

WELDING *Journal*

JULY 2020



Inspection
Pathways
Cutting Tools

PUBLISHED BY THE AMERICAN WELDING SOCIETY TO ADVANCE THE SCIENCE, TECHNOLOGY, AND APPLICATION OF WELDING AND ALLIED JOINING AND CUTTING PROCESSES WORLDWIDE, INCLUDING BRAZING, SOLDERING, AND THERMAL SPRAYING

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GRANT HELPS SCHOOLS TRAIN MORE WELDERS

The AWS Foundation is pleased to announce the winners of the Spring 2020 Welding Workforce Grant. The following educational institutions have received grant funding of up to \$25k each to enhance and improve their welding programs.

- ◆ Airport Community Schools – Carlton, MI
- ◆ Chippewa Falls High School – Chippewa Falls, WI
- ◆ Paso Robles High School – Paso Robles, CA
- ◆ Somerset Community College – Somerset, KY
- ◆ Ida High School – Ida, MI - Detroit Section Grant

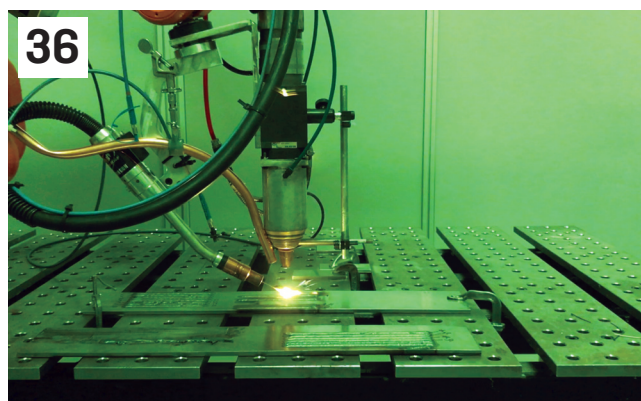
We thank these educational and training institutions for going the extra mile to help train the next generation of welders!

Since 2017, more than \$850,000 in Welding Workforce Grants have been awarded.

Learn more at www.aws.org/workforcegrant.

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At the American Welding Society (AWS), we are actively following the Novel Coronavirus (COVID-19) outbreak. The welding and fabrication industries have been determined to be an essential business, especially as it relates to repair and maintenance of key infrastructure. The content of the July 2020 issue of the Welding Journal is intended to be accurate when published, but we recognize that we are in a rapidly changing situation. For AWS's official statement on COVID-19, as well as the latest updates and frequently asked questions, please visit aws.org.

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On the cover: Northern Tool + Equipment's Klutch plasma cutting device is used to shorten a barrel section and trim mild steel.

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Managing Editor, Digital and Design Carlos Guzman
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Subscriptions Representative Sonia Aleman
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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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NOMINATION DEADLINE FOR AWS FELLOW OF THE SOCIETY



American Welding Society®

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

IMPORTANT
Announcement!



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August 1, 2020
Submission Deadline

Even during a Global Pandemic, There's Still Light



Steve Fyffe
WEMCO Chair

“Once the virus is mitigated, welding and the trades should bounce back faster than other occupations. It would provide a signal to young people planning their careers this is an area that, over the years, has experienced a growing skills gap — but now is an opportunity.”

“I Want You” was the theme of the last Editorial I assembled for the September 2019 *Welding Journal*. My intention was to bring awareness to the popular “I Want You” adage, which dates back to the War of 1812, and became a recruiting tool with the Uncle Sam posters during World War II.

That Editorial also served to encourage volunteering, because “We Need You” to help keep moving forward.

In addition, I called for those of us in our welding and fabrication industry, who could do so, to act as mentors.

Last year, we were celebrating the American Welding Society’s (AWS’s) 100th anniversary since its founding in 1919 (aws.org/about/page/aws-100).

This year, however, the whole world has changed right before our eyes.

The COVID-19 pandemic is an example that disasters can happen rapidly, with little or no notice. This virus has impacted the global community over a matter of weeks. Our lives, industry, education systems, and many other factors have been disrupted.

As necessary containment protocols were enacted, governments worldwide mandated procedural guidelines. This measure included practicing social distancing; closing restaurants, hotels, and more, devastating many small and large businesses; stopping sporting and concert events; disrupting the education system; and onward. Working from home became a new way of operating, too, for those able to do so.

Governments also enacted mandatory orders for nonessential persons to stay in place. These actions were previously unimaginable to us prior to the virus outbreak.

States were just starting to reopen during the publication time of this magazine, bringing a little bit of a light to the surface.

AWS’s COVID-19 website is another bright spot. Important information, including educator resources and online education discounts, is at aws.org/COVID19.

Because the virus changed the way schools taught their classes, most were struggling to figure out how they could provide quality education materials. The welding training materials AWS offered enabled some students to be able to complete the semester remotely. In the future, online training will be even more essential for schools and corporations to embrace.

This website also has a document making a case that welding and cutting organizations are “essential businesses.”

AWS has always helped provide an amazing network where members can exchange ideas and get to know people in the industry. Now more than ever, whether you work for a small or large company, get involved and exchange experiences of what worked and what didn’t during this trying time. As an industry, that will lead us to be better prepared for the future.

All together, we really can glow and make a difference in this family of ours that is based on welding as well as allied joining and cutting process.

Once the virus is mitigated, welding and the trades should bounce back faster than other occupations. It would provide a signal to young people planning their careers this is an area that, over the years, has experienced a growing skills gap — but now is an opportunity.

Today, like previous historic times, the call to welding is still “We Need You.” Please don’t forget that statement. Our industry needs your help to support both welding and our communities as we work to turn a new page and leave COVID-19 in the history books. **WJ**

AWS Announces COVID-19 Standards Addenda and Subscribes Members to *Inspection Trends*

The American Welding Society (AWS), Miami, Fla., has issued a COVID-19 notice to users of AWS Standards who require periodic maintenance of personnel qualifications. AWS has also subscribed its members to *Inspection Trends*.

- To view the notice on the AWS COVID-19 website, aws.org/COVID19, locate the “Welder Qualification Continuity Requirements within AWS Standards” header. AWS has issued addenda to the Welder Qualification Continuity Requirements within AWS Standards.

The announcement may be viewed by clicking on “Learn More.” The addendum will allow an extension on the continuity of joining or allied process qualifications for those who have experienced an employment interruption due to the COVID-19 outbreak for an additional six months, under these conditions: the qualification was valid at the time of the employment interruption, and the qualification was scheduled to expire during the employment interruption.

This extension will expire September 30, 2020, and applies to a list of 34 standards that include the current editions of B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*; D1.1/D1.1M, *Structural Welding Code — Steel*; and D17.1/D17.1M, *Specification for Fusion Welding for Aerospace Applications*.

