metal and simulated CGHAZ was evaluated using the DHCT. The conclusions are summarized as follows:

1. The DHCT is capable of evaluating the effect of microstructure on the HAC susceptibility of Grade T24 steel welded joints.
2. No failure or cracking in the base metal of Grade T24 steel occurred for up to 672 h under the testing condition. The time to failure of the CGHAZ was about 2 h for when all four sides were charged and 4 h for only ID charging.
3. The difference in HAC susceptibility arise from the microstructure. The base metal has a tempered bainitic-martensitic microstructure, while the CGHAZ has an untempered martensite microstructure. The latter has higher microhardness, leading to a higher HAC susceptibility.
4. The presence of the decarburized layer at the tube ID

surface delayed the development of critical hydrogen concentration in the CGHAZ. This improved the resistance to HAC, indicated by the longer time to failure when only charged from the ID surface compared to being charged from all four sides.

5. Fracture analysis showed the crack initiated on the sides without the decarburized layer. This further proved the decarburized layer was beneficial to the HAC resistance.

6. In both charging conditions, the crack initiated with IG, then propagated with QC and ended with MVC. This fracture behavior was explained using Beachem's model.

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Enhanced Penetration Depth during Reduced Pressure Keyhole-Mode Laser Welding

Modeling and experiments took place to understand deeper laser keyholes at lower pressures

BY M. JIANG, Y. B. CHEN, X. CHEN, W. TAO, AND T. DEBROY

ABSTRACT

Keyhole-mode laser welding under reduced ambient pressure is known to provide improved weld penetration, narrower width, and reduced incidences of defects, but the underlying mechanism for these benefits is not known. We sought to elucidate the mechanism by an experimental and theoretical program of investigation. Potential causative factors, such as the depression of the boiling point of alloys at reduced pressures and the changes in laser beam attenuation by metal vapors/plasma, were investigated using a well-tested heat transfer and fluid flow model of keyhole-mode laser welding for various ambient pressures. The model was tested with experimental data for the welding of four alloys — Structural Steel Q690, Aluminum Alloy A5083, commercially pure titanium, and Nickel 201 — that have very different thermophysical properties. The results showed the changes in the boiling point alone were unable to explain the enhanced depth of penetration at low ambient pressures. The experimental and calculated fusion zone geometries showed excellent agreement when both the boiling point depression and the beam attenuation by metal vapor were considered. The reduction of ambient pressure also affected the heat transfer pattern near the keyhole, owing to a decrease in the keyhole wall temperature and changes in the temperature gradient near the keyhole wall.

KEYWORDS

- Laser Welding • Ambient Pressure • Keyhole Depth
- Heat Transfer • Fluid Flow • Weld Geometry
- Boiling Point • Beam Attenuation

Introduction

High energy density welding, such as laser or electron beam welding, is often used for the fabrication of thick section components where a high aspect ratio (depth/width) and a narrow heat-affected zone (HAZ) are desired. Laser welding, commonly used at atmospheric pressure, underperforms electron beam welding, conducted at much lower pressures, in both depth of penetration of welds and reduced incidences of defects such as macroporosity (Refs. 1–3). With the development of ultra-high power lasers, 10- to 100-kW lasers have now become available for welding (Refs.

4–6). They enable welding with improved depth of penetration, but weld defects are easily formed when higher depth of penetration is achieved by increasing laser power (Refs. 7–9). Process parameter optimization (Refs. 10, 11), shielding gas adjustment (Refs. 12), laser beam modulation (Refs. 13, 14), addition of an external energy field (Ref. 15), and application of vacuum (Refs. 16, 17) were attempted to improve weld quality in high-power laser welding. These previous works have shown that reducing ambient pressure in laser welding is the most effective method for improving both the penetration depth and weld quality.

Laser welding under vacuum or reduced ambient pressure was first reported by Arata et al. in the 1980s (Ref. 18). After that, several studies have confirmed a reduction of the ambient pressure had a significant beneficial effect on weld geometry and defects (Refs. 19–24). For example, Katayama et al. showed, for certain welding conditions, the depth of penetration under vacuum was about twice that obtained at atmospheric pressure for the same welding parameters (Ref. 19). A laser weld with narrow and deep fusion zone geometry characteristics of electron beam welds could be obtained at reduced ambient pressures between 10^{-3} and 10^{-2} atmosphere (atm) (Ref. 17), which is much higher than the typical operating pressure (10^{-7} atm) of electron beam welding. An operating vacuum of about 10^{-3} atm is very easy to achieve quickly using a simple mechanical pump. The excellent weld quality and less stringent vacuum requirement make laser welding at a reduced pressure compete favorably with electron beam welding.

The important roles of the reduction of boiling point and the interaction of laser and plasma plume owing to a reduction of ambient pressure have been recognized in the literature. The commonly observed plasma plume at atmospheric pressure practically disappeared when ambient pressure was reduced (Ref. 20). Youhei et al. (Ref. 25) studied the effect of ambient pressure on the attenuation of a low-power solid state laser beam passed horizontally through a plasma/vapor plume. They showed the effect of plasma plume was significantly diminished as the ambient pressure was reduced. Similarly, Jiang et al. (Ref. 26) also demonstrated the laser energy attenuation caused by the plasma plume significantly decreased with a decreasing ambient pressure. The boiling point of alloys is also significantly affected by the ambient pressure. Reisgen et al. (Ref. 17) suggested the smaller difference between the boiling point and the melting point under vacuum would result in a thinner molten pool.

Various mathematical models ranging from heat conduction simulations to comprehensive 3D heat transfer and fluid flow calculations, considering the presence of a moving liquid-vapor interface for keyhole-mode laser welding and electron beam welding, are available in the literature (Refs. 27–38). However, most of previous models did not consider the effect of ambient pressure. A quantitative study is needed to definitively elucidate the mechanism by which the benefits of reduced ambient pressure keyhole-mode laser welding are achieved. Numerical simulation of heat transfer, considering both the depression of the boiling point and the attenuation of the laser beam by metal vapor/plasma, can provide a realistic assessment of the development of the fusion zone geometry during keyhole-mode welding of alloys at various pressures.

Here, we sought to elucidate the underlying mechanism for the enhanced depth of penetration during keyhole-mode laser welding at reduced ambient pressure through experiments and modeling. We developed a 3D heat transfer and fluid flow model for the keyhole-mode welding at various ambient pressures. The model considers the role of ambient pressure by including its effects on the depression of the boiling point of the alloy and the variation of plume attenuation coefficient. The predictions of the model were tested with experimental data for the keyhole-mode welding of four alloys — Structural Steel Q690, Aluminum Alloy A5083, commercially pure titanium, and Nickel 201 (Ref. 16) — that have very different thermophysical properties. Both the depression of the boiling point and the pressure dependent variation of the metal vapor/plasma plume attenuation of the beam intensity are shown to be responsible for the superior performance of the keyhole-mode laser beam welding at reduced ambient pressure. Analysis of the results also show the local heat transfer patterns near the keyhole changes with ambient pressure and contributes to the fusion zone shape and size.

Experimental Procedure

Laser welds under reduced ambient pressures were made in a specially designed vacuum chamber. Figure 1 shows a schematic diagram of the experimental setup. An IPG continuous wavelength fiber laser with maximum output of 10 kW was used in this experiment. The 1070-nm wavelength laser was transmitted via a 200- μ m-diameter optical fiber to a laser head equipped with a set of 1:2.3 focusing optics, consisting of 200-mm collimator lens and 460-mm focus lens. Therefore, the beam at focus had a theoretical spot size of approximately 0.46 mm. The vacuum chamber contained a mobile platform on which the specimen was welded. A two-stage pumping system consisting of a 15-L/s rotary pump and a 70-L/s roots pump was used to rapidly attain the preset ambient pressure.

Bead-on-plate laser beam welding was performed on 15-mm-thick Structural Steel Q690 and Aluminum Alloy A5083 samples at a laser power of 5000 W and a welding speed of 16.7 mm/s. The laser beam was focused on the specimen surface, i.e., no defocusing was used. Structural Steel Q690 had a composition of 1.28% Mn, 0.26% Si, 0.19% Cr, 0.16% C, 0.13% Mo, 0.027% Nb, 0.02% Ni, 0.018% Ti, 0.007% P, 0.003% S, and balance Fe. The Aluminum Alloy A5083 had a composition of 0.1% Cu, 0.4% Si, 0.4% Fe, 4.1% Mg, 0.08% Cr, 0.25% Zn, 0.15% Ti, and balance Al. After laser welding,

the specimens were prepared for metallography using a wire electrical discharge machining. The samples were polished and etched according to standard procedure, and the fusion zone cross sections were obtained using a digital optical microscope. The data for the Grade 2 commercially pure titanium (> 99.5 wt-% Ti) and Nickel 201 (> 99 wt-% Ni) were taken from literature (Ref. 16).

Mathematical Model

A three-dimensional heat transfer and fluid flow model for laser welding under reduced ambient pressure was developed by modifying our previous keyhole-mode welding models (Refs. 39–44). The model considers the main physical process during keyhole-mode laser welding, including keyhole formation, liquid metal flow driven by the spatial gradient of surface tension, melting, solidification, two-phase mushy zone, and heat transfer in the weldment. The quasi-steady state assumption makes the model computationally efficient. Details about this model are available in the literature (Refs. 39–44), and only the salient features of the model are presented here. The data used for calculation are presented in Table 1.

Keyhole Calculation

A point-by-point heat balance and pressure balance on the keyhole wall was used to calculate the keyhole geometry in this model. The calculation of keyhole geometry was based on materials properties and welding parameters. The calculation procedure includes the following steps.

An initial keyhole geometry was determined by a point-by-point energy balance on the keyhole wall. The detailed procedures of the point-by-point energy balance are provided in Appendix A. The keyhole wall temperature was assumed as the boiling point at the local pressure, which was determined by the equilibrium pressure vs. the temperature relationship for the base metal. The multiple reflections of the

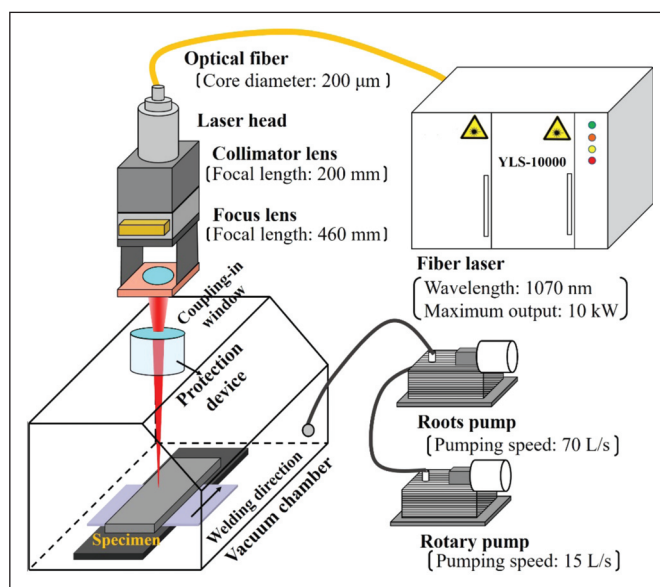


Fig. 1 — A schematic diagram of the experimental setup used for laser welding under reduced ambient pressure.

Table 1 — Data Used for Calculations

Physical Property	Structural Steel (Q690)	Aluminum Alloy (5083)	Titanium (commercial purity)	Nickel (201)
Density of the liquid (kg m ⁻³)	7000	2660	4400	8890
Density at the boiling point (kg m ⁻³)	5800	2380	4110	7800
Heat of evaporation (J kg ⁻¹)	6.52 × 10 ⁶ (Fe)	1.05 × 10 ⁷ (Al) 5.26 × 10 ⁶ (Mg)	1.03 × 10 ⁶ (Ti)	6.21 × 10 ⁶ (Ni)
Heat of fusion (J kg ⁻¹)	1.2 × 10 ⁵	3.95 × 10 ⁵	2.9 × 10 ⁵	3.0 × 10 ⁵
Solidus temperature (K)	1745	847	1941	1708
Liquidus temperature (K)	1785	933	1941	1719
Viscosity (kg m ⁻¹ s ⁻¹)	6.7 × 10 ⁻³	4.2 × 10 ⁻³	5.0 × 10 ⁻³	5.31 × 10 ⁻³
Specific heat of solid (J kg ⁻¹ K ⁻¹)	711	1050	700	456
Specific heat of liquid (J kg ⁻¹ K ⁻¹)	795	1197	800	500
Thermal conductivity of liquid (W m ⁻¹ K ⁻¹)	21	90	28	74.9
Thermal conductivity of solid (W m ⁻¹ K ⁻¹)	21	235	28	74.9
Coefficient of thermal expansion (K ⁻¹)	1.0 × 10 ⁻⁵	1.0 × 10 ⁻⁶	1.5 × 10 ⁻⁴	1.33 × 10 ⁻⁵
$d\gamma/dT$ of material (N m ⁻¹ K ⁻¹)	-0.49 × 10 ⁻³	-0.15 × 10 ⁻³	-0.26 × 10 ⁻³	-0.37 × 10 ⁻³
Surface tension (N m ⁻¹)	1.87	1.67	1.7	1.82
Plume attenuation coefficient at atmospheric pressure (cm ⁻¹)	3	4	5	3.5

laser beam inside the keyhole was considered by calculating the number of reflections according to the keyhole geometry. The beam attenuation was computed by using a plume attenuation coefficient in the model. The initial keyhole geometry was refreshed according to the energy absorption induced by multiple reflections and the energy attenuation caused by metal vapor/plasma. After the calculation of the initial keyhole geometry, the keyhole geometry data was stored in a data file to do the following calculations.

Secondly, the keyhole wall temperatures were modified according to the pressure balance on the keyhole wall. Inside the keyhole, the vapor pressure tended to keep the vapor cavity open, while the surface tension and hydrostatic pressure tried to close the keyhole. The force balance on the keyhole wall was given as follows:

$$P_v = P_A + \gamma(T)/r(z) + \rho gz \quad (1)$$

where P_v is the vapor pressure inside the keyhole, P_A is the ambient pressure, $\gamma(T)$ is the surface tension at local wall temperature T , ρ is the density, and g is the acceleration due to gravity. $r(z)$ is the average keyhole radius at the depth z from the top surface and is taken as half of the keyhole diameter in the welding direction. The vapor pressure at any depth z from the top surface is calculated using Equation 1 according to the saved data of keyhole geometry in the first step. Subsequently, the temperature on the keyhole wall at

any depth can be calculated from the equilibrium temperature vs. pressure relation, assuming ideal solution behavior.

Thirdly, the point-by-point energy balance was conducted again using the modified value of keyhole wall temperatures at all depths. Finally, the pressure and energy balance were done alternately and repeatedly to correct the keyhole geometry and keyhole wall temperature. The iterations were stopped when the keyhole depth became less than 10⁻⁴ mm.

Heat Transfer and Fluid Flow in the Weld Pool

After the calculation of keyhole geometry, the computed keyhole profile was mapped into a calculation domain for subsequent calculation of fluid flow and heat transfer. The molten metal was assumed to be an incompressible, laminar, and Newtonian fluid. The 3D fluid flow and temperature field were determined by solving the following conservation equations of momentum, mass, and energy.

Momentum Conservation Equation or Navier-Stokes Equation (Refs. 41, 45)

$$\rho \frac{\partial u_j}{\partial t} + \rho \frac{\partial(u_i u_j)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(\mu \frac{\partial u_j}{\partial x_i} \right) + S_j \quad (2)$$

where ρ and μ are the density and the viscosity of the alloy,

respectively; u_i and u_j are the velocity components along the i and j directions, respectively; and S_j is the source term for the momentum conservation equation and is given as follows:

$$S_j = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left(\mu \frac{\partial u_j}{\partial x_j} \right) - C \left(\frac{(1-f_L)^2}{f_L^3 + B} \right) u_j + \rho g \beta (T - T_{ref}) - \rho U \frac{\partial u_j}{\partial x_j} \quad (3)$$

where p represents pressure, U is the welding velocity, and β is the coefficient of volume expansion. The third term represents the frictional dissipation in the mushy zone according to the Carman-Kozeny equation for flow through a porous media (Refs. 32, 46), where f_L is the liquid fraction, B is a very small computational constant introduced to avoid division by zero, and C is a constant accounting for the mushy zone morphology. The fourth term is the buoyancy source term. The last term accounts for the relative motion between the laser source and the workpiece (Refs. 47, 48).

Mass Conservation Equation or Continuity Equation

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \quad (4)$$

The mass conservation equation is solved in conjunction with the momentum equation to obtain the pressure field.

Energy Equation

$$\rho \frac{\partial h}{\partial t} + \rho \frac{\partial(u_i h)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(\frac{k}{c_p} \frac{\partial h}{\partial x_i} \right) + S_h \quad (5)$$

where k is the thermal conductivity and h is the sensible heat. The sensible heat h is expressed as follows: $h = \int C_p dT$, where C_p is the specific heat and T is the temperature. The source term S_h is due to the latent heat content and is given as follows:

$$S_h = -\rho \frac{\partial(\Delta H)}{\partial t} - \rho \frac{\partial(u_i \Delta H)}{\partial x_i} - \rho U \frac{\partial h}{\partial x_i} - \rho U \frac{\partial \Delta H}{\partial x_i} \quad (6)$$

where ΔH is the latent heat content. The latent heat content ΔH is given as follows: $\Delta H = f_L L$, where L is the latent heat of fusion. The liquid fraction f_L is assumed to vary linearly with temperature for simplicity (Ref. 47), and is given as follows:

$$f_L = \begin{cases} 1 & T \geq T_L \\ \frac{T - T_S}{T_L - T_S} & T_S < T < T_L \\ 0 & T \leq T_S \end{cases} \quad (7)$$

where T_L and T_S are the liquidus and solidus temperatures, respectively.

The heat transfer and fluid flow equations were solved in three dimensions for the complete workpiece. For the region inside the keyhole, the coefficients and source terms in the discretized algebraic equations were adjusted to obtain the modified keyhole wall temperature at all depths and zero fluid velocities.

Boundary Conditions

A 3D Cartesian coordinate system was used in the calculation, and only half of the workpiece was considered because of the symmetry of welding process with respect to the weld centerline. A schematic of the boundary conditions is shown in Fig. 2. These boundary conditions are further discussed as follows.

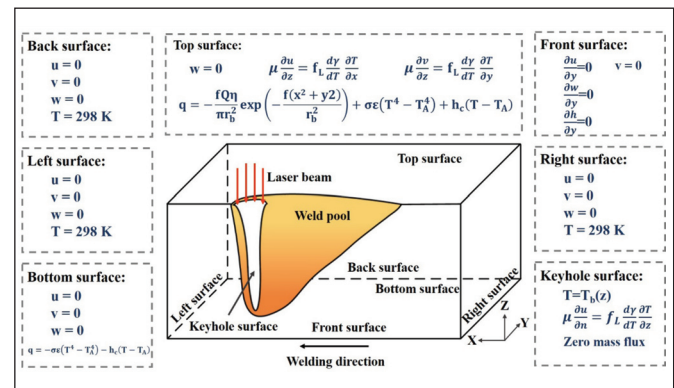


Fig. 2 — Schematic diagram of boundary conditions.

Top Surface

The top surface, except the keyhole region, is assumed to be flat. The velocity components along the x and y direction, u and v , induced by the Marangoni effect were considered as the velocity boundary condition (Ref. 49). The velocity components along the z direction, w , is set as zero due to the negligible outward flow at the top surface. Therefore, the

$$\begin{cases} \mu \frac{\partial u}{\partial z} = f_L \frac{d\gamma}{dT} \frac{\partial T}{\partial x} \\ \mu \frac{\partial v}{\partial z} = f_L \frac{d\gamma}{dT} \frac{\partial T}{\partial y} \\ w = 0 \end{cases} \quad (8)$$

where the $d\gamma/dT$ is the temperature coefficient of surface tension.

The heat boundary condition was derived from the heat input and heat loss by radiation and convection. The expression is given as follows:

$$q = -\frac{fQ\eta}{\pi r_b^2} \exp\left(-\frac{f(x^2+y^2)}{r_b^2}\right) + \sigma \epsilon (T^4 - T_A^4) + h_c (T - T_A) \quad (9)$$

where r_b is the beam radius, f is the power distribution factor, Q is the total power, η is the absorption coefficient, σ is the Stefan-Boltzmann constant, ϵ is the emissivity, h_c is the heat transfer coefficient, and T_A is the ambient temperature. In Equation 9, the first term on the right-hand side is the heat input from the heat source. The second and third terms represent the heat loss by radiation and convection, respectively.

Symmetry Plane

The symmetric plane is the front surface in Fig. 2. Zero flux condition was applied for both momentum and enthalpy at the symmetric plane. Therefore, the velocity components and heat flux along the y direction were set as zero. The boundary condition can be defined as follows:

$$\begin{cases} \frac{\partial u}{\partial y} = 0 \\ v = 0 \\ \frac{\partial w}{\partial y} = 0 \\ \frac{\partial h}{\partial y} = 0 \end{cases} \quad (10)$$

Keyhole Surface

The keyhole wall temperature at any depth was fixed by assigning a corresponding enthalpy value at that depth:

$$h = h_b(z) \quad (11)$$

where $h_b(z)$ is the sensible heat of the material at the local wall temperature, which is determined by the wall temperature at depth z from the keyhole geometry calculation. The velocity component perpendicular to the keyhole surface was assigned zero to represent no mass flux due to convection. The temperature gradient along the keyhole wall resulted in the melt flow along the z direction. Therefore, the w velocity boundary condition along the keyhole walls is given as follows:

$$\mu \frac{\partial u}{\partial n} = f_L \frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial z} \quad (12)$$

where n is the direction vector normal to the keyhole surface.

Bottom Surface

Fluid velocities at three directions were fixed at zero because of the no-melt flow on the bottom surface in partial joint penetration welds. A radiation and convective heat transfer boundary condition with a given heat transfer coefficient was specified for the bottom surface.

Solid Surfaces

At all the solid surfaces far away from the weld pool, including the back, left, and right surfaces in Fig. 2, temperatures were set at ambient temperature, and the fluid velocities were set to be zero.

Turbulence Model

During keyhole-mode laser welding, the presence of fluctuating velocities in the weld pool often enhances the transport rates of heat, mass, and momentum. The values of effective viscosity and thermal conductivity vary with the location in the weld pool and depend on the local characteristics of the fluid flow. An appropriate turbulence model is needed to provide a systematic framework for calculating these properties by considering the contribution of the fluctuating velocities. In this work, a turbulence model based on Prandtl's mixing length hypothesis was used to estimate the turbulent viscosity (Ref. 41):

$$\mu_t = \rho l_m v_t \quad (13)$$

where μ_t is the turbulent viscosity, l_m is the mixing length, and v_t is the turbulence velocity. The turbulence velocity can be estimated from the turbulent kinetic energy. The turbulent kinetic energy (TKE) is assumed to be about 10% of the mean kinetic energy. It follows that TKE ($0.5 m v_t^2$) equals $0.1 \times 0.5 m v^2$ and the fluctuating component of the mean velocity, v_t , becomes equal to $0.316 v$. Thus, the turbulent component of the velocity (or fluctuating velocity) is about 30% of the mean velocity, and the turbulent viscosity can be expressed by the following expression:

$$\mu_t = 0.3 \rho l_m v \quad (14)$$

Effective viscosity at a particular point was given as the sum of the turbulent (μ_t) and laminar (μ_l) viscosities, i.e., $\mu = \mu_t + \mu_l$. The corresponding local turbulent thermal conductivity k_t was calculated from the turbulent Prandtl number

$$Pr = \mu_t c_p / k_t \quad (15)$$

For the calculations described here, the Prandtl number was set to a value of 0.9, based on previous modeling work (Ref. 49).

Results and Discussion

Figure 3 shows a comparison between the calculated and the experimentally observed fusion zone cross sections for the keyhole-mode welding of Structural Steel Q690. The red line indicates the solidus temperature (1745 K), which marks the weld fusion cross-section boundary. The black line in the figure indicates the A1 line temperature (1000 K), which marks the HAZ region of the weld section. The experimental results showed the weld depth and half weld width were 4.23 and 1.6 mm, respectively, and the corresponding computed values were 4.43 and 1.55 mm, respectively. The calculated weld fusion cross section and HAZ agreed well with the corresponding experimental results.

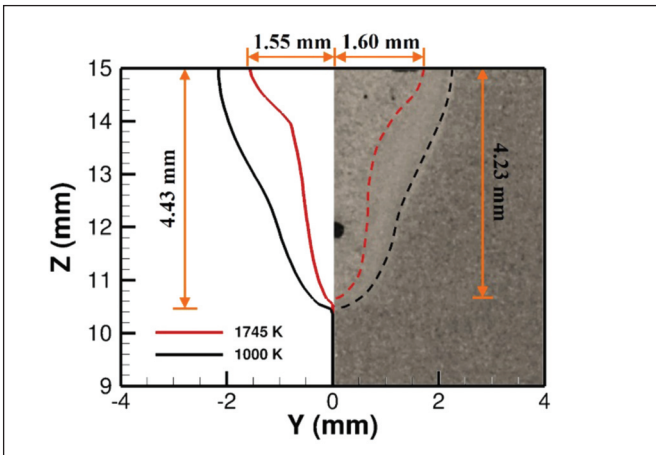


Fig. 3 — Comparison between the calculated weld fusion cross sections and HAZs of the laser weld for Structural Steel Q690 obtained at atmospheric pressure with the corresponding experimental results.

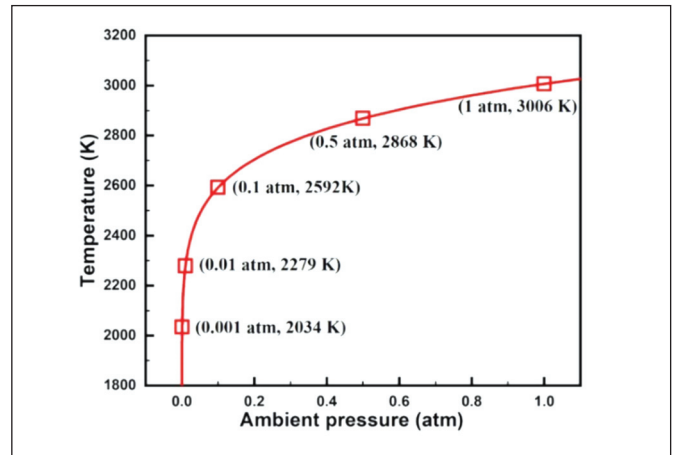


Fig. 4 — The calculated boiling point of Structural Steel Q690 at different ambient pressures according to the equation of equilibrium vapor pressure vs. temperature given by Yaws (Ref. 50).

Boiling point is the temperature at which the equilibrium vapor pressure of a liquid alloy equals the ambient pressure surrounding the liquid. Therefore, ambient pressure has a significant effect on boiling point. In our model, the equilibrium vapor pressure was calculated, assuming ideal solution behavior according to the alloy composition. In this study, the relationship of temperature and the equilibrium vapor pressure over the pure-iron liquid was used for Structural Steel Q690 because the iron content is more than 98% in the base metal. The equation of equilibrium vapor pressure of pure iron vs. temperature is given by Yaws (Ref. 50).

$$\log(P \times 760) = 11.559 - \frac{1.9538}{T} - 0.62549 \log T - 2.7182 \times 10^{-9} T + 1.9086 \times 10^{-13} T^2 \quad (16)$$

where P is the equilibrium vapor pressure, and T is the temperature.

Figure 4 shows the calculated boiling point of Structural Steel Q690 at different ambient pressures according to Equation 13. The boiling point decreased dramatically with the decrease in ambient pressure. The difference in boiling point for pure iron is about 1000 K when the ambient pressure ranged from 1 to 0.001 atm.

The effect of ambient pressure on boiling point was considered in the heat transfer and fluid flow model. In the calculation of keyhole geometry, the boiling point at any local ambient pressure was considered as the local keyhole wall temperature according to the boiling point vs. ambient pressure relationship in Equation 13.

Figure 5 shows the experimental and the corresponding calculated penetration depth and weld width for Structural Steel Q690 by only considering the variation of boiling point for five ambient pressures. In Fig. 5A, the experimental results show the penetration depth increased significantly from 4.23 to 10.21 mm with the decrease of ambient pressure from 1 to 0.01 atm, but when the ambient pressure reduced to 0.01 atm and below, the penetration depth re-

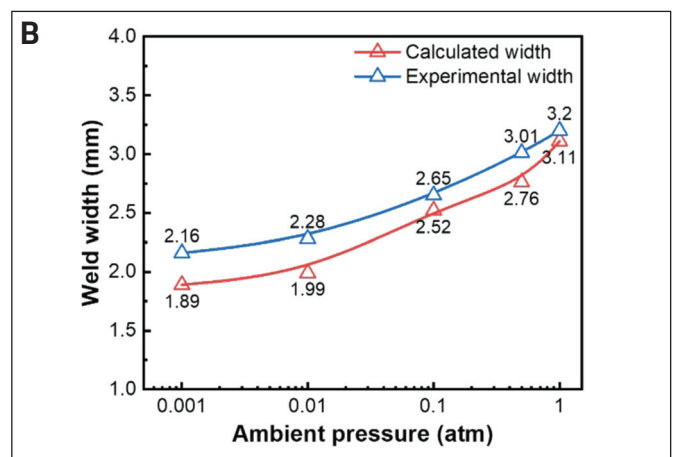
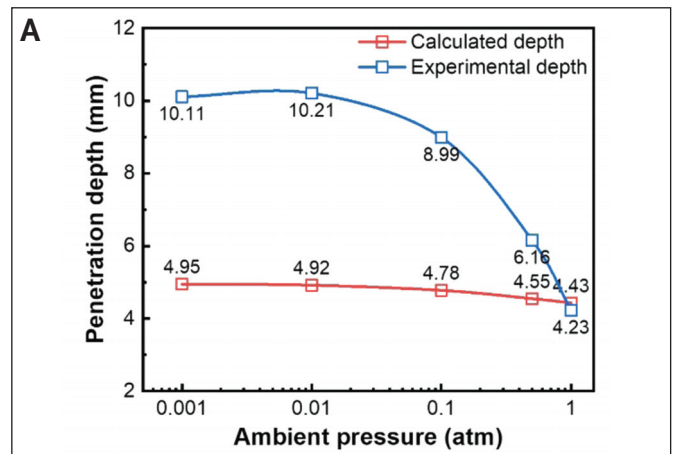


Fig. 5 — The experimental and corresponding calculations: A — Penetration depth; B — weld width for Structural Steel Q690 by only considering the variation in boiling point for five ambient pressures.