Please note since AWS cannot issue addenda to previous editions of codes and standards, the Society recommends owners and their engineers recognize the rationale for this action and agree to allow their fabricators this exception on existing projects.

- In addition, AWS members will automatically be subscribed to start receiving a digital copy of the Society’s welding inspection magazine, *Inspection Trends*.

This quarterly publication features articles on the latest trends in inspection techniques, as well as the newest technologies and products. Learn more at aws.org/publications/page/inspection-trends.

Honda Engineers Use Manufacturing Prowess to Produce 130,000 Face Shields

As part of its response to help protect frontline healthcare professionals during the COVID-19 pandemic, Honda engineers have developed new methods to use manufacturing equipment in the production of critically needed face shields. They have donated 70,000 face shields to healthcare workers at 305 medical facilities in 45 states to date with plans to donate another 60,000.

Engineers at Honda Engineering North America (EGA) in Marysville, Ohio, the in-house company that creates much of the automaker’s production equipment, made the face shields by designing new uses for high-speed injection-molding technology ordinarily used in the production of vehicle components. While EGA is manufacturing face shields, a multicompany effort in Canada is making the frames, shields, and headbands for additional units.

“We make a car about every 50 seconds, and that’s the same type of approach that we’re taking for these face shields. We’re using our mass production expertise and



Healthcare workers at Mary Rutan Hospital, Bellefontaine, Ohio, are among the recipients of the face shields. (Credit: Honda.)

equipment to produce a large quantity of shields to help people in our communities,” said Hugo Beltran, associate chief engineer at EGA.

Program Development at Penn College Receives National Science Foundation Grant



Pennsylvania College of Technology is developing two certificates and an associate degree centering on NDE.

Recently, the Pennsylvania College of Technology has received a three-year National Science Foundation (NSF) grant. The nearly \$600,000 grant — A Collaborative Approach to Expanding Nondestructive Testing Education Within a Welding Program — is funded by the NSF’s Advanced Technological Education program. This series is geared toward the education of technicians for advanced-technology fields that drive the nation’s economy, such as nondestructive examination (NDE).

Pennsylvania College of Technology is developing two certificates and an associate degree focusing on NDE. The certificate programs are scheduled to be offered in the 2021–22 academic year, followed a year later by the associate degree.

“There is both a high demand for nondestructive testing [examination] and a shortage of training programs,” said Bradley M. Webb, dean of industrial, computing, and engineering technologies. “We believe our initiatives will successfully address both of those issues.”

Those initiatives include two stand-alone certificates in NDE methods (radiography and ultrasound). Both of the short-term programs are being built to comply with American Society for Nondestructive Testing Level II certification.

The college is also developing an associate degree in NDE and welding. According to Webb, the degree will combine a year of welding instruction with a year focusing on NDE. **WJ**

California National Guard Welder Sews Face Masks, Newport News Shipbuilding Undergoes a Shift Schedule, and More COVID-19 News



U.S. Army Sgt. Edwin Rodriguez, a welder at the California National Guard's Combined Support Maintenance Shop, sewed face masks for soldiers on a vintage sewing machine in the Long Beach, Calif., facility. (Credit: Staff Sgt. Matthew Ramelb.)

As the COVID-19 pandemic continues to dominate headlines, here's a range of informative industrial stories.

- Sgt. Edwin Rodriguez, a full-time welder for the **California Army National Guard's** combined support maintenance shop (CSMS) in Long Beach, has been busy working with different tools — namely, a sewing machine, fabric, and thread.

He is sewing cloth masks that will help protect his fellow service members from COVID-19. The entire process takes him less than 3 min. "Sewing is the easy part," he said. "I'd say cutting and cleaning takes the most time."

Rodriguez, who also serves as a wheeled-vehicle mechanic, has sewn more than 90 masks for fellow soldiers since



Operated by an Airbus crew, an A400M airlifter performed an air-bridge between Toulouse, France, and Madrid, Spain, to deliver critically-needed face mask supplies for the Spanish health system. (@ Pablo Cabellos)



A Metal Supermarkets store in Indianapolis built these protective booths for doctors to safely stand while administering nasal swabs to test patients for COVID-19 at Hancock Regional Hospital in Indiana. (Credit: Metal Supermarkets.)

COVID-19 began to influence uniform standards. The Department of Defense and the California National Guard require service members to include face coverings as part of their personal protective equipment (PPE) when physical distancing cannot be achieved.

Chief Warrant Officer 2 Ben Johnson and Chief Warrant Officer 2 Mark T. Bun, California National Guard technicians who work with Rodriguez, approached the Compton, Calif., native with the idea of making masks. After guidelines required the use of face masks to help slow the spread of the virus, Bun, the CSMS foreman, began thinking of ways he and his soldiers could help those without access to PPE. He consulted with his mother, an avid sewer, to create a prototype based on the Centers for Disease Control and Prevention specifications, then showed the design to Rodriguez.

"I asked him if he could start sewing some stuff for us to protect the soldiers. That's the least we could do, make them feel safer here and give them peace of mind," Bun said.

Sewing machines aren't commonly thought of as maintenance shop equipment, but they are occasionally used to repair Humvee doors, Rodriguez mentioned. While he knew the CSMS had three 40-year-old sewing machines, he also knew some hadn't been used in years. After repairing two of the three machines, Rodriguez began sewing, using his civilian skills as a former upholstery technician. Johnson and Bun gathered fabric donations of T-shirts and trousers from the maneuver area training equipment shop (MATES) at Fort Irwin, as well as the 118th Maintenance Co. in Stockton.

While making the masks, Rodriguez noticed an issue

when sewing the fabric together, but he solved that by adding a layer of gauze within the fabric, he noted.

The masks were given to California Guard soldiers at the CSMS, MATES, and the 118th Maintenance Co. facility.

- An **Airbus A400M** airlifter has performed an air-bridge between Toulouse, France, and Madrid, Spain, to deliver critically-needed mask supplies to the Spanish health system. The aircraft recently took off from Airbus' headquarters in Toulouse, landing at the Getafe Air Base in Madrid, to off-load and deliver the masks to the Spanish Ministry of Defence. The cargo is part of the approximately 2-million masks transported by a test Airbus A330-800 aircraft from Tianjin, China, to Europe.

- In addition, while **Metal Supermarkets**, a national supply store of small-quantity metals with nearly 100 locations across the United States and Canada, has seen a reduction in sales like most businesses at this time, locations in North America have been open as essential businesses.