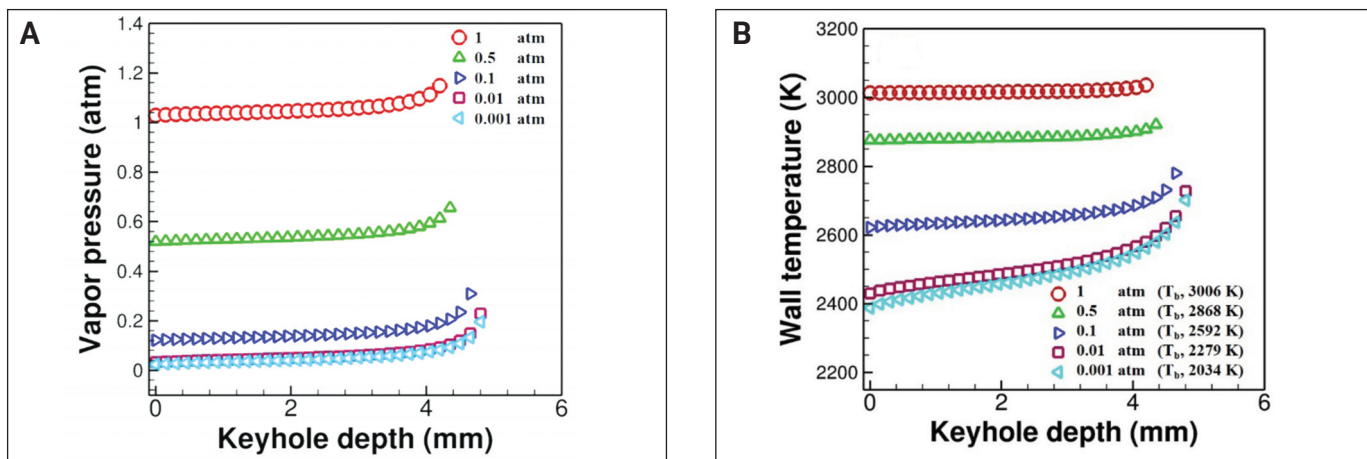


Fig. 6 — The variation of the following: A — Vapor pressure; B — keyhole wall temperature with keyhole depth for laser welding of Structural Steel Q690 at five level ambient pressures by only considering the variation in boiling point. (T_b indicates the boiling temperature in Fig. 6B.)

mained stable. The calculated results show the reduction of boiling point only induced an increase of 0.5 mm in penetration depth when the ambient pressure ranged from 1 to 0.001 atm. In contrast, as shown in Fig. 5B, the calculated weld width had a good agreement with the corresponding experimental results. Both the experimental and calculated weld width decreased from about 3 to about 2 mm when ambient pressure was reduced from 1 to 0.001 atm.

Figure 6A shows the variation of vapor pressure with keyhole depth for laser welding of Structural Steel Q690 with 5-kW input power and 16.7-mm/s welding speed for five values of ambient pressures. The values in the plot conformed to the pressure balance, considering the surface ten-

sion and hydrostatic pressures at the keyhole wall. A pressure difference between the bottom and the top of keyhole existed to keep the keyhole open. Therefore, the vapor pressure was greater than 1 atm for welding at atmospheric pressure. The results show that although the vapor pressure values depended on the ambient pressure, the difference in pressure from the bottom to the top of the keyhole for different ambient pressures were roughly similar. Figure 6B shows the variation of the calculated keyhole wall temperature with keyhole depth for various ambient pressures. As expected, the keyhole wall temperature decreased with the decrease in boiling point. Furthermore, owing to the similar vapor pressures inside the keyhole, the keyhole wall temper-

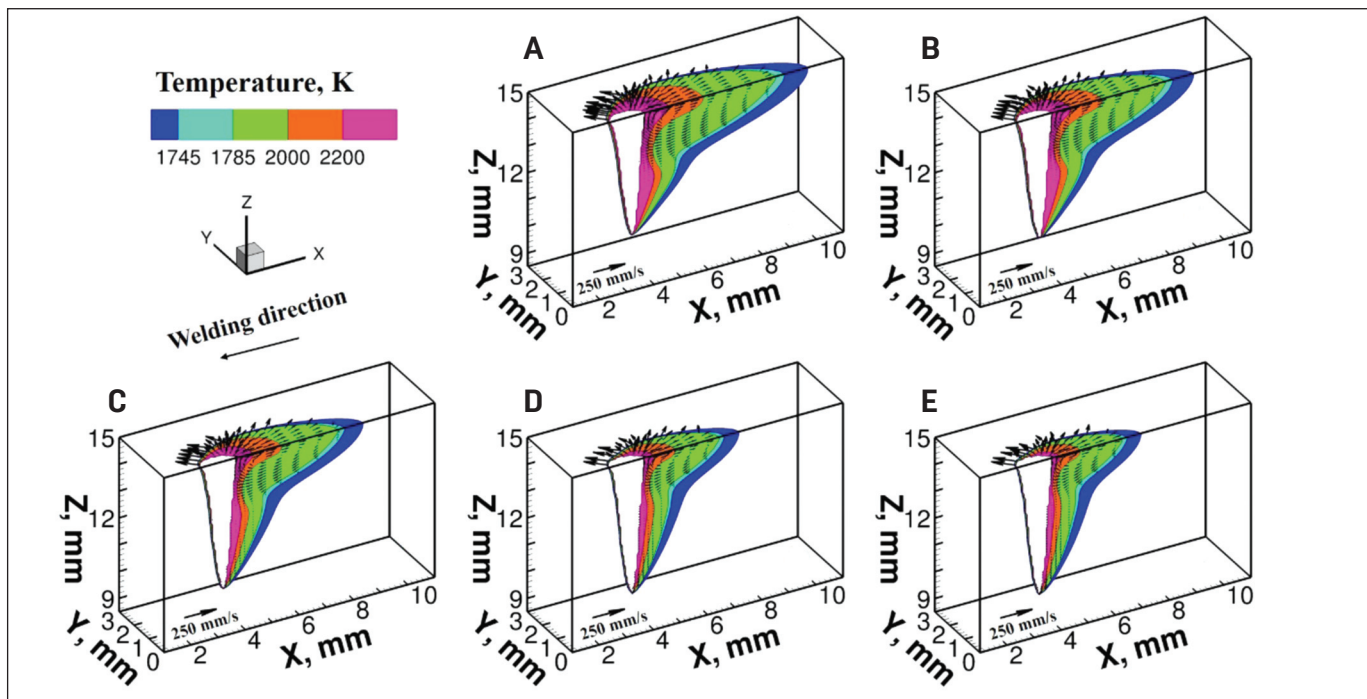


Fig. 7 — The calculated temperature and fluid flow field for laser welding of Structural Steel Q690 at five level ambient pressures: A — 1 atm; B — 0.5 atm; C — 0.1 atm; D — 0.01 atm; E — 0.001 atm by only considering the variation in boiling point.

atures were similar for ambient pressures of 0.01 and 0.001 atm. More important, the temperature gradient along the keyhole wall was different for various ambient pressures. Although an excess pressure inside the keyhole from the bottom to the top exited at atmospheric pressure, the temperature gradient on the keyhole wall was very small at an ambient pressure of 1 atm. This is the reason why the keyhole wall temperature can be set as boiling in the simulation of conventional laser welding at atmospheric pressure (1 atm) (Refs. 33, 39). For a similar excess pressure in the keyhole at reduced ambient pressure, the temperature difference between the bottom and the top of the keyhole was much larger than the corresponding value for laser welding at atmospheric pressure. The wall temperature varied by about 313 K from the 2388 K at the top surface to 2701 K near the keyhole bottom at an ambient pressure of 0.001 atm. The temperature gradient on the keyhole wall drove a Marangoni convection along the keyhole wall.

Figure 7 shows the calculated temperature and fluid flow field during laser welding of Structural Steel Q690 at 5 kW and 16.7 mm/s for various ambient pressures by only considering the variation in boiling point. The lower keyhole wall temperature reduced heat conduction in the horizontal direction at a reduced ambient pressure compared with the atmospheric pressure. Therefore, the weld pool length and weld pool width decreased with the decrease in ambient pressure. There was no significant Marangoni convection along the keyhole walls at atmospheric pressure because of the lack of a strong temperature gradient along the keyhole wall. While at reduced ambient pressure, there was an upward flow on the keyhole walls due to the Marangoni convection. It drove the melt liquid to flow from the high-temperature region to the low-temperature region and brought heat from the keyhole bottom to the surface. Although the decrease in boiling point was not the main reason for the improvement of penetration depth in laser welding under reduced ambient pressure, it significantly changed the heat transfer and fluid flow in the weld pool.

When a high-power density laser impinges on a base metal surface, the material vaporizes violently, resulting in the formation of a deep and narrow cavity called keyhole (Refs. 35, 42). A plasma/vapor plume forms during welding and consists of ions, excited atoms, neutral atoms, and electrons (Refs. 51–53). The number densities of each species depend on the vaporization rates of various alloying elements, laser beam power density distribution, shielding gas flow rate, and total pressure (Refs. 54–58). Figure 8A shows, schematically, as the laser beam traverses through the plasma plume into the keyhole, the laser energy decreases due to the attenuation by vapor/plasma plume before it is absorbed by the keyhole wall. An important component of the attenuation is through the inverse Bremsstrahlung absorption, which involves electron-atom and electron-ion collisions. It has been demonstrated the inverse Bremsstrahlung absorption is the main absorption mechanism for a CO₂ laser (wavelength: 10.6 μm) (Refs. 56–58). While for solid-state laser with a wavelength of about 1 μm, the inverse Bremsstrahlung absorption can be negligible because the inverse Bremsstrahlung absorption is directly proportional to the laser wavelength squared. The attenuation induced by condensed metal vapors is the dominant attenuation mech-

anism for a short wavelength laser, and it is described by the Rayleigh or Mie scattering theory (Refs. 57, 58). Under these, the attenuation coefficient β is the sum of absorption coefficient β_{abs} and scattering coefficient β_{sca} . The absorption coefficient β_{abs} and scattering coefficient β_{sca} are given as follows (Refs. 58, 59):

$$\beta_{abs} = \frac{\pi^2 d^3 N_p}{\lambda} \text{Im} \left(\frac{m^2 - 1}{m^2 + 2} \right) \quad (17)$$

$$\beta_{sca} = \frac{2\pi^5 d^6 N_p}{3\lambda^4} \text{Im} \left(\frac{m^2 - 1}{m^2 + 2} \right)^2 \quad (18)$$

where d is the particle diameter inside the vapor plume, N_p is the particle density, λ is the laser wavelength, and m is the complex refractive index. According to the equation of state for ideal gas: $N_p = n_p/V_p = P_A/rT$, where n_p is the number density of the particles, V_p is the occupied volume by particles, r is the gas constant, and T is temperature. When N_p is taken into Equations 17 and 18, the absorption coefficient β_{abs} and scattering coefficient β_{sca} are described as follows:

$$\beta_{abs} = \frac{\pi^2 d^3 P_A}{\lambda r T} \text{Im} \left(\frac{m^2 - 1}{m^2 + 2} \right) \quad (19)$$

$$\beta_{sca} = \frac{2\pi^5 d^6 P_A}{3\lambda^4 r T} \text{Im} \left(\frac{m^2 - 1}{m^2 + 2} \right)^2 \quad (20)$$

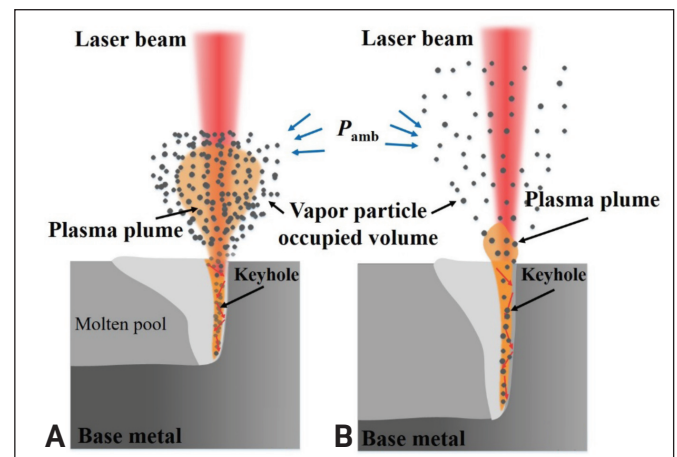


Fig. 8 — The schematic drawing of keyhole-mode laser welding: A — Atmospheric pressure; B — reduced ambient pressure.

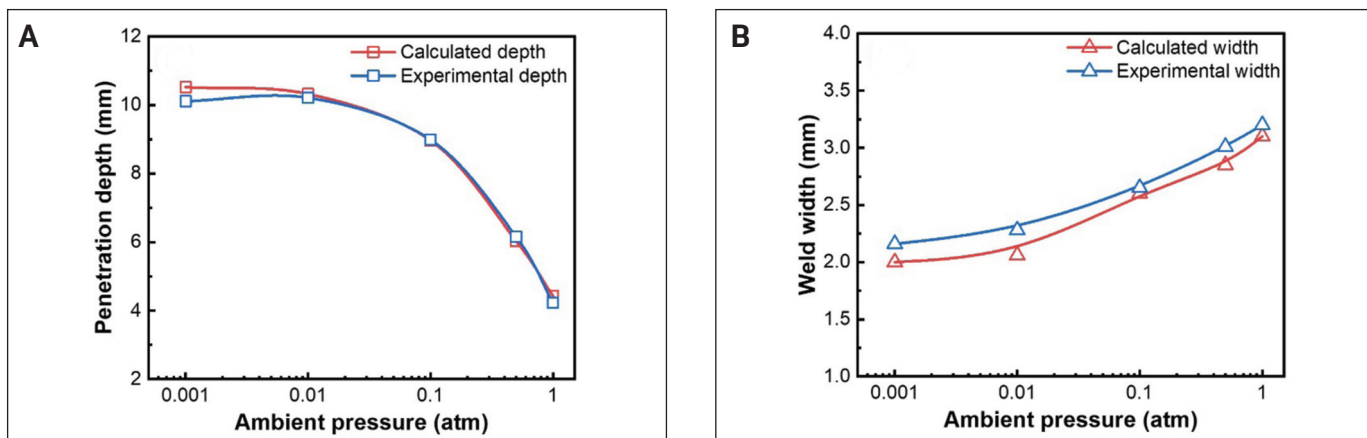


Fig. 9 — The experimental and corresponding calculations: A — Penetration depth; B — weld width for Structural Steel Q690 by considering both the variation in boiling point and plume attenuation coefficients for five ambient pressures.