Stores have provided vital metal supplies to hospitals and manufacturers converting metal materials into respirators, masks, and other PPE. Many are providing around-the-clock service for users needing metal for jobs requiring frontline support to produce critical items to prevent the spread of the Coronavirus. As examples, aluminum plates were donated to make more than 150 acrylic safety masks for Providence Alaska Medical Center; steel tube was purchased by a customer in Virginia to make racks for a local hospital to sterilize personal protective equipment worn by its staff; and aluminum tread plate was bought by a Maryland cus-

tomor to repair out of service ambulances.

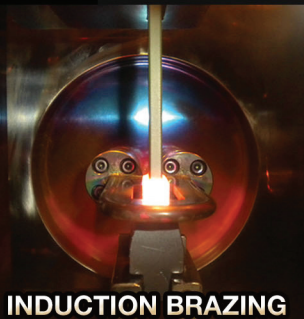
"As an essential business, Metal Supermarkets has remained open during the COVID-19 pandemic to support critical infrastructure and other essential businesses. Many of our stores have played a role in providing metal materials to both hospitals and manufacturers converting their operations to develop life-saving items, such as respirators, masks, and other personal protection equipment," said President and CEO Stephen Schober. "Our franchisees have quickly responded to the needs in their communities, and several stores across the U.S. are offering 24/7 service for customers requiring metal for frontline support and emergency services. Metal Supermarkets is proud to support our local communities in the fight against the spread of the Coronavirus."

- **Huntington Ingalls Industries**, Newport News, Va., recently announced its Newport News Shipbuilding division moved to a new work schedule beginning May 4.

"My commitment to remain open while offering liberal leave allows every employee to make the decision that least impacts them and their families," said Jennifer Boykin, president of Newport News Shipbuilding. "For those employees who are coming to work, we will transition from three to two, more balanced, eight-hour shifts to reduce close personal contact and keep employees and their families safe while ensuring continuity of critical operations."

The shifts are 6 a.m. to 2:30 p.m. and 6 p.m. to 2:30 a.m. They primarily involve production workers and other employees who directly support production and provide water-

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front support services. Because more than 70% of employees work on first shift, transitioning to two 8-h shifts balances the number of employees working at a time.

• The **U.S. Department of Labor's Occupational Safety and Health Administration**, Washington, D.C., has translated and published its "Ten Steps All Workplaces Can Take to Reduce Risk of Exposure to Coronavirus" poster in 11 additional languages. Previously only available in English and Spanish, the poster highlights 10 infection prevention measures every employer should implement to protect workers' safety and health during the Coronavirus pandemic. The poster is available for download in the following languages: Arabic, Brazilian Portuguese, Chinese Simplified and Traditional, French Creole, Hmong, Korean, Polish, Russian, Tagalog, and Vietnamese. Visit [osha.gov/pls/publications/publication.html](https://www.osha.gov/pls/publications/publication.html).

New 2-Week Online AWS CWI Training Available

Starting this month, the American Welding Society (AWS), Miami, Fla., will be offering a 2-Week Online Certified Welding Inspector (CWI) Seminar.

Much like the AWS 8-Week Online CWI Seminar, this course is designed to prepare students for all three parts of the CWI exam from the comfort of their own homes. Interactive, 4-h online sessions hosted by an AWS instructor will allow attendees to establish the knowledge base needed to

handle the CWI exam with confidence.

At aws.org, clicking on "online courses" then "2 week CWI seminar" provides more details, including the schedule (July 6–17, July 20–31, and August 24–September 4); member and nonmember prices; and how to register.

San Diego Student Sharla Knight Selected as Top Female Welder in Nationwide Search



Sharla Knight completes a welding project at San Diego Continuing Education.

Sharla Knight is one of 18 women selected as a top female welder during a nationwide search by the Ironworkers Union.

Qualified female welders from the United States and Canada are chosen once a year to complete a preapprenticeship at the Ironworkers Training Center in the Bay Area, an opportunity achieved while a student at San Diego Continuing Education (SDCE) in California. "I came to SDCE to pursue welding. I didn't expect success this quick at all," said Knight, 35. "There were plenty of deserving women in my class. I felt special that I was one of them."

Students at SDCE opt to specialize in one to five welding certificates. Free welding classes usually take place at SDCE's Educational Cultural Complex; however, the campus temporarily closed in March due to COVID-19. While learning remotely, student welders are studying blueprint reading, welding symbols, theory, and math.

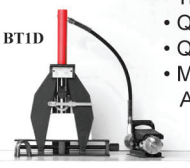
"It is a male dominated field, but to me, it's art. We aren't scared to get dirty and work hard," she said.

Before she started welding, Knight earned a kinesiology degree at San Diego State University in 2009, determined to become a high school teacher. "Back then, teachers were getting pink slips and I wondered if I wanted to keep doing this," she said. Then Knight apprenticed at her friend's metal fabrication shop for two years and fell in love with the craft. Last fall, she enrolled in SDCE's free welding program.

This past March, Knight was chosen for the Ironworkers International Union Pre-Apprenticeship, a program designed to prepare more women to enter the profession.

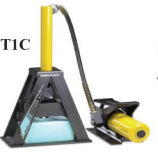
"The instructors/master welders at SDCE definitely prepared me for this," she said. Knight placed top two in academics and was the first one in her class during the preapprenticeship to get spot plug certified.

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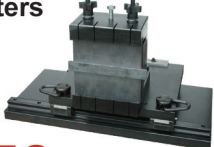
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When stay-at-home orders are lifted and worksites are safely operating, Knight will start an apprenticeship with the Ironworker Local 229 in San Diego with plans of advancing to a journeywoman welder.

Victor® Names Winners of “Rulers of the Flame” 2020 Student Contest

Victor®, Annapolis Junction, Md., an ESAB brand, has announced its winners in the Rulers of the Flame oxyfuel student contest. Students — from a total of six schools participated in two categories — a team fabrication project or an essay competition — centered on the contest theme.

The essay competition asked students to describe how oxyfuel processes and working with oxyfuel equipment have shaped their character, affected their daily lives or the lives of others, influenced something they’re passionate about, and will empower their future careers. The winners were Joshua Doyle from Springfield Clark Career Technology Center, Springfield, Ohio; Kyle Hiener from Oxarc Welding School, Spokane, Wash.; and Elizabeth Chaney from Carroll County Career & Technology Center, Westminster, Md.