According to Equations 19 and 20, the directly proportional relationship between the attenuation coefficient β and ambient pressure P_A was obtained while assuming the particle diameter and the ambient temperature were the same for the different ambient pressures. As shown schematically in Fig. 8B, the decrease of ambient pressure reduced the vapor particle density, lowering the value of the

attenuation coefficient β . The value of β was difficult to estimate because of the uncertainties in the values of the variables in the above equations. Mazumder and Steen used a value of 800 m^{-1} for welding of mild steel (Ref. 28). Kaplan provided a mean attenuation coefficient value of 100 m^{-1} for iron (Ref. 33). Rai et al. simulated keyhole mode laser welding of tantalum, Ti-6Al-4V, 304L stainless steel, and vana-

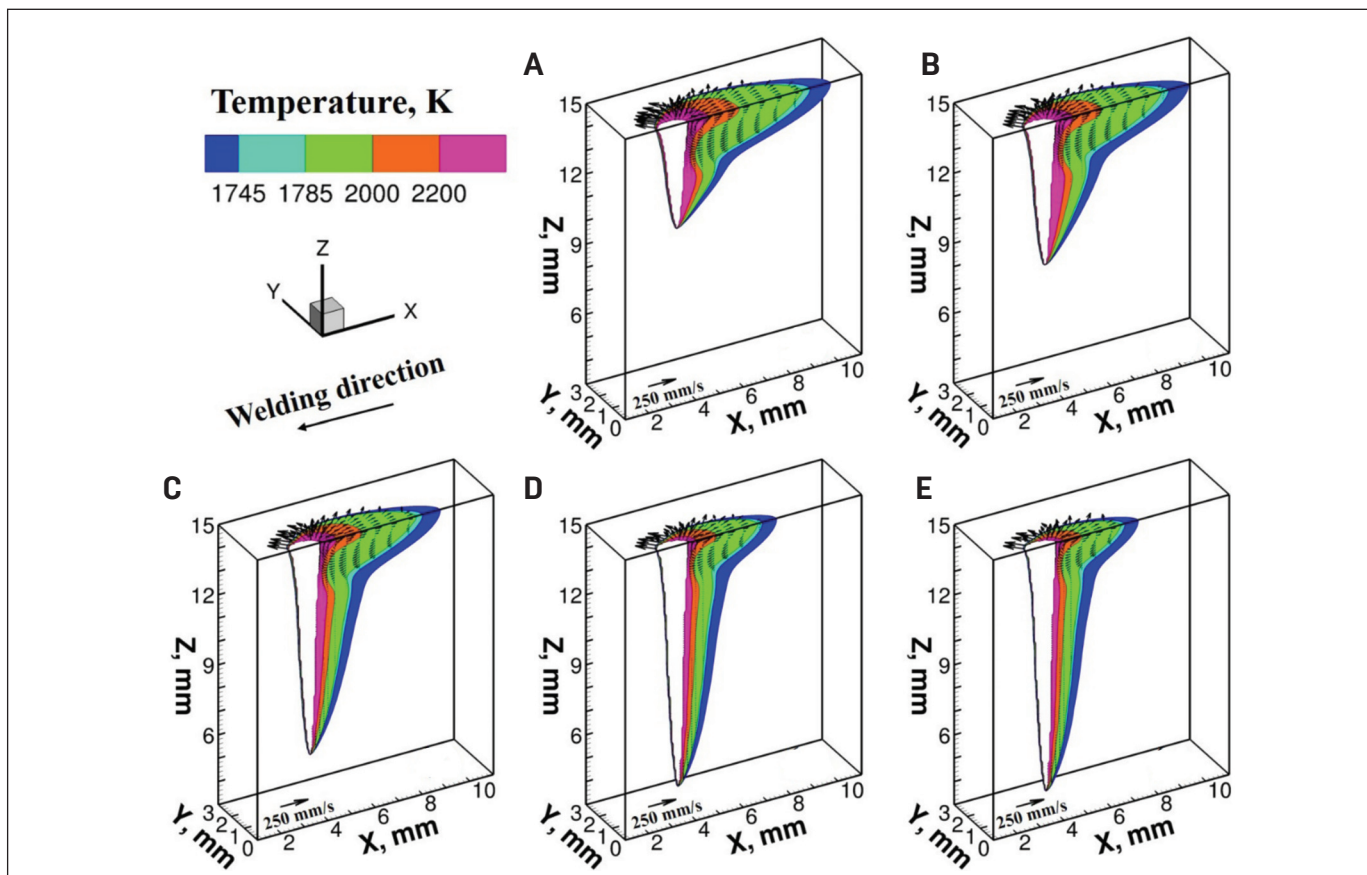


Fig. 10 — The calculated temperature and fluid flow field for laser welding of Structural Steel Q690 at five level ambient pressures: A — 1 atm; B — 0.5 atm; C — 0.1 atm; D — 0.01 atm; E — 0.001 atm by considering both the variation in boiling point and plume attenuation coefficient.

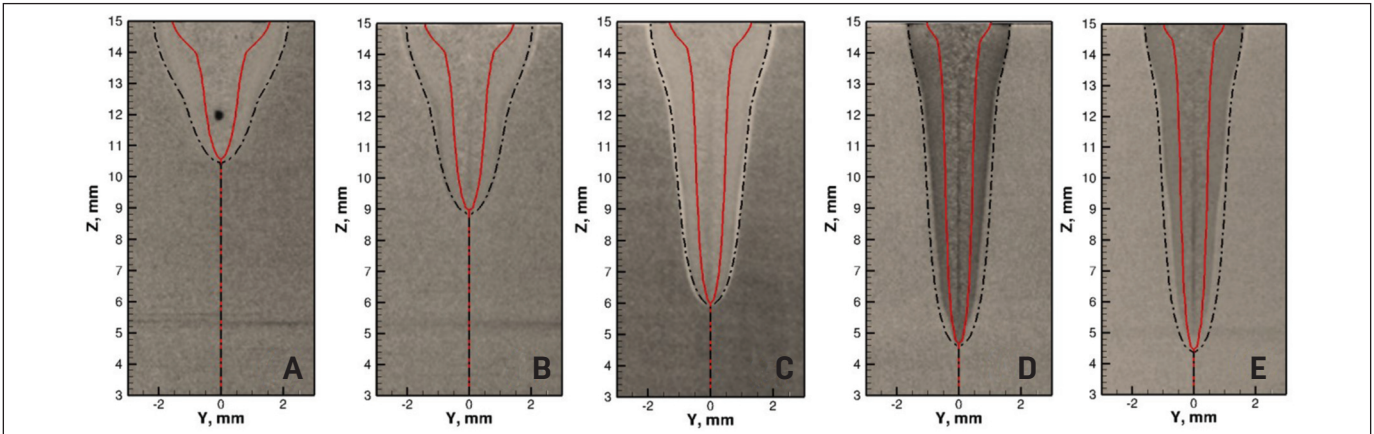


Fig. 11 — Comparison between the experimental and the calculated weld fusion cross sections of Structural Steel Q690 laser welds at various ambient pressures: A — 1 atm; B — 0.5 atm; C — 0.1 atm; D — 0.01 atm; E — 0.001 atm by considering both the variation in boiling point and plume attenuation coefficient.

dium using the same attenuation coefficient value of 100 m^{-1} (Ref. 35). The literature values of the attenuation coefficient range from 800 to lower than 100 m^{-1} , depending on the type of laser, power, speed of welding, material used, shielding gas, and other variables (Refs. 28, 35). Determining an exact value for a particular laser welding condition is a highly complex undertaking. However, there is a proportional relation between the attenuation coefficient and the total pressure for any given set of welding parameters, as observed from Equations 19 and 20. To consider the laser energy attenuation caused by metal vapors/plasma, the average attenuation coefficient used in this model is determined by achieving a good agreement of calculated and experimental fusion zone geometries at atmospheric pressure. The values of the attenuation coefficients β for various materials at atmospheric pressure used in this work are listed in Table 1. The attenuation coefficients at lower pressures were obtained from the proportional relationship between plume attenuation coefficient and the ambient pressure.

Figure 9 shows the experimental and the corresponding calculated penetration depth and weld width for Structural Steel Q690, considering both the variation of the boiling point and laser beam attenuation for five ambient pressures. The calculated results of both the penetration depth and weld width showed good agreement with the corresponding experimental results. Figure 10 shows the calculated temperature and fluid flow field for Structural Steel Q690 welds made at various ambient pressure by considering both the variation of boiling point and plume attenuation coefficient. The keyhole depth increases with a decrease in ambient pressure. Comparing the temperature fields for various ambient pressures, the heat transfer was enhanced in the depth direction and was reduced in horizontal direction due to the decrease of beam attenuation and keyhole wall temperature. To illustrate the significance of the role of heat transfer by convection relative to heat transfer by conduction, the dimensionless Peclet number (Pe) was calculated for ambient pressure of 1 and 0.001 atm.

$$Pe = \rho u C_p (w/2)/k \quad (21)$$

where ρ is the density, u is the characteristic velocity, C_p is the specific heat, w is the weld pool width, and k is the thermal conductivity. Considering a typical velocity of 100 mm/s, the properties of the liquid metal, and the calculated weld pool width, the Peclet number for 1 and 0.001 atm works out to be 41 and 13, respectively. Since the Peclet number is much greater than 1, convection plays a significant role in the heat transfer process for both cases. In addition, the convective flow plays a more important role in the heat transfer at atmospheric pressure than that at reduced ambient pressures. The strong outward flow in the weld pool results in a relatively wide weld fusion zone at atmospheric pressure.

Figure 11 shows a comparison between the calculated and the experimental weld fusion cross sections of Structural Steel Q690 laser welds at various ambient pressures. A laser weld with deep penetration depth and narrow weld width characteristic of an electron beam weld was obtained at low ambient pressures. The calculated weld fusion cross sections agreed well with the corresponding experimental

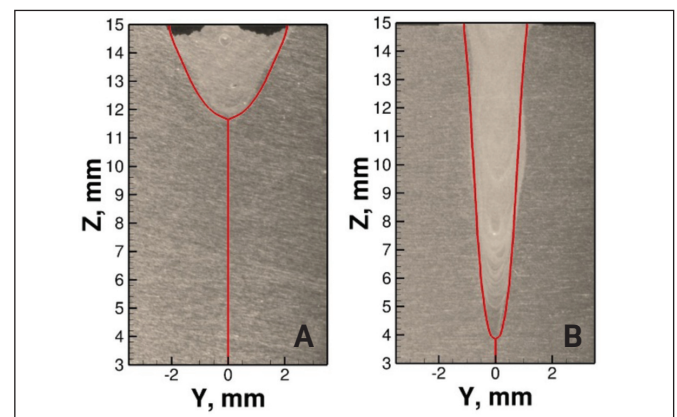


Fig. 12 — Comparison between the calculated weld fusion cross sections of Aluminum Alloy A5083 laser welds: A — Atmospheric pressure (1 atm); B — reduced ambient pressure (0.001 atm) with the corresponding experimental results.

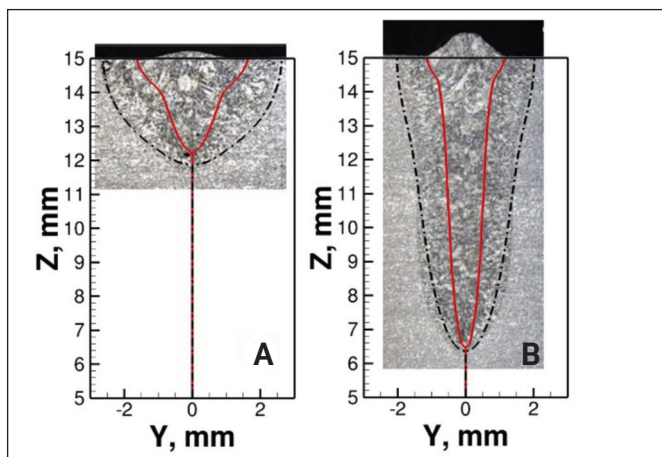


Fig. 13 — Comparison between the calculated weld fusion cross sections of pure titanium laser welds: A — Atmospheric pressure (1 atm); B — reduced ambient pressure (0.1 mBar) with the corresponding experimental results of Elmer et al. (Ref. 16).

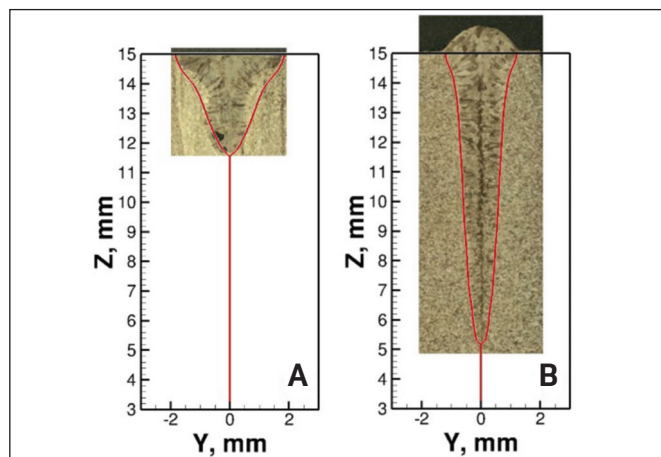


Fig. 14 — Comparison between the calculated weld fusion cross sections of Nickel 201 laser welds: A — Atmospheric pressure (1 atm); B — reduced ambient pressure (0.1 mBar) with the corresponding experimental results of Elmer et al. (Ref. 16).

results for all ambient pressures.

To examine the effectiveness of the model to explain the role of reduced ambient pressure, experimental data for three other alloys that had very different thermophysical properties than the Q690 steel were compared with the model predictions. First, experimental data for the welding of Aluminum Alloy A5083 were compared with the corresponding model predictions. The results shown in Fig. 12 indicate good agreement between the calculated and experimental data. This agreement indicates promise that the model accurately represents the most important physical processes for keyhole-mode welding at various ambient pressures.

In addition to the data for Aluminum Alloy A5083, the independent experimental data of Elmer et al. (Ref. 16) for the welding of commercially pure titanium and Nickel 201 were also simulated. The commercially pure titanium was welded using 2075-W laser power and 17-mm/s welding speed, and the Nickel 201 was welded using 4150-W laser power and 12-mm/s welding speed. Figures 13 and 14 show a comparison between the experimental and the predicted results for commercially pure titanium and Nickel 201, respectively. The fair agreement between the calculated and the experimentally obtained fusion zone cross sections of commercially pure titanium and Nickel 201 welded at different ambient pressures indicates the validity of the physical processes considered in the simulations. The variation of the fusion zone geometry at various ambient pressures results from the effects of the depression of boiling point and changes in the plume attenuation coefficient.