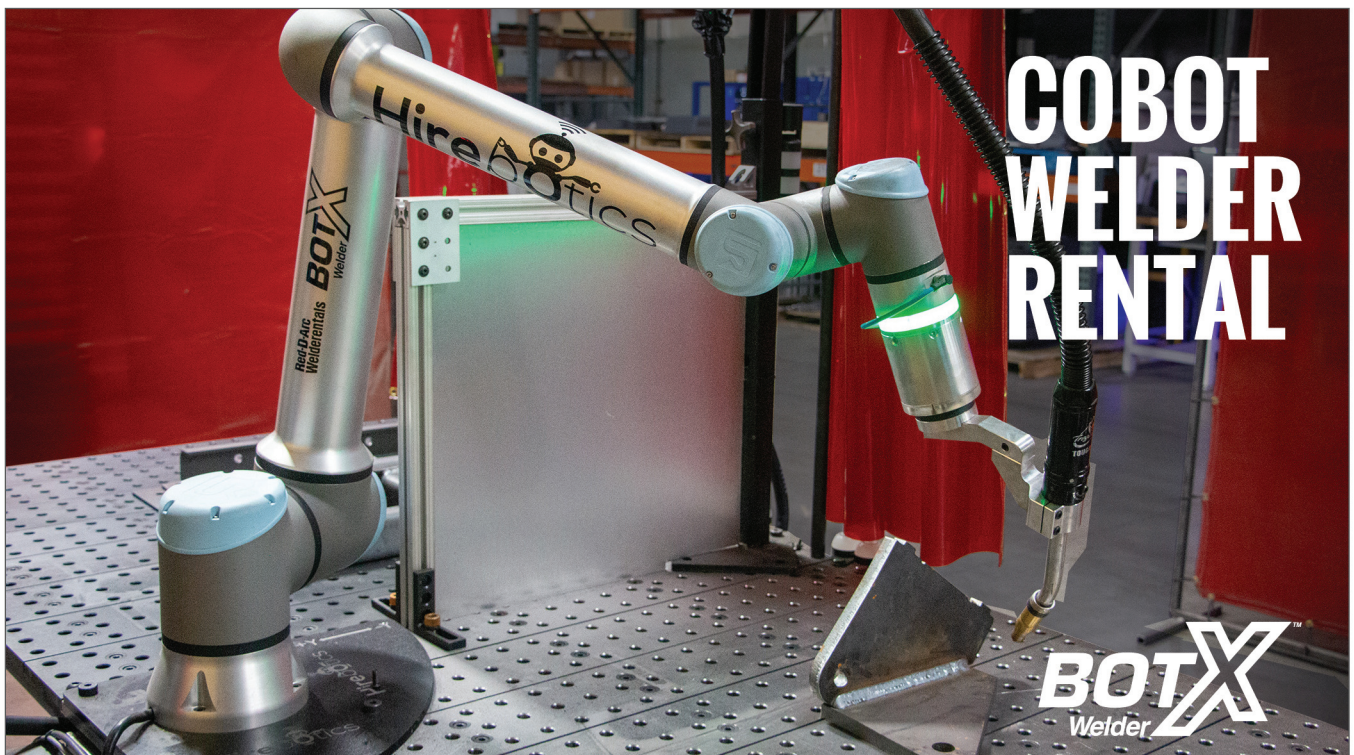
The team fabrication project winners came from Iron Workers 40 & 361 Training Center, Astoria, N.Y.; Rockland BOCES, West Nyack, N.Y.; and Ogden-Weber Technical College, Ogden, Utah. Winning projects were, respectively, a “stairway to success,” inspired by artist M. C. Escher’s Relativity staircase cut into a twisted I-beam; King of the Moun-



Winning projects in the Victor® Rulers of the Flame student contest included this fire pit from Ogden-Weber Technical College.

tain, named for an off-road truck climbing an I-beam mountain; and The Fire Pit, a hexagonal show of flames.

— continued on page 57



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Q: We have put 304L and 316L stainless steel weldments into service in seawater for several years. Some weldments show no damage, but many show pitting. The pitting seems to start at welds, but eventually the base metal develops pits as well. We cannot understand why some weldments are undamaged in seawater, why pitting starts at welds, and why even the base metal pits at times. Is there an explanation? Would another stainless steel do better?

A: Seawater is not kind to many metals, including most stainless steels. The chlorides (about 19,000 parts per million) are only part of the problem. Two other major actors are sediments and biofouling by marine organisms. These serve to create artificial crevices that help the chlorides do their dirty work. A man-made crevice (e.g., at a flange interface) also assists the chlorides. Pitting is the normal mode of failure in seawater for stainless steels like 304L and 316L. Welds of near-matching composition to the base metal are generally somewhat anodic to the base metal, due to microsegregation, so they are often preferentially pitted.

An extensive review of austenitic stainless steel in seawater was prepared more than 40 years ago by Moller (Ref. 1). It clearly shows the effects of sediments and biofouling. If the seawater was quiescent or relatively slow moving (less than 4 ft/s velocity relative to 304 or 316 stainless steel), sedimentation and biofouling could occur, causing the stainless steel to become pitted rather quickly. However, if the seawater velocity was greater than 4 ft/s, the 304 or 316 stainless steel was unaffected; the 316 weld was also unaffected after nearly four years. The fast-moving water prevented sedimentation and biofouling on the stainless steel. One conclusion of that review is that the difference in performance of the various grades of 300 series stainless steels is not of practical significance.

It is worth noting that, at the time of the work cited by Moller, low-carbon stainless steels and weld metals were considerably more expensive than the non-low-carbon grades because argon-oxygen decarburization had not yet proliferated in the steel-making industry. As a result, non-low-carbon grades were commonly used. However, sensitization and the resultant intergranular corrosion were seldom observed.

As an alternative to rapid seawater velocity relative to the stainless steel, electrical contact of the stainless steel with a sacrificial anode such as aluminum, zinc, carbon steel, or cast iron can protect the stainless steel. Then the less-noble metal is preferentially corroded, and the stainless steel is not pitted. If the stainless steel happens to be coupled with one of these less-noble metals, it may be protected from pitting without the designer being aware of the sacrificial anode protection. The aforementioned can explain why stainless steel serves well in seawater under certain conditions but suffers pitting under other conditions.

It is also possible to make the stainless steel the cathode by applying a direct-current negative polarity to it in seawater, thereby protecting it from pitting.

Garner (Ref. 2) extensively studied the resistance of various stainless steels and weld metals to pitting using a 10% ferric chloride solution to find critical pitting temperatures below to which the material was immune to pitting. The greater the critical pitting temperature, the greater the pitting resistance. One finding showed that 317L stainless steel was a little more resistant to pitting than 316L, but the matching weld metals were inferior to the base metals in this regard, and there was essentially no difference between the 316L and 317L weld metals despite the higher Cr and Mo content of the latter. Figure 1, reproduced from Garner's work, shows that the weld metal is generally inferior in pitting resistance to the matching base metal. Furthermore, the disparity between the base metal and matching weld metal becomes greater as the Mo content increases due to segregation of the Mo to dendrite cores in the austenitic weld metal (note the diverging trend lines for base metals vs. weld metals in Fig. 1).