Summary and Conclusions

The improvement of the depth of penetration during keyhole-mode welding of steel, aluminum alloy, commercially pure titanium, and Nickel 201 due to reduced ambient pressure was studied experimentally and theoretically. The investigation showed both the depression of the keyhole-wall temperature as well as the reduced absorption of the in-

tensity of the laser beam by the plasma were responsible for the improved depth of penetration at lower ambient pressures. The following are the main findings.

1) The experimental results for the keyhole-mode welding of steel, aluminum alloy, commercially pure titanium, and Nickel 201 showed the weld geometry was sensitive to ambient pressure. The penetration depth increased and weld width decreased with the reduction of ambient pressure from 1 to 0.001 atm.

2) The computed depths of penetration in a steel weld were considerably lower than the observed depths in a steel weld at low ambient pressures when the depression of the boiling point with a decrease in ambient pressure was considered. However, the experimental weld widths agreed well with the corresponding computed values.

3) The improvements in the depth of penetration could be accurately predicted for the keyhole-mode welding of steel, aluminum alloy, commercially pure titanium, and Nickel 201 when both the depression of the boiling point as well as the change in the vapor/plasma plume attenuation were considered.

4) The improvement in the depth of penetration at reduced ambient pressure was mainly due to the improved transmission of the laser beam through the vapor/plasma plume. Estimated values for laser attenuation coefficients are proposed for the four alloys studied.

5) The lower keyhole wall temperature and the reduced temperature gradient near the keyhole wall reduced the rate of heat transfer into the weld and resulted in narrower welds.

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Appendix A

Calculation of Keyhole Geometry

The laser energy is absorbed on the keyhole wall and transferred into the molten metal. The local angle of the keyhole wall is determined by the balance between heat flux transferred into the keyhole wall, the locally absorbed beam energy flux, and the heat loss due to heat of evaporation. The local keyhole wall angle with the vertical direction is given by the following (Ref. 33):

$$\tan(\theta) = \frac{I_c}{I_a - I_v} \quad (\text{A1})$$

where I_c is the radial heat flux conducted into the keyhole wall, I_a is the locally absorbed beam energy, and I_v is the evaporative heat flux on the keyhole wall.

The value of I_c is obtained from a two-dimensional temperature field in an infinite plate with reference to a linear heat source as follows (Ref. 33):

$$I_c(r, \varphi) = -\lambda \frac{\partial T(r, \varphi)}{\partial r} \quad (\text{A2})$$

where $T(r, \varphi)$ indicates a location in the plate with the line source as the origin, T is the temperature, and λ is the thermal conductivity. The two-dimensional temperature field, $T(r, \varphi)$, can be calculated conduction heat from the keyhole wall into the plate as follows (Ref. 33):

$$T(r, \varphi) = T_a + \frac{P'}{2\pi\lambda} K_0(\Omega r) e^{-\Omega \cos \varphi} \quad (\text{A3})$$

where T_a is the ambient temperature, P' is the power per unit depth, $K_0()$ is the zero-order second kind modified Bessel function, and $\Omega = v/(2\kappa)$, where v is the welding speed and κ is the thermal diffusivity.

The locally absorbed beam energy flux, I_a , on the keyhole wall is obtained by considering the Fresnel absorption during multiple reflections and the metal vapors/plasma absorption as follows (Ref. 33):

$$I_a = e^{-\beta L} (1 - (1 - \alpha)^{1 + \pi/4\theta}) I_0 \quad (\text{A4})$$

where β is the plume attenuation coefficient, L is the average path of the laser beam in metal vapors/plasma before it reaches the keyhole wall, α is the absorption coefficient of the workpiece, θ is the average angle between the keyhole wall and the initial incident beam axis, and I_0 is the local beam intensity, which varies with depth from the surface and radial distance from the beam axis, and is given by the following (Ref. 33):

$$I_0 = I_p \left(\frac{r_0}{r_f} \right)^2 \exp \left(-\frac{r^2}{r_f^2} \right) \quad (\text{A5})$$

where I_p is the peak intensity at the focal point, given by $2P/(\pi r_0^2)$, P is the laser power, r_0 is the beam radius at the

focal point, and r_f is the local beam radius, which is calculated by the following (Ref. 33):

$$r_f = r_0 \left(1 + \left(\frac{z + z_0}{2r_0 l / d_b} \right)^2 \right)^{1/2} \quad (\text{A6})$$

where z and z_0 are the depth and the beam defocusing, respectively. l is the beam focal length, and d_b is the beam diameter on the laser focusing lens.

The vaporization flux, I_v , on the keyhole wall is given by the following (Ref. 33):

$$I_v = \sum_{i=1}^n J_i \Delta H_i \quad (\text{A7})$$

where J_i is the vaporization flux of element i , ΔH_i is the heat of vaporization of element i , and n is the total number of alloying elements in the alloy. For simplicity, the vaporization flux of element i was calculated by using the Langmuir equation as follows (Ref. 60):

$$J_i = \frac{P_i}{7.5} \sqrt{\frac{M_i}{2\pi R T_b}} \quad (\text{A8})$$

where P_i is the vapor pressure of element i over the alloy, M_i is the molecular weight of element i , T_b indicates the boiling temperature of the alloy, and R is the gas constant.

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Control of Weld Residual Stress in a Thin Steel Plate through Low Transformation Temperature Welding Consumables

A new LTTW consumable for welding of advanced high-strength steels was developed for welding thin sheets

BY X. WU, Z. WANG, J. R. BUNN, L. KOLBUS, Z. FENG, Z. YU, AND S. LIU

ABSTRACT

Low transformation temperature welding (LTTW) consumables are characterized by a low martensite start temperature and a large fraction of martensite forming in the weld. It can efficiently reduce the tensile residual stress because the volume expansion associated with the martensitic transformation compensates for the thermal contraction during cooling. In this work, a LTTW wire, designated as EH200B, was created for the arc welding of advanced high-strength steel thin plates. In comparison to conventional ER70S-3 wires, this LTTW wire generated an opposite distortion pattern. Neutron diffraction measurements along the center thickness of the welded plates showed the maximum residual stress along the longitudinal direction (LD) in the weld region, and the heat-affected zone (HAZ) immediately adjacent to the weld region was reduced from ~330 MPa to below 240 MPa by using the LTTW wire. A finite element (FE) model was developed to predict the residual stress distributions of the plates welded under these two wires. The simulation results showed reasonable agreement with the volume-average neutron diffraction data. Compressive residual stress in the weld region using the LTTW wire was predicted by the FE method. Electron backscattered diffraction and x-ray diffraction measurements confirmed ~90% martensite was present in the LTTW weld. The fatigue life of DP980 steel lap joint panels using EH200B wire nearly doubled that of ER70S-3 wire. This improvement was attributed to the high strength and low LD residual stress in the weld and HAZ immediately adjacent to the weld.

KEYWORDS

- Low Transformation Temperature Welding Consumables
- Gas Metal Arc Welding • Weld Residual Stress
- Neutron Diffraction • Numerical Simulation

Introduction

There have been evolving applications of advanced high-strength steels (AHSSs) in the automotive industry due to the increasing demand in higher levels of car safety and fuel

efficiency. Fusion welding of AHSS, such as gas metal arc welding (GMAW), generally produces undermatching weldments due to the limited strengths of the commercially available welding consumables (Ref. 1). Moreover, the presence of tensile residual stresses in the softened heat-affected zone (HAZ) often leads to premature failure/accidental fatigue fracture (Ref. 2). For automotive applications, significant distortion could also occur during the welding of thin AHSS sheets and thus be problematic for auto body assembly (Refs. 3, 4).

Methods for relieving residual stresses in thin plate welds include postweld heat treatment and postweld cold rolling (Refs. 5–7). These methods, however, are generally costly, time consuming, and limited by component size and geometry. An attractive alternative approach is to use low transformation temperature welding (LTTW) consumables that can control the evolution of tensile residual stress and distortion during the welding process by phase transformation, resulting in a large fraction of martensite. The concept of LTTW consumables was first proposed by Jones and Alberry in 1977 (Ref. 8). The volume expansion associated with the austenite-to-martensitic transformation could compensate for the thermal contraction during cooling. A low transformation temperature is critical to ensure no further thermal contraction occurs in the martensitic phase as the weld region cools back down to room temperature, since martensite has an extremely large elastic modulus (Ref. 8). Jones and Alberry reported the residual stress in AISI 316 stainless steel welds was decreased significantly using a 9CrMo wire due to the austenite-to-martensite transformation during cooling (Ref. 8). Compressive residual stress is also achievable, as reported by Ohta et al. (Ref. 9), where a 10Cr-10Ni LTTW consumable was used for welding in a 20-mm-thick 1024 steel plate.

There have been rising interests in the development of LTTW filler alloys for various applications in the past two decades (Refs. 9–16). In these reported studies, the LTTW consumables contained up to 15 wt-% Ni and 15 wt-% Cr, leading to a martensite starting temperature, M_s , at 200°C or below (Ref. 17). There were also other reported benefits associated with LTTW wires, including improved fatigue strength (Refs. 18, 19), reduced distortion (Ref. 20), and enhanced fracture toughness (Ref. 21) in steel weldments.

<https://doi.org/10.29391/2020.99.012>

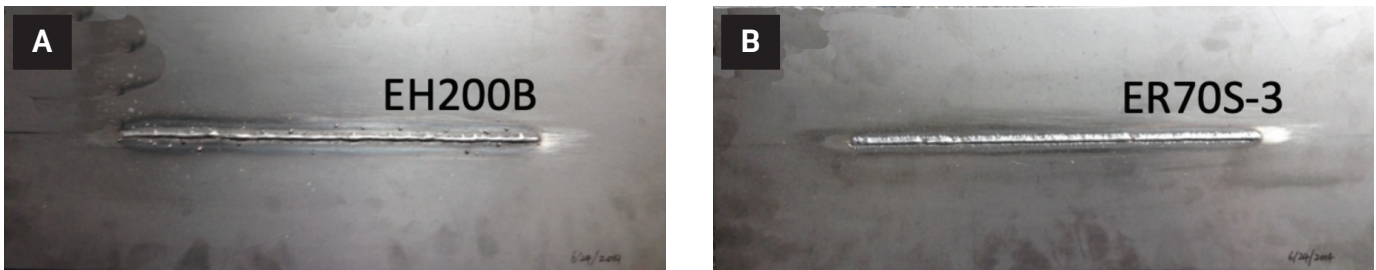


Fig. 1 — Welded plates with a BOP weld with a length of 254 mm using (A) EH200B and (B) ER70S-3 wires.

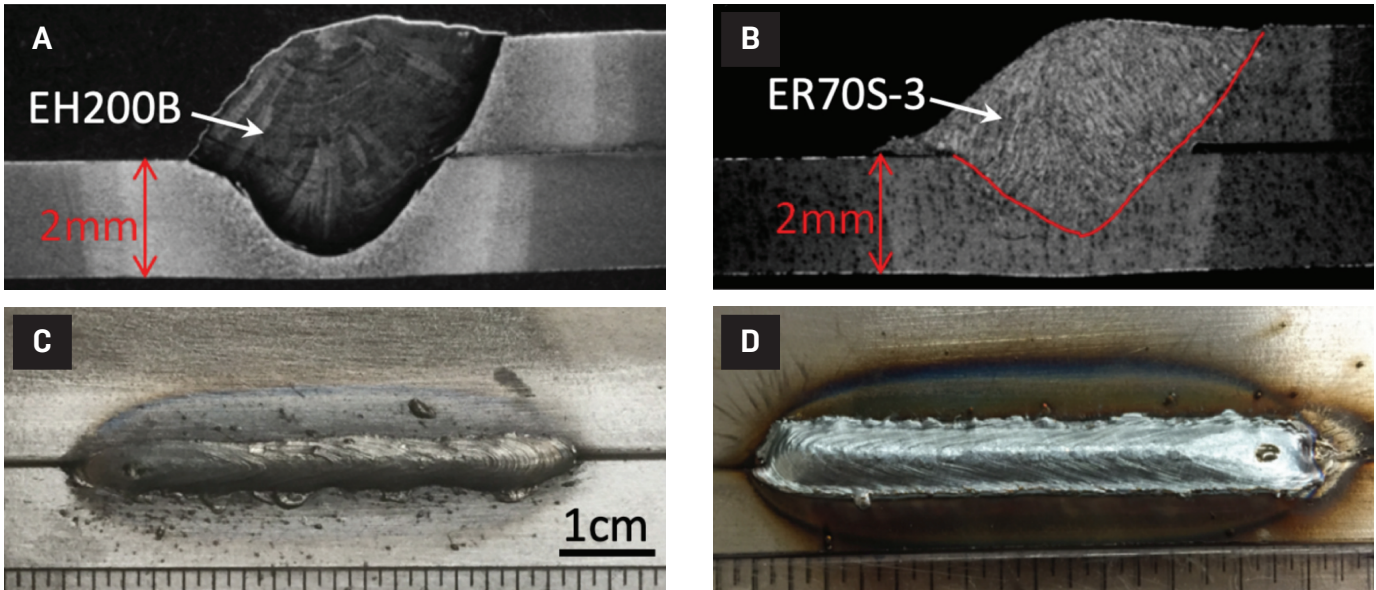


Fig. 2 — Optimized lap joint bead morphologies: A, B — Cross-sectional view of the lap joints using EH200B and ER70S-3 wires, respectively; C, D — top view of the lap joints using EH200B and ER70S-3 wires, respectively.

Presently, there is very limited research on LTTW consumables for welding of AHSS thin plates. Therefore, in this work, a new LTTW consumable was developed for welding thin sheets of AHSS DP980. Conventional ER70S-3 wire was also used to generate welds for comparison. The weldment microstructure was systematically examined using optical and electron microscopies, hardness mapping, and x-ray diffraction (XRD) methods. The residual stress profile was evaluated by neutron diffraction measurement and finite element modeling (FEM). The model coupled the thermal, mechanical, and metallurgical effects to provide the complete residual stress profile in the welded plates. A fatigue test was also performed in both weldments to compare their fatigue life.

Experimental Details

LTTW Consumables

In this study, a metal-cored LTTW consumable, namely EH200B, was fabricated based on an earlier design by earlier researchers of the Center for Welding, Joining and Coatings Research at Colorado School of Mines (Refs. 16, 22). The Eichelman and Hull equation (Ref. 23), as expressed below, was relied on to get the desired M_s temperature of 200°C:

$$M_s (^{\circ}\text{C}) = 1305 - 41.7\text{Cr} - 61.1\text{Ni} - 33.3\text{Mn} - 27.8\text{Si} - 1667(\text{C}+\text{N}) \quad (1)$$

where M_s is the martensite start temperature, and elemental weight percent is used in this calculation.