Empirical studies of pitting resist-

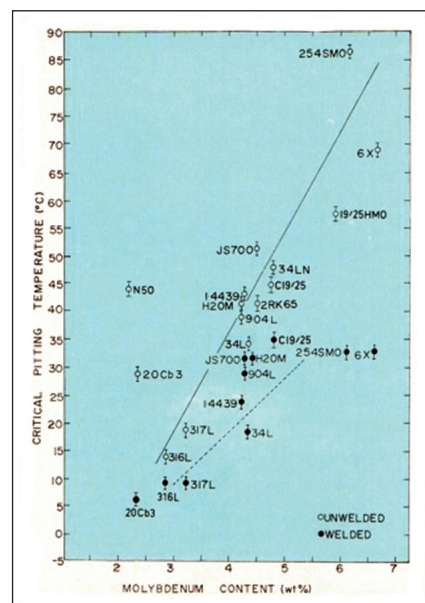


Fig. 1 — Critical pitting temperatures vs. Mo-content of commercial austenitic steels after testing in 10% FeCl₃. Resistance to pitting corrosion increases with alloy Mo-content and decreases after autogenous gas tungsten arc welding with an energy input of about 0.5 kJ/mm. (Photo adapted from Ref. 2.)

ance have led to a relative ranking of pitting resistance according to a material's Pitting Resistance Index, PRE_N, which is generally defined as follows:

$$PRE_N = \%Cr + 3.3x\%Mo + 16x\%N$$

This ranking for base metals seems to correlate reasonably well with relative service performance of various stainless steels in pitting environments, such as seawater. It has been found that the only austenitic stainless steels that are fully resistant to pitting in quiescent seawater are those containing 6% Mo and high nitrogen. The two best known examples are AL-6XN® (UNS N08367) and 254 SMO™ (UNS S31254). For such steels, the PRE_N is greater than 40. Additionally, to obtain weld metal that is equally pitting resistant, nickel-based alloy filler metals with 9% Mo or more are necessary to overcome the effects of Mo segregation in the as-welded condition. The most common filler metals are E/ERNiCrMo-3 and E/ERNiCrMo-10.

Compositions of 304L, 316L, 317L, matching stainless steel filler

Table 1 — Compositions and PRE_N Values for the Steels and Filler Metals Considered

Material	Composition, Weight Percent (single values are maximum except where noted, N.S. = Not Specified, Rem. = Remainder)														Approximate PRE _N
	C	Mn	P	S	Si	Cr	Ni	Mo	W	Nb	Fe	Cu	N	Other	
304L	0.030	2.00	0.045	0.030	0.75	18.0 to 20.0	8.0 to 12.0	N.S.	N.S.	N.S.	Rem.	N.S.	0.10	N.S.	20
316L	0.030	2.00	0.045	0.030	0.75	16.0 to 18.0	10.0 to 14.0	2.00 to 3.00	N.S.	N.S.	Rem.	N.S.	0.10	N.S.	25
317L	0.030	2.00	0.045	0.030	0.75	18.0 to 20.0	11.0 to 15.0	3.0 to 4.0	N.S.	N.S.	Rem.	N.S.	0.10	N.S.	30
AL-6XN	0.030	2.00	0.040	0.030	1.00	20.0 to 22.0	23.5 to 25.5	6.0 to 7.0	N.S.	N.S.	Rem.	0.75	0.18 to 0.25	N.S.	45
254 SMO	0.020	1.00	0.030	0.010	0.80	19.5 to 20.5	17.5 to 18.5	6.0 to 6.5	N.S.	N.S.	Rem.	0.50 to 1.00	0.18 to 0.22	N.S.	44
E308L-XX	0.04	0.5 to 2.5	0.04	0.03	1.00	18.0 to 21.0	9.0 to 11.0	0.75	N.S.	N.S.	Rem.	0.75	N.S.	0.50	20
ER308L	0.03	1.0 to 2.5	0.03	0.03	0.30 to 0.65	19.5 to 22.0	9.0 to 11.0	0.75	N.S.	N.S.	Rem.	0.75	N.S.	0.50	21
E316L-XX	0.04	0.5 to 2.5	0.04	0.03	1.00	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	N.S.	N.S.	Rem.	0.75	N.S.	0.50	24
ER316L	0.03	1.0 to 2.5	0.03	0.03	0.30 to 0.65	18.0 to 20.0	11.0 to 14.0	2.0 to 3.0	N.S.	N.S.	Rem.	0.75	N.S.	0.50	24
E317L-XX	0.04	0.5 to 2.5	0.04	0.03	1.00	18.0 to 21.0	12.0 to 14.0	3.0 to 4.0	N.S.	N.S.	Rem.	0.75	N.S.	0.50	27
ER317L	0.03	1.0 to 2.5	0.03	0.03	0.30 to 0.65	18.5 to 20.5	13.0 to 15.0	3.0 to 4.0	N.S.	N.S.	Rem.	0.75	N.S.	0.50	27
ENiCrMo-3	0.10	1.0	0.03	0.02	0.75	20.0 to 23.0	55.0 min.	8.0 to 10.0	N.S.	3.15 to 4.15	7.0	0.50	N.S.	0.50	42
ERNiCrMo-3	0.10	0.50	0.02	0.015	0.50	20.0 to 23.0	58.0 min.	8.0 to 10.0	N.S.	3.15 to 4.15	5.0	0.50	N.S.	0.50	42
ENiCrMo-10	0.02	1.0	0.03	0.015	0.2	20.0 to 22.5	Rem.	12.5 to 14.5	2.5 to 3.5	N.S.	2.0 to 6.0	0.50	N.S.	0.50	51
ERNiCrMo-10	0.015	0.50	0.02	0.010	0.08	20.0 to 22.5	Rem.	12.5 to 14.5	2.5 to 3.5	N.S.	2.0 to 6.0	0.50	N.S.	0.50	51

metals, AL-6XN, 254 SMO, and the high Mo nickel-based alloy filler metals are listed in Table 1, along with their approximate PRE_N values. Because Mo segregates strongly in stainless steel and nickel-based alloy weld metals, and pitting starts in the low Mo areas, it is recommended that only two-thirds of the nominal Mo content be used in the PRE_N calculation for weld metal (Ref. 3); that practice was used in preparing Table 1. It can be anticipated from these compositions that the 6% Mo-based metals and high Mo nickel-based alloy filler metals are considerably more expensive than 304L or 316L. If you go that route, brace yourself for sticker shock. [WJ](#)

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1. Moller, G. E. May 1976. The success-

ful use of austenitic stainless steels in sea water. *Offshore Technology Conference*, Houston, Tex.: p. 959–976.