Table 1 tabulates the compositions and estimated M_s temperature of EH200B and commercial ER70S-3 wires that are commonly used for welding DP980 steel. The chromium and nickel equivalent (Cr_{eq} and Ni_{eq}) were calculated using the expressions below (in weight percent) (Ref. 24):

$$\text{Cr}_{eq} = \text{Cr} + \text{Mo} + 1.5\text{Si} + 0.5\text{Nb} \quad (2)$$

$$\text{Ni}_{eq} = \text{Ni} + 0.5\text{Mn} + 30\text{C} \quad (3)$$

Welding Procedure

GMAW was used to make weldments with both wires. The wire diameter was 0.045 in. for both the solid ER70S-3 wire and the metal-cored EH200B wire. Two types of weldments were produced in this study, including bead-on-plate (BOP) welds for residual stress evaluation and lap joints for fatigue testing. The neutron diffraction method was used to

Table 1 — Comparison of Wire Composition (wt-%) and Calculated M_s (°C) Based on Eichelman and Hull Equation

Wire	C	Mn	Cr	Ni	Si	Mo	Ti	Cr _{eq}	Ni _{eq}	M_s (°C)
EH200B	0.1	2.0	9.0	8.0	0.1	0.25	0.01	9.4	12.0	200
ER70S-3	0.09	1.02	0.05	0.03	0.41	< 0.01	< 0.01	0.7	3.2	1106

Table 2 — Optimized Welding Parameters for Bead-on-Plate Welds Using EH200B and ER70S-3 Wires*

Wire	WFS (in./min)	Travel Speed (in./min)	Voltage (V)	Current (A)	Heat input (J/mm)
EH200B	260	34.8	25	184.8	313
ER70S-3	260	34.8	25	207	351

*WFS (in./min) denotes wire feed speed in in. per min.

Table 3 — Optimized Welding Parameters for Lap Joints Using EH200B and ER70S-3 Wires

Wire	WFS (in./min)	Voltage (V)	Current (A)	Travel Speed (in./min)	Work Angle (deg)	Travel Angle (deg)	Heat Input (J/mm)
EH200B	220	21.4	173	27	33	17	226.7
ER70S-3	180	17.5	168	32	31	13	151.9

measure and compare the residual stress distributions in BOP welds using LTTW and ER70S-3 wires, respectively. Note that the base material was A36 steel in BOP weldments to avoid complications associated with phase transformations in the DP980 base metal. A36 steel sheets with a dimension of $508 \times 203 \times 2$ mm³ were used for BOP welds. For lap joints, 2-mm-thick DP980 steel sheets were used, which is the typical thickness for automotive applications. The DP980 sheets were 150 mm wide and 125 mm long.

Welding parameters for each wire were optimized based on visual inspection of bead morphology. The final set of welding parameters are tabulated in Tables 2 and 3, respectively. Figures 1 and 2 demonstrate the optimized BOP welds and cross sections of lap joints. Both the BOP welds and lap joints used 85%Ar-15%CO₂ shielding gas. For all BOP welding, the welding torch had a 15-deg travel angle, and the weld length was 254 mm. Lap joints 50 mm long were made in the middle of the 150-mm-long edge using both wires. The welding torch had a 15- to 17-deg travel angle and a 33-deg work angle.

Distortion Measurement, Residual Stress Measurement, and Hardness Testing

Distortion profiles of the welded plates were measured by a dial gauge. The plates were marked with 10×10 mm square grids and fixed to a flat surface using wax. The distortion was measured with a dial gauge at every grid location. The resolution of distortion measurement was approximately 0.013 mm (0.0005 in.).

Neutron diffraction measurements were conducted at the 2nd generation Neutron Residual Stress facility beam line of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) (Ref. 5). Neutron diffraction mapping

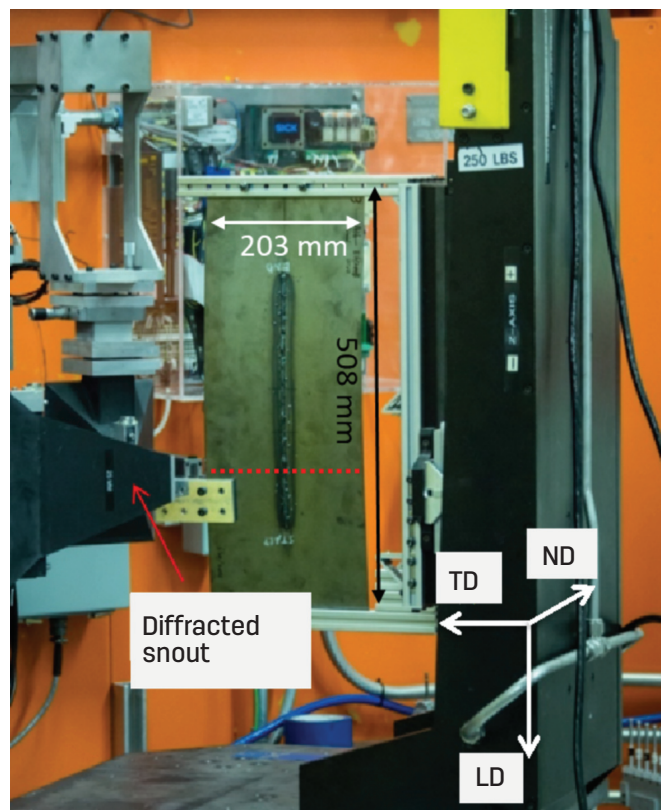


Fig. 3 — A neutron diffraction experiment setup at the HB-2B beam line of HFIR, ORNL. LD, TD, and ND denote longitudinal, transverse, and normal directions.

was performed along the transverse and longitudinal directions (TD and LD) to map the distribution lattice spacing,

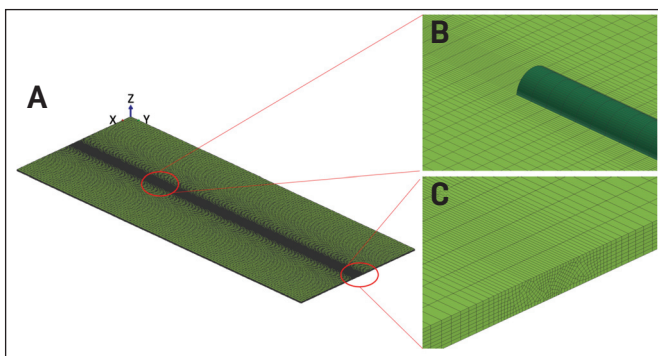


Fig. 4 — A — The meshed model for the BOP weld; B, C — enlarged views showing the local meshes.

d_{211} , in the welded plates. In the case of such a thin plate, the normal direction (ND) stress was assumed to be zero, and a plane stress assumption was utilized. The weld reference samples for $d_{0,211}$ mapping were extracted from the welded plates using electric discharge machining to allow for mechanical relief of the residual stress while maintaining the chemical gradients across the HAZ and weld zone. The d_0 samples were 2 mm thick along the LD, 12 mm long starting from the weld center toward the base metal along the TD; these plates had the same thickness as the welded plate. The stresses were calculated with 1) plane stress assumption, 2) elastic modulus $E_{211} = 220$ GPa, and 3) Poisson's ratio $\nu_{211} = 0.28$ (Ref. 26). The neutron experimental setup is shown in Fig. 3 with the red dotted line across the weld representing the strain mapping locations. The beam slit size was about 0.5 (ND) $\times$ 0.5 (TD) $\times$ 10 mm (LD) for TD strain measurements and 0.5 (ND) $\times$ 0.5 (TD) $\times$ 0.5 mm (LD) for LD strain mapping. A relatively large vertical slit size was selected to reduce the measurement time at each mapping location in the TD measurements. All the mapping locations were located along the center thickness of the plate. The measurement time at each location was about 8 to 12 min for TD and up to 20 min for LD due to the decreased gauge volume.

Metallographic Characterization

Microstructural characterizations were performed using light optical microscopy (LOM), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), XRD, and electron backscattered diffraction (EBSD).

Samples for LOM analysis were cut at the weld-cross sections from the steady-state region of the welds. The samples were ground with 240-, 320-, 400-, 600-, 800-, and 1200-grit SiC abrasive papers, and then polished with 6, 3, and $1\text{ }\mu\text{m}$ diamond suspensions. ER70S-3 and LTTW welds were etched by freshly prepared 2% nital and Kalling's No. 1 etchant, respectively. For SEM and EDS characterization, both the FEI Quanta 600i Environmental SEM and the JEOL JSM-7000F Field Emission SEM with Genesis EDS were used. To prepare samples for the SEM work, the same procedure as for LOM samples was used but with an extra 30-min vibratory polishing using $0.02\text{ }\mu\text{m}$ noncrystallizing colloidal silica suspension. The samples were rinsed immediately after the final polishing with 2% micro organic soap (Allied 148-10000) to remove the remaining silica colloidal

on the sample surface. EBSD samples were prepared the same way as the SEM samples. Images with a $50 \times 50\text{ }\mu\text{m}$ area size under $2000\times$ magnification were taken at the top, middle, and bottom of the weld transverse cross section, respectively, with a step size of $0.13\text{ }\mu\text{m}$. The accelerated voltage was set to be 20 kV with a 12-pA probe current and a work distance of 18 mm. The XRD sample was extracted by grinding off the reinforcement of the weld to maximize the area of examination, which was 15 mm (LD) $\times$ 5 mm (TD). Cu target was used with 45 kV and 40 mA; each test measurement lasted for 25 min. The samples were first ground, polished, and cleaned in the freshly prepared solution (two parts hydrogen fluoride, 20 parts H_2O_2 , 20 parts deionized water in volume ratio) for 15 min to remove the surface layer of scale and martensite phase that could potentially be induced by the mechanical force during the sample preparation process. X-ray diffraction results were analyzed based on the peak intensity of austenite (γ) and martensite (α/α') phases. The volume fraction of the γ phase is calculated by averaging the ASTM standard (Ref. 27) as well as the literature by Deshayes (Ref. 28) and Cullity (Ref. 29), in which the volume fraction of γ phase, V_γ , can be calculated from the peak intensity, I , and the θ -angle dependent function, R . Detailed expressions for these standards can be found in Refs. 27–29. Vickers hardness mapping was also performed on the welds. The testing loads were 500 g with a dwell time of 10 s.

Simulation Model

The finite element (FE) code SYSWELD was used to calculate the complete residual stress profiles of the BOP welds using the two different consumables to quantify the effect of Ms and thus potentially optimize the residual stress control in the future through fine tuning of LTTW composition. The simulation constitutes two runs: a heat transfer analysis and a subsequent stress analysis. In the heat transfer model, the heat source parameters were adjusted based upon the experimentally observed weld fusion zone geometry. The residual stress calculation couples the thermal-mechanical-metallurgical effect involved in the welding process. In other words, the residual stress was determined by the temperature output and the physical properties of the phases, among which the most important factor was the martensitic transformation temperature. Detailed information about the model is given below. The calculated distortion and residual stresses were compared to the experimental results for validation purpose.

Meshed Model

The meshed model for the BOP weld was built based on the actual dimensions of the welded plates and the fusion zone morphology, as shown in Fig. 4. The vicinity of the weld joint contains fine meshes to capture the thermomechanical behavior within and across different zones of interest under large temperature gradients and fluctuations imposed by the weld heat source. Coarser meshes were applied in the region away from the heat source boundary to reduce computation time without sacrificing accuracy. The models contained around 310,000 eight-node brick elements.

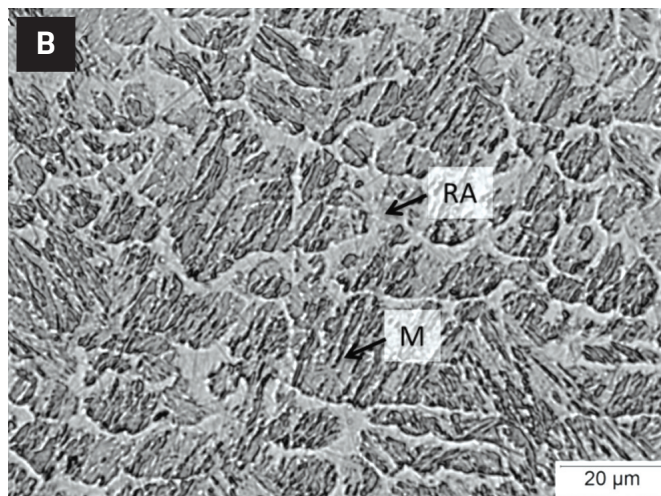
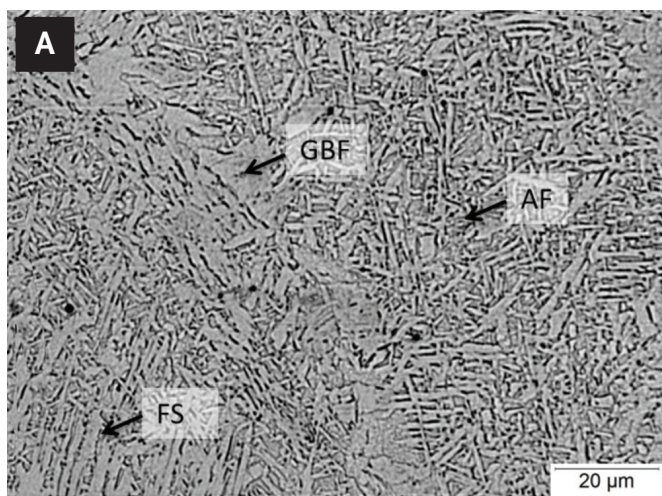


Fig. 5 — Weld microstructure by LOM using (A) ER70S-3 and (B) EH200B wires. 2% nital and Kalling's No. 1 etchant was used.

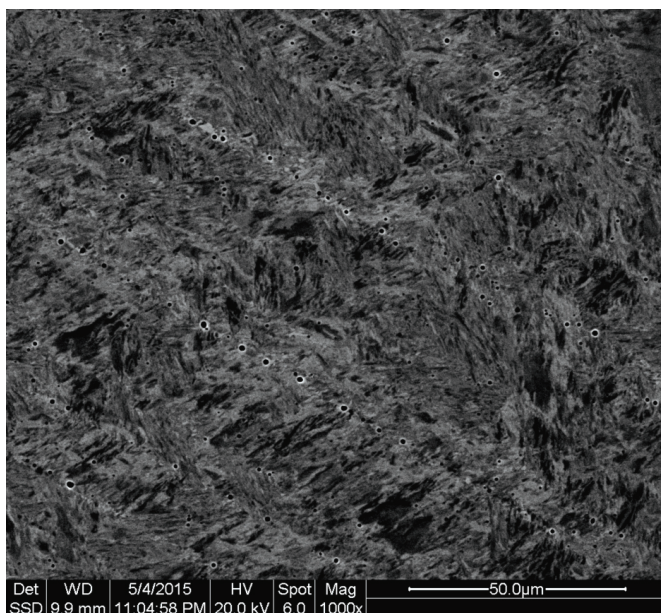


Fig. 6 — A backscattered electron image of the EH200B weld sample unetched.

was used in the Goldak heat source model. The total heat input energy was set based on the heat input value in Table 2. Surface convective and radiative loss was taken into consideration. The four corners of the plate were fixed as a mechanical boundary condition to represent the clamping condition in welding experiments.