2. Garner, A. 1983. Pitting corrosion of high alloy stainless steel weldments in oxidizing environments. *Welding Journal* 62(1): 27–34.

3. Grubb, J. F. 2020. Private communication.

DAMIAN J. KOTECKI is president, *Damian Kotecki Welding Consultants Inc.* He is a past treasurer of the IIV and a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals, DIK Subcommittee on Stainless Steel Structural Welding, and WRC Subcommittee on Welding Stainless Steels and Nickel-Base Alloys. He is a past chair of the A5 Committee on Filler Metals and Allied Materials, and served as AWS president (2005–2006). Questions may be sent to Damian J. Kotecki c/o Welding Journal, 8669 NW 36 St., # 130, Miami, FL 33166-6672, or via email at damian@damiankotecki.com.



American Welding Society

Do You Have a Stainless Question?

Email your submission to the *Welding Journal's* Stainless Q&A author, Damian J. Kotecki, at damian@damiankotecki.com or send it to his attention at

Welding Journal Dept.
Damian J. Kotecki
8669 NW 36 St., #130
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Your stainless question may be chosen for this bimonthly column and help other individuals better understand how to solve a particular problem.

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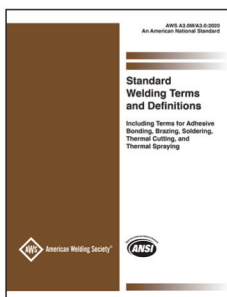


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The WIKI-SCAN 2.0™ handheld, noncontact welding quality management system achieves accurate inspections of weld joint preparations, joint fitup, and weld bead geometry to ensure the reliability of the welding process. It delivers measurements of many features, including leg size and undercut, as well as critical parameters, such as root and face opening, gap, mismatch, and bevel angles. Offering automatic defect detection with little prior training, the lightweight and fast system limits redundant inspection operations, unneeded repairs, and overwelding, thus shortening inspection time. It also provides a comprehensive and immediate digital report as well as wireless communication to allow for efficient electronic data management, traceability, and quality control.

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Maxx 12-V SSE 12 BL Compact, the 18-V SSE 18 LTX BL, and the 18-V SSE 18 LTX BL Compact. Capable of cutting metal, wood, and plastic, the saws feature a 180-deg rotatable blade for working in confined spaces, as well as an adjustable shoe for setting the cutting depth limit, which is useful when cutting into a wall to avoid cutting the pipes and wires that lay behind it. The saws also showcase a tool-free, quick-change system; integrated LED work lights that illuminate cutting areas for increased visibility; and an ergonomic, angled, soft-grip handle coupled with a lightweight design to reduce fatigue. The compact models deliver up to 3000 strokes per min with a stroke length of $\frac{1}{2}$ in. For versatility, either a reciprocating saw blade or a T-shank jigsaw blade can be inserted into the compact models. They are both offered as bare models. Available as a bare model or a kit, the SSE 18 LTX BL accomplishes up to 2700 strokes per min with a stroke length of $1\frac{1}{4}$ in. Its kit comes with two 5.5-ampere-hour batteries, a five pack of blades, a charger, and a carrying case. All of the saws come with a 3-year warranty and a 3-year replacement guarantee on the battery and charger systems.

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The eStore helps customers view and order precision mechanical locating systems as well as thermoforming and blow molding accessories. The site is designed to provide a simple, user-friendly experience. It can be found on the company's website under eStore, where users can then enter into catalog showrooms to see and purchase products. The products featured for purchase on the site include standard thermoform molding accessories, such as peening hammers, sheet clamps, and chopper bars; bushing blocks and pins for blow molding; and the company's Segen Quick-Change cylinders, knobs, and accessories.

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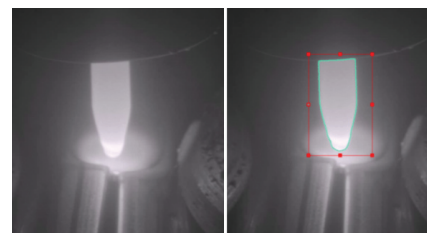
Guide Lists Steps for Disinfecting Electrical Equipment

The GD 4-2020, *COVID-19 Cleaning and Disinfecting Guidance for Electrical Equipment* addresses common questions from manufacturers regarding the cleaning and disinfecting of electrical equipment to prevent the spread of COVID-19. The five-page document unveils eight steps that can be taken to safely clean electrical equipment while also preventing the spread of germs. It cautions that the use of U.S. Environmental Protection Agency (EPA) List N-approved disinfectants can have a long-term, detrimental impact on the performance, reliability,

and safe operation of electrical equipment. Additionally, it states that the use of foggers, sprays, and other types of atomized cleaning agents can contaminate the components inside the electrical equipment, resulting in severe damage, outages, and potential personal injury. The electronic guide can be downloaded for free on the company's website.

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Updated Software Enhances Weld Camera Functionality



The updated WeldStudio™ software offers additional functions to support the company's weld cameras in capturing and processing high-quality weld images. Its pre-recording buffering feature easily captures the beginning of a weld and collects up to 10 s of video. It also contains three advanced edge detectors to help highlight subtle features in the welding environment that are not easily seen by the human eye. Additionally, its pattern and template matching tools help locate, inspect, or qualify a feature in the welding process. These added software tools are designed to help welding personnel extract real-time data from their weld video images, as well as expand options for process monitoring and control.