Results and Discussions

Microstructure in the BOP Welds

As shown in Fig. 5A, grain boundary ferrite, ferrite with second phase, and acicular ferrite were present in the microstructure at the top weld region using ER70S-3 wire. For the weld produced using the EH200B wire, in Fig. 5B, the microstructure at the top region of the weld constitutes a large fraction of martensite (M) and retained austenite (RA). The presence of martensite in the EH200B weld was also demonstrated by backscattered electron image, as shown in Fig. 6.

XRD and EBSD methods were used to quantify the fraction of martensite and RA phases. EBSD scanning results are shown in Fig. 7, in which the red color represents the martensite phase and the green color represents the retained austenite phase. The fraction of RA varied from 13% at the weld top, 9% in the middle, to 7% at the bottom; the remaining larger fraction in red was the martensite phase. The variation in the volume fraction of RA could be attributed to the differences in cooling rate from the weld top to the weld bottom. The bottom of the weld had a higher cooling rate than the weld top due to the surrounding base metal. Thus, the alloying elements had less time to segregate to the solidification cell boundaries, leading to less austenite to be stabilized and retained. The effect of elements segregation on the austenite stabilization can also be explained through the Schaeffler Diagram (Ref. 24). Moreover, the spacing between the retained austenite grains is around 20 μm , which is close to the solidification cell width. Therefore, it is reasonable to conclude that RA followed the solidification boundary, to which all elements except iron segregated. Figure 8 shows the XRD pattern of the EH200B weld, demonstrating a much higher peak intensity from the

Material Database and Heat Source

The temperature-dependent material properties for both the base and filler materials, including Young's modulus, specific heat, thermal conductivity, yield strength, density, and Poisson's ratio, were taken from Ref. 30. The M_s value used in SYSWELD was estimated using the Eichelman and Hull equation, as shown in Table 1. The density value for EH200B was chosen as 7850 and 7290 kg/m^3 at 20° and 1400°C, respectively. The Poisson's ratio was set as 0.29 for the weld metal and 0.26 for the base metal. The latent heat of fusion was not considered in the simulations.

Goldak's three-dimensional double-ellipsoid model (Ref. 31) was used to input the volume heat source into the material. The dimensions of the double ellipsoid were adjusted to match the molten zone geometry from the experimental characterization. Gaussian distribution of the heat input

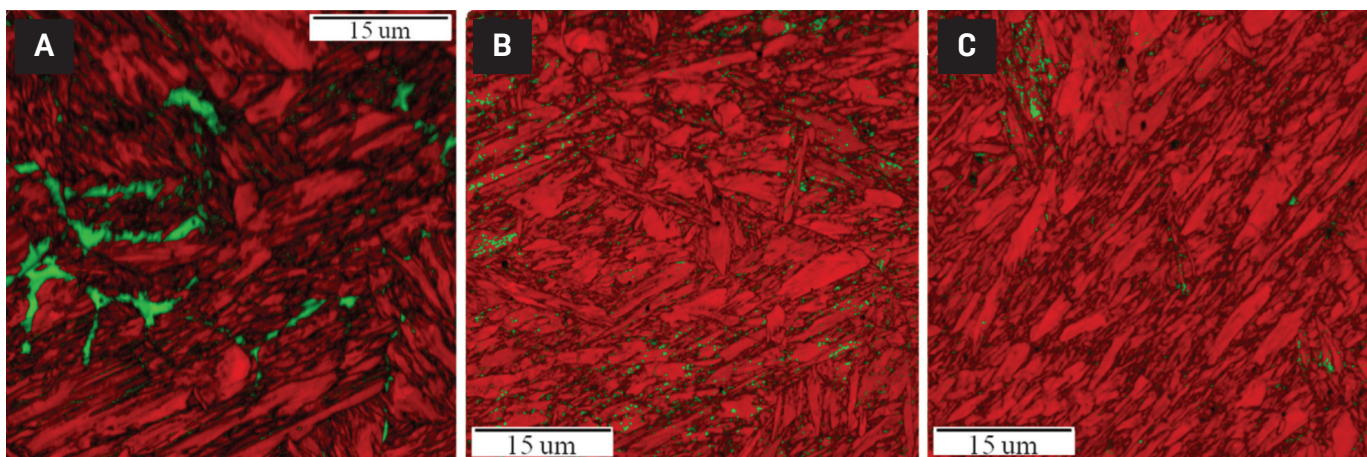


Fig. 7 — EBSD results from the (A) top, (B) middle, (C) bottom locations of the EH200B weld transverse cross section. The red and green colors represent the martensite and austenite phases.

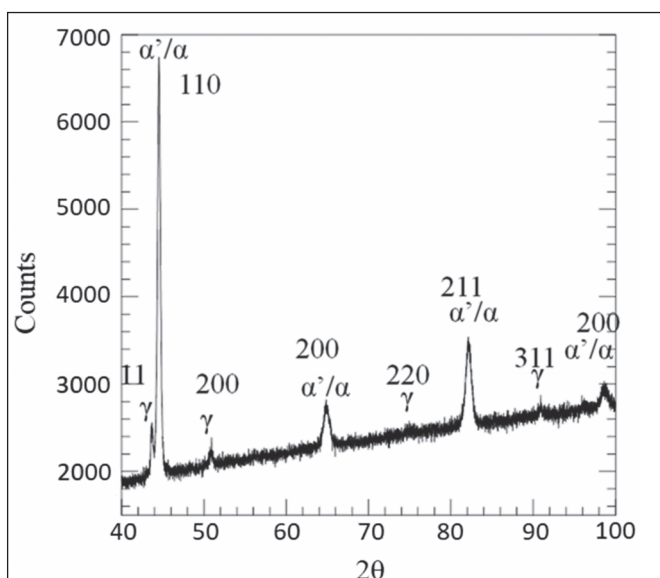


Fig. 8 — XRD data for the weld using EH200B wire.

Table 4 — Summary of Martensite Volume Fraction of EH200B Weld Using Both XRD and EBSD Techniques

Technique	Austenite Fraction	Martensite Fraction
XRD	10.5%	89.5%
EBSD	9.6%	90.3%

martensite phase than that from RA. By averaging the calculated results from Cullity and Deshayes, as well as the ASTM standard, the austenite fraction in the EH200B weld was estimated to be about 10.5%. The martensite volume fractions of EH200B weld predicted by both XRD and EBSD techniques are summarized in Table 4. It was reported that an appreciable amount of retained austenite could help prevent cold cracking (Ref. 32), and the amount of retained austenite can be controlled by adjusting the martensite starting temperature, M_s , and finishing temperature, M_f .

Distortion in the BOP-Welded Plates

The surface contours and profiles of the BOP weld sheets obtained from experimental measurement and FE analysis using EH200B and ER70S-3 wires are summarized in Fig. 9. Comparing Fig. 9A to C, it is obvious the two plates exhibited opposite distortion patterns. Along the LD, the welded plate using ER70S-3 wire had a concave shape while the welded plate using EH200B wire had a convex shape, which is an indication that the stress distributions in the two plates were possibly opposite. Similarly, opposite distortion patterns were observed along the TD, i.e., convex in ER70S-3 and concave in EH200B. The simulation results showed reasonable agreement with the experimental measurements. From the distortion profiles shown in Fig. 9E and F, the opposite distortion patterns could also be clearly observed along the LD and TD.

Residual Stresses in the BOP-Welded Plates

Based on the line mapping of d and d_0 spacing along the red dotted line in Fig. 3 along the TD and LD, residual strains ϵ were calculated by $(d - d_0)/d_0$, and the results are shown in Fig. 10. The bead width is close to 4 mm for both welds. As shown in Fig. 10A, EH200B led to a much lower LD strain in the weld region and the HAZ immediately adjacent to the weld than ER70S-3, which is expected for LTTW wire (Refs. 33–35). In comparison, a relatively high strain along the TD was observed in the EH200B weld as shown in Fig. 10B.

Figure 11 demonstrates the calculated LD residual stresses using Hooke's Law with plane stress assumption in the EH200B and ER70S-3 welds. Note that the stress curves were force balanced since a plane stress assumption within a very thin plate (i.e., 2 mm thick) indicates no significant change of stress along the thickness direction in the overall large welding plate of 508 mm long and 203 mm wide, although within the small weld bead and HAZ region (about 3–4 mm wide) stress variation along the thickness is expected. This assumption is supported by the simulation results. After stress balance within the whole plate, the maximum stress was reduced by 10% in the ER70S-3 weld and 15% in

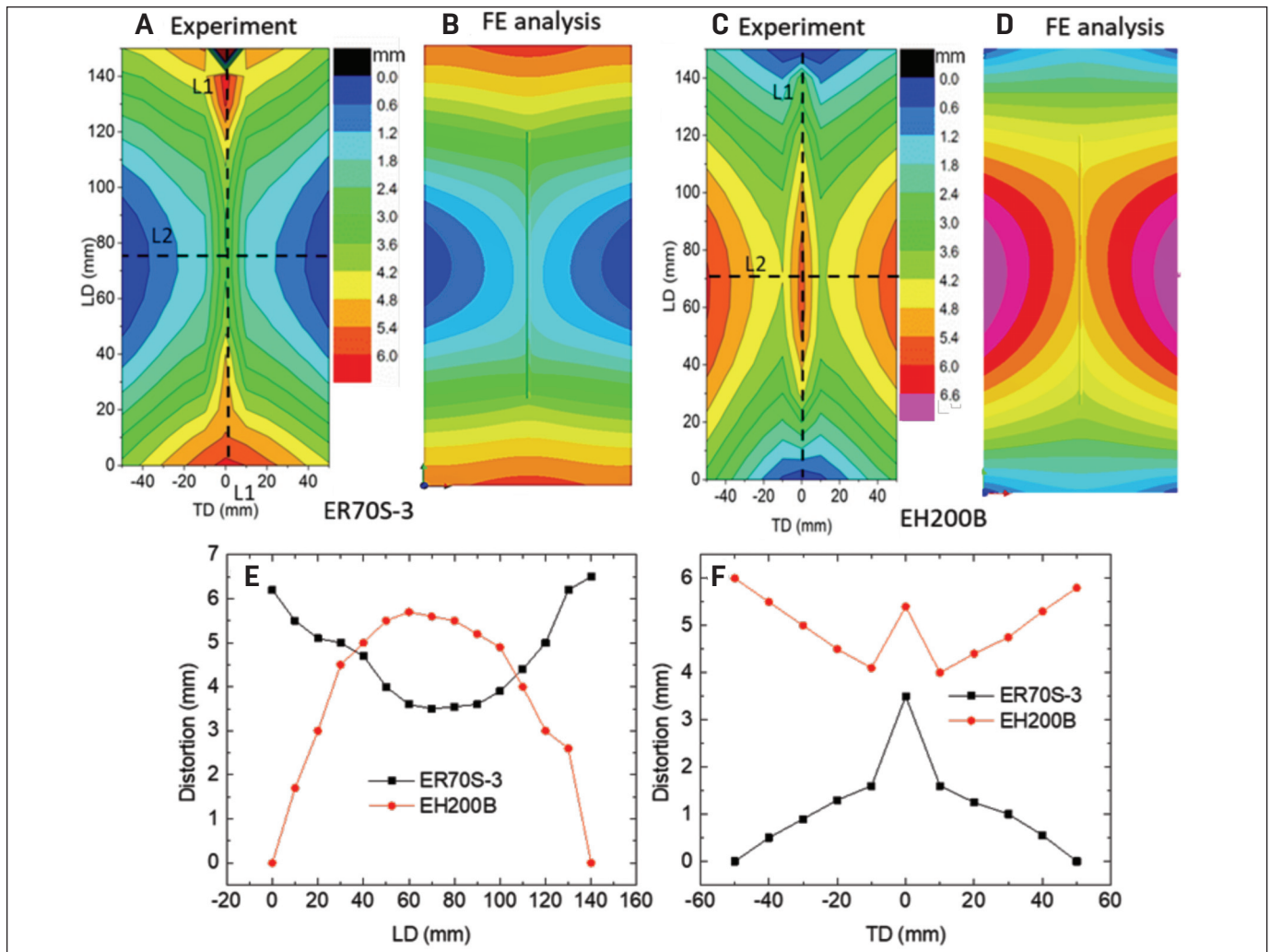


Fig. 9 — A–D — Comparison of distortion contour maps obtained from experimental measurement and FE analysis in BOP welds using ER70S-3 and EH200B; E, F — the corresponding distortion profiles from experimental measurement along the LD path L1 and TD path L2 for ER70S-3 and EH200B. Paths L1 and L2 are shown as dotted lines in A and C.

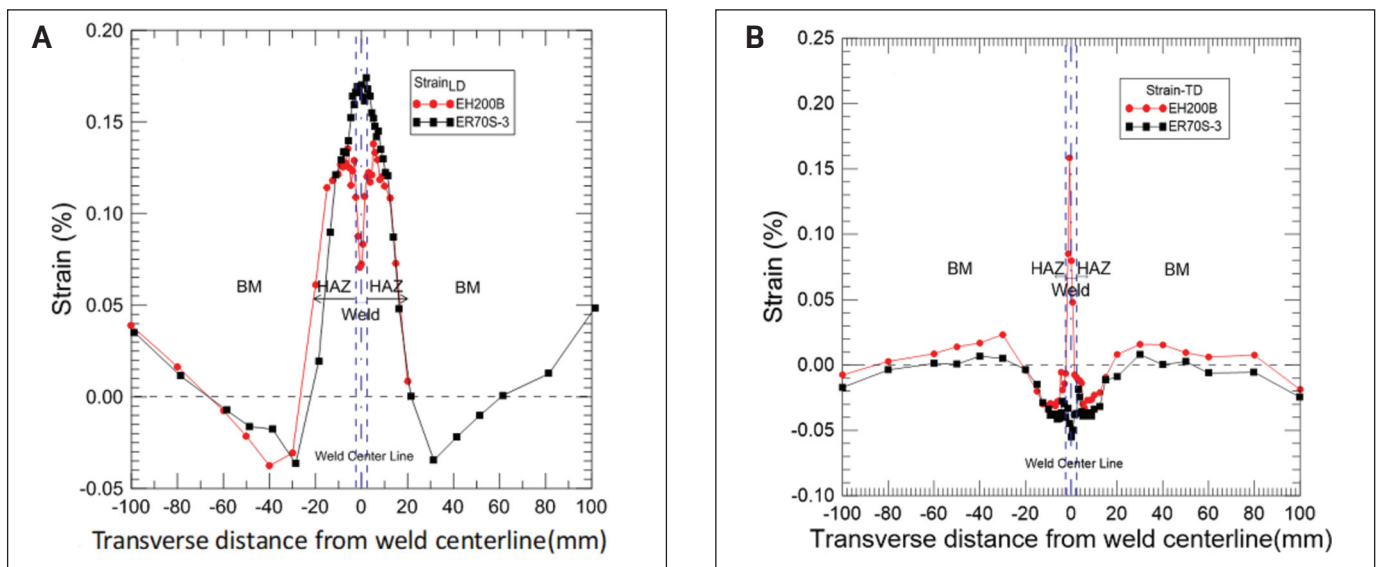


Fig. 10 — Strain distributions in (A) longitudinal and (B) transverse directions (LD and TD) in the welds using EH200B and ER70S-3.

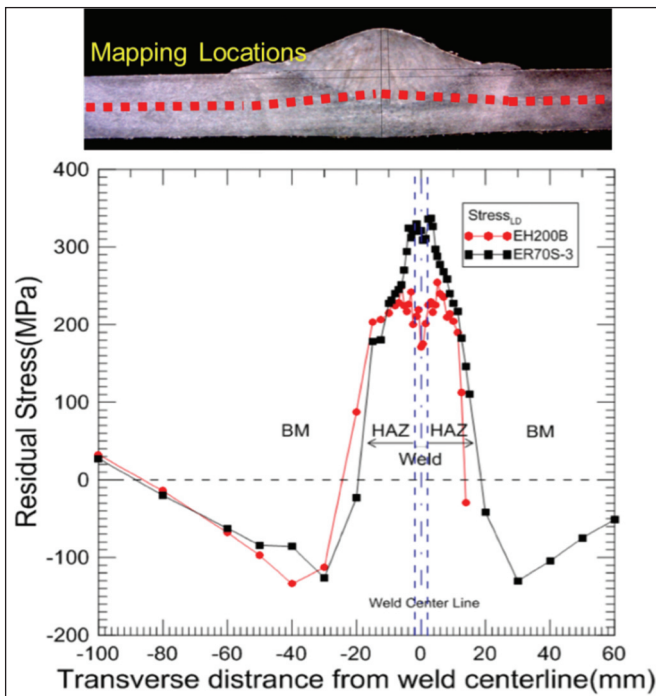


Fig. 11 — LD residual stress measured by the neutron diffraction method with the mapping locations marked in the photograph above.

the EH200B weld. A potential cause of the data difference could be that the stresses in the reference samples were not completely relieved. Furthermore, the samples were allowed to deform after welding, meaning that some of the residual stress generated through welding, which would be maintained in a constrained sample, is relieved due to the deformation of the thin walled plates. The EH200B wire demonstrated to be effective in controlling residual stress in the HAZ but not the expected compressive residual stresses based on the opposite distortion pattern between the EH200B and ER70S-3 welds (Refs. 33–35). It is worth noticing that the large slit size used for the neutron diffraction measurement yields volume-averaged residual stress data, and due to the thin nature of the plates, a map through thickness is not feasible.

Finite element analysis provided a complete residual stress distribution, which is used to explain the stress profile obtained by the neutron diffraction experiment. Figure 12 gives the overall LD residual stress distributions predicted by SYSWELD for both LTTW and conventional wires. It was observed that, while the conventional wire induced large tensile stress in the weld zone, the LTTW wire would induce compressive residual stress in the weld. Despite the material database used for EH200B from literature (Ref. 30) possibly leading to some deviations from the experimental measurement results, it should not cause the large deviation as observed between Figs. 11 and 12. The main reason for the observed discrepancy can be attributed to the relatively large sampling area, i.e., 0.7×0.7 mm, in comparison to the 2-mm plate thickness and 4-mm bead width, as indicated in Fig. 13B, C. Therefore, the stress profile in Fig. 13A that averaged the values of the sampling area matches the neutron diffraction results reasonably well, which covers both tensile

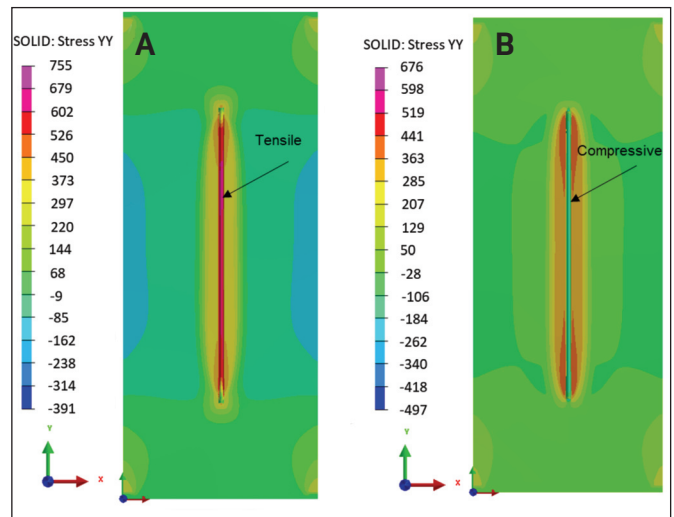


Fig. 12 — Overall residual stress contour distributions along LD for BOP welded by (A) ER70S-3 and (B) EH200B.

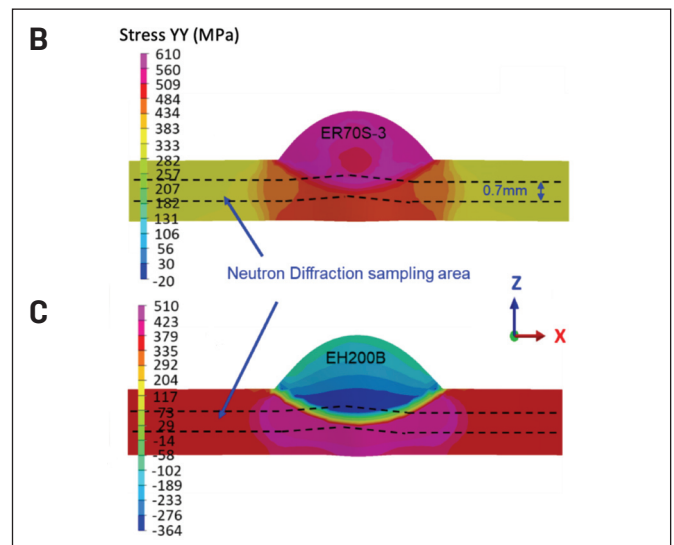
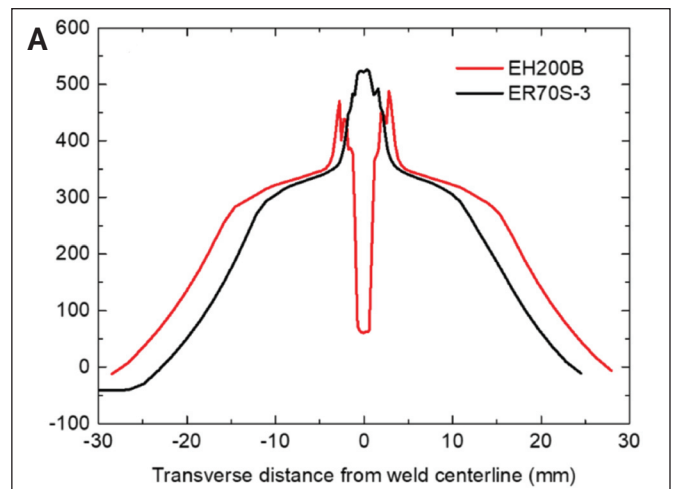


Fig. 13 — A — LD residual stress profiles averaged in the sampling areas marked in (B) and (C) cross-sectional stress contour predicted by FE analysis in ER70S-3 and EH200B welds.

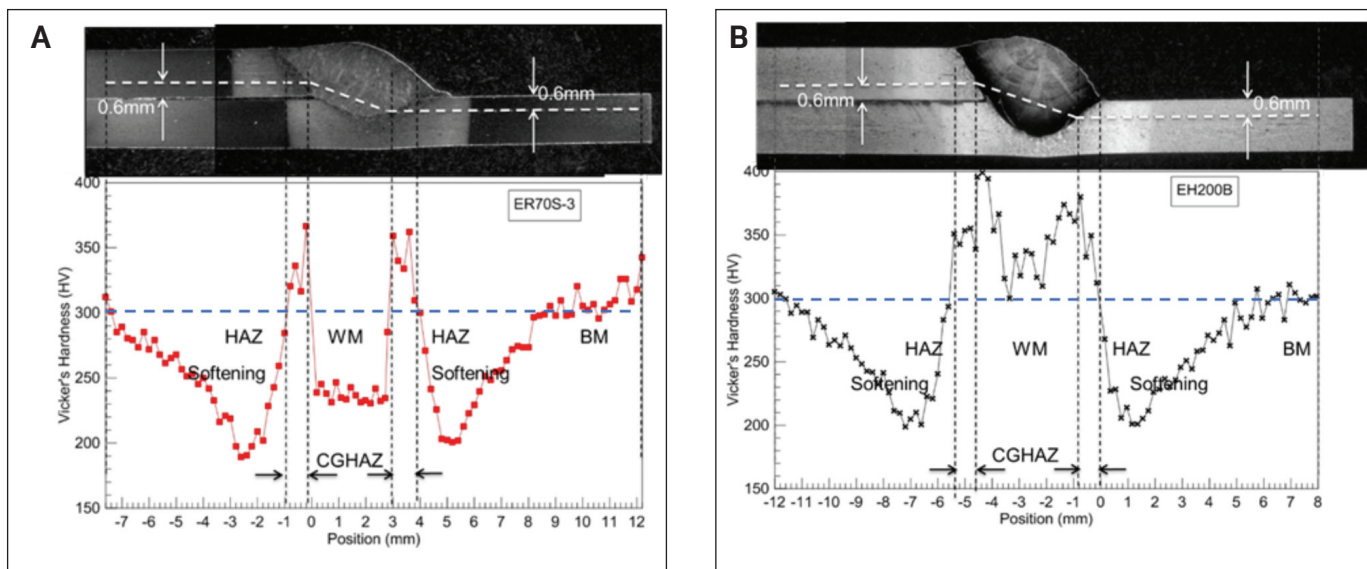


Fig. 14 — Optical macrographs of the weld transverse cross sections using (A) ER70S-3 and (B) EH200B wires, respectively, and their Vickers hardness line mapping results.

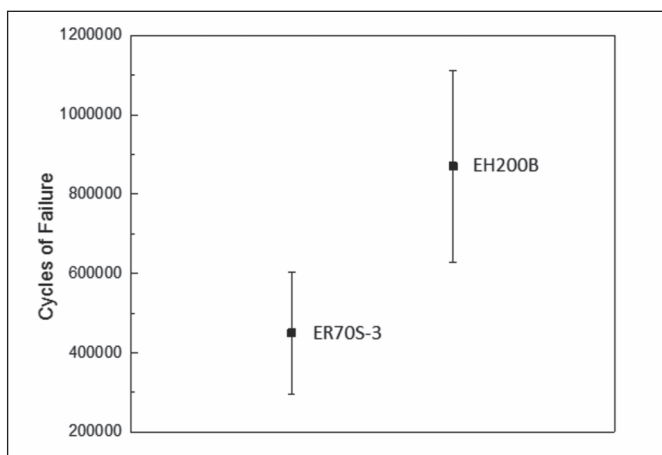


Fig. 15 — Fatigue life comparison of the welds made by ER70S-3 and EH200B.

and compressive stress regions. Moreover, the opposite stress profiles in Fig. 12 are in agreement with the opposite distortion patterns in Fig. 9 between the two welds. For better distortion control in the future, the LTTW wire composition (i.e., Ms) may need to be further optimized to lower the martensite fraction and thus reduce the tensile residual stress to near zero instead of compressive.

Microhardness and Fatigue Life of Lap Joints

Vickers hardness line mapping results across the DP980 lap joints made with both wires are summarized in Fig. 14. The DP980 steel base metal shows an average hardness of 300 HV. The HAZ softening was observed in both welds since the materials in the HAZ experienced similar thermal profiles. A dashed horizontal line at 300 HV was drawn in Fig. 14 to demonstrate the undermatching and overmatching phenomenon in the weld metals generated from ER70S-3

and EH200B wires, respectively. EH200B wire was overmatching due to the presence of more than 87% of the martensite phase, while the ER70S-3 wire was undermatching because of the prevalent ferrite phase. For the EH200B weld, the hardness varied between 300 to 400 HV. In comparison, the hardness for the ER70S-3 weld was as low as 230 to 250 HV. The coarse grain HAZ with a coarse martensite microstructure was present right next to the ER70S-3 weld interface, leading to an increase in hardness up to ~370 HV.

A fatigue test was also conducted on lap joints produced by these two wires with a maximum load level of 9.5 kN (i.e., a maximum stress level of 95 MPa), a stress ratio of a minimum to maximum of 0.1 at a frequency of 10 Hz. Three lap joint welds of each wire were tested. The average fatigue life of lap joint panels using the EH200B wire was about 8.7×10^5 cycles in comparison to the 4.5×10^5 cycles using the ER70S-3 wire, as shown in Fig. 15. Therefore, EH200B nearly doubled the fatigue life of the DP980 thin sheet lap joints, which is most likely caused by a combination of increased strength in the fusion zone and lower residual stress in the HAZ.

Conclusion

1) The newly developed LTTW consumable, EH200B wire, effectively lowered the LD residual stresses in the fusion zone and HAZ in comparison to the conventional ER70S-3 wire in the BOP welds of thin steel sheets.

2) Microstructural characterization of the weld metal showed that more than 87% of martensite was generated in the weld using EH200B wire.

3) A FE numerical model was developed to simulate the stress and distortion initiated for the weld under two different types of wires. The simulation results obtained similar distortion patterns for the two wires. Meanwhile, the stress distribution profile in the neutron diffraction test was explained, and a compressive residual stress in the weld for LTTW was predicted.

4) With a high fraction of martensite (~90%), the EH200B wire generated an opposite distortion pattern in the BOP weld to ER70S-3 wire. For a better distortion control, the LTTW wire composition may need to be further optimized to lower the martensite fraction and reduce the tensile residual stress to near zero instead of compressive.

5) Fatigue life of DP980 lap joint panels using the EH200B wire nearly doubled that of the ER70S-3 wire because of the high strength of the weld and lower LD residual stress in the HAZ and weld regions.

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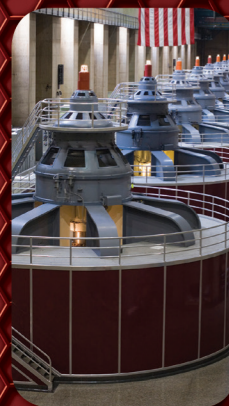
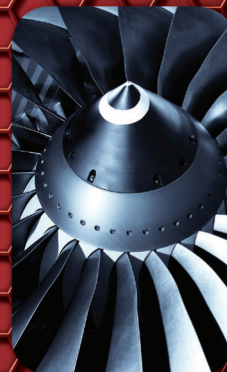
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