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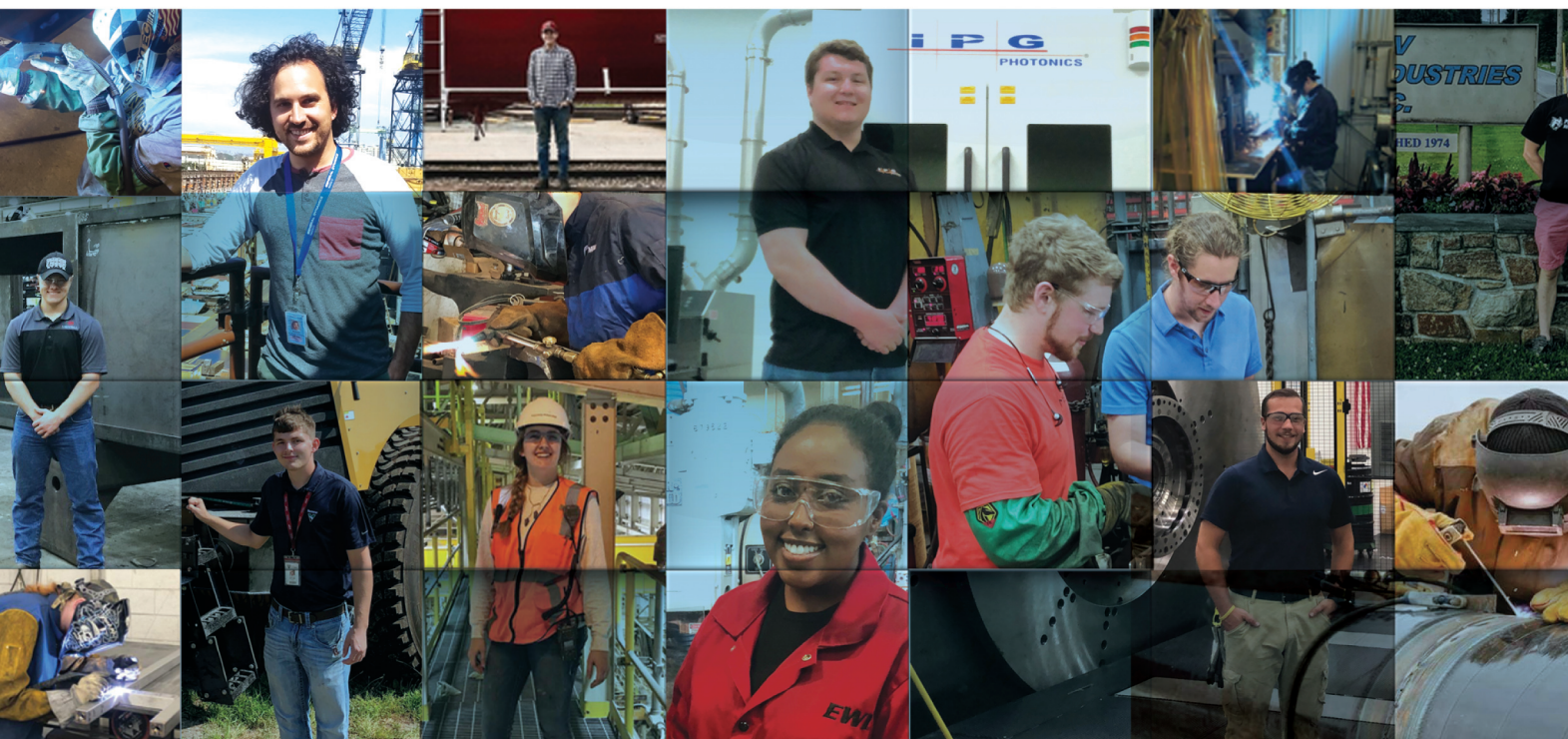
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— continued on page 57



American Welding Society®
FOUNDATION



2019-2020 ANNUAL REPORT

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William A. Rice
Chairman, AWS Foundation

Message from the Chair

The year 2019 was not only a year of celebration for the 100-year-old American Welding Society, but also a celebration of the 30th anniversary of the American Welding Society Foundation.

In 1989, the AWS Foundation was established to support welding education and research, starting with one \$20,000 research fellowship. In 1993, the

AWS Foundation awarded its first scholarships to 82 welding students totaling \$59,000.

Thanks to the ongoing support of our donors and members of the American Welding Society, we have been able to greatly expand our programs from those humble beginnings. I'm pleased to report that in 2019 the AWS Foundation awarded over \$1.5 million in scholarships to more than 1,000 welding students.

Add research fellowships (\$120,000) and grants to schools (\$200,000), and the AWS Foundation provided more than \$1.8 million dollars to impact welding education in the past year.

Last year also included numerous new initiatives, such as: scholarships for welding contest winners; the relaunch of *CareersinWelding.com* as a modernized, mobile-friendly site; and the creation of engaging articles, videos, and blog posts for *WeldingDigest.com*, aimed at educating targeted audiences about opportunities in welding.

With your support, we will continue to expand our mission to support and inspire the next generation of welding professionals. If you have the means, please consider establishing a new scholarship or grant, or donate to an existing fund or initiative.

To establish a scholarship or grant endowment, or make a general donation, please contact Monica Pfarr, Executive Director of the AWS Foundation, at 800-443-9353 Ext. 461 or mpfarr@aws.org.

Thank you again for your support. Because of you, the AWS Foundation is as strong as ever, and the next decade shows the promise of continued growth and unprecedented impact on the future of our industry.

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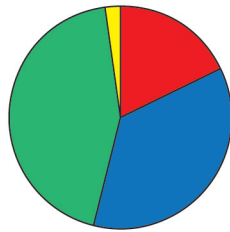
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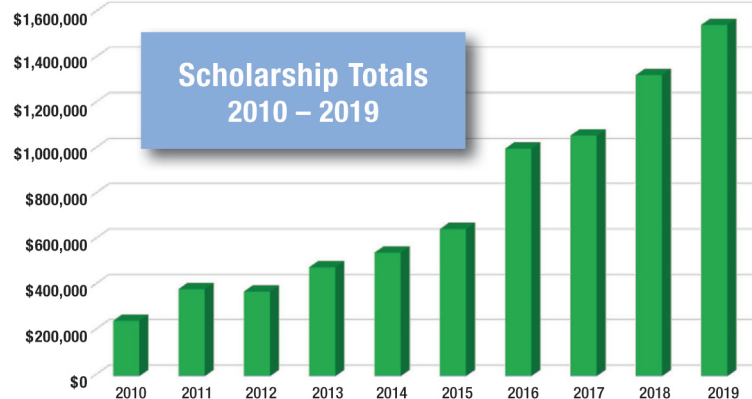
AWS Foundation awards \$1.5 million in scholarships to more than 1,000 students

- Scholarship recipients attend more than 400 different academic and training institutions.
- Recipients are 19% Female – According to Emsi, 5% of the current welding workforce are women. AWS Foundation scholarships continue to help provide opportunities for women in welding.

Recipients are enrolled in the following programs:



■ Bachelor's Degree	18%
■ Associate Degree	36%
■ Certificate	44%
■ Other	2%



Liya Amanuel
The Ohio State University
2019-20 Recipient – John C. Lincoln Memorial Scholarship

“Being the oldest of my siblings and the first to go to college, I hope to make my family proud with the opportunities I have been given. Additionally, I hope to one day give back by giving someone the gift of pursuing education. I am excited to continue my fourth year at OSU and I am optimistic of what this year will hold.”



Callahan Jobe
Santa Fe Community College
2019-20 Recipient – Air Products Women of Gases and Welding Scholarship

“I am very excited about learning how to weld this fall at the Santa Fe Community College and would like to thank you again for selecting me for this scholarship! Ultimately, I want to use welding to teach other women how to weld.”



Braxton Boothe
Front Range Community College
2019-20 Recipient – Jack and Jo Dammann Technical Scholarship

“I plan to make the most of this opportunity you have afforded me to help attain my goals of using my education to one day start my own business in custom fabrication and design of commercial and residential products, including furniture, art, and decor.”



Austin Turner
Brigham Young University
2019-20 Recipient – Richard J. Seif Technical Sales & Marketing Scholarship

“I cannot thank you enough for awarding me this scholarship! Thank you so much for supporting me in educational pursuits and my professional goals to help advance the welding industry as I prepare to enter the welding workforce as a technical sales representative.”

\$120,000 in Graduate Research Fellowships

In 2019, three graduate students from Ohio State University and one from Penn State University each received a \$30,000 fellowship to support research projects in welding, additive manufacturing, and other allied technologies.

Grants/Scholarships

| \$750,000 in Grants Awarded Since 2017

The following schools were awarded grants of up to \$25,000 in 2019

- Alma High School — Alma, MI
- Diman Regional Vocational Technical High School — Fall River, MA
- Eastpointe High School — Eastpointe, MI (Detroit Section Grant)
- Midlands Technical College — West Columbia, SC
- Mountainland Technical College — Lehi, UT
- Northampton Community College — Bethlehem, PA
- Rowan-Cabarrus Community College — Salisbury, NC
- San Jacinto College Central — Pasadena, TX
- St. Charles Community College — Cottleville, MO

“Our program was hampered in the past by only having eight multi-process machines, thus limiting what we could offer for classes. Once we received the AWS grant, we used that money to help purchase seven new multi-process machines. Now we can offer up to 30 students SMAW, GMAW and GTAW which helps those students obtain a welding certificate, giving them the skills to start an entry level welding job.”

- JAK Keller, Welding Instructor, Hutchinson Community College, Welding Workforce Grant Recipient



Students in the welding lab at Alma High School



Students watch a welding demonstration at Northampton Community College



Welding Summit Conference Co-Chair Scott Witkowski and District 18 Director Tom Holt present a plaque to Les Crnkovic, Department Chair, Industrial Technology at San Jacinto College Central

| Welding Competition Scholarships

In 2019, AWS District Directors awarded up to \$5,000 in scholarships to winners of welding competitions in their respective districts. The program was a huge hit and will continue in 2020!



CAREERS IN WELDING

powered by 

| Launched in 2019 – a new *CareersinWelding.com* website!

The site has an all-new look with refreshed content to appeal to the next generation of welding professionals. The mobile-enhanced website includes:

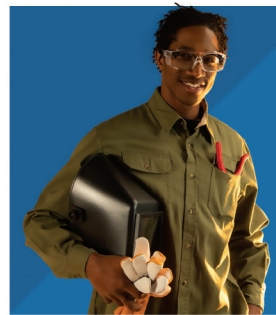
- A Career Assessment Quiz
- In-Depth Career Profiles and Salary Data
- Education and Training Opportunities
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Ironworker

National Median Pay

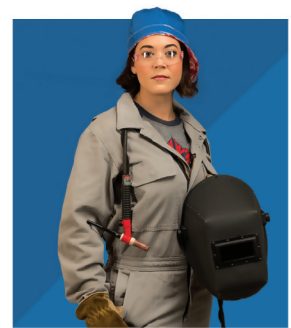
\$52,000



Robotic Welding Technician

National Median Pay

\$41,000



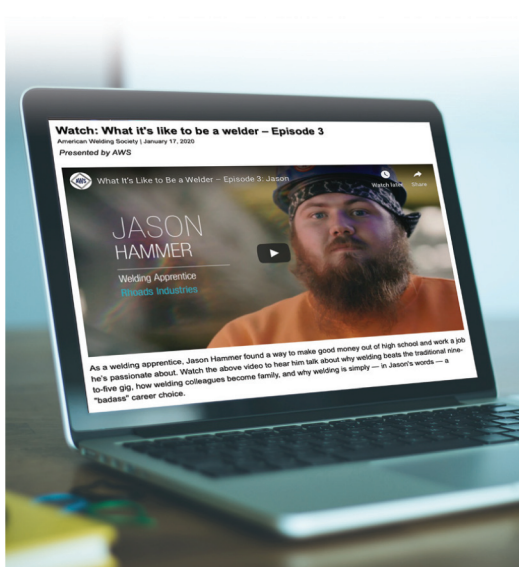
Boilermaker

National Median Pay

\$63,000

| Careers & Education Content on *WeldingDigest.com*

The Careers & Education segment on *WeldingDigest.com* launched in November 2019 as a digital presence to promote welding careers to multiple audiences, including students, career changers, parents, and veterans. Site visitors can view engaging blogs, articles, and videos, with new content released weekly to maintain and engage new/existing users.



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Careers in Welding Trailer

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Since the trailer hit the road in 2011
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In Memoriam...



John M. Stropki Jr., former chairman, president, and CEO of The Lincoln Electric Co., Cleveland, Ohio, passed away on May 11. He was 68. Stropki had a successful career at Lincoln Electric for 41 years and served as the company's CEO from 2004 to 2012. He started at the company as a summer intern while attending college and rose through the sales organization to become executive vice president and president, North America, in 1996. He joined the board of directors in 1998 and was promoted to chairman, president, and CEO in 2004. During his tenure, he transformed operations, oversaw numerous acquisitions and product innovations, and expanded the company's global footprint. Additionally, he served on the boards of The Sherwin-Williams Co., Hyster-Yale Materials Handling Inc., and Rexnord Corp. He also dedicated his time and efforts to support numerous industry associations and nonprofit organizations. He is survived by his wife, Liz, and many friends and family.

Significant Contributions to the AWS Foundation

- Instrumental in Lincoln Electric Company's sponsorship of the AWS Careers in Welding Trailer. Since its inception in 2011, the interactive, mobile virtual reality lab has introduced nearly 250,000 to career opportunities in the welding industry.
- Contributed more than \$100,000 to establish the John M. Stropki Scholarship, which awards more than \$20,000 annually to the children of Lincoln Electric employees and other outstanding students in welding and related fields.
- Spearheaded the Lincoln Electric Foundation's commitment of \$250,000 towards AWS Foundation Workforce Development Program.



Dietrich K. Roth, co-founder of RoMan Manufacturing, passed away on November 15, 2019. After receiving his electrical engineering degree in Germany, Roth emigrated to Grand Rapids, Mich., in 1959 and went to work for the Kirkhof Manufacturing Co. as an electrical engineer. He rose up through the company, becoming the chief engineer and later the division general manager. He met his business partner, Robert Hofman, at Kirkhof, and they started RoMan Manufacturing in 1980. Roth was a Life Member of the American Welding Society (AWS) and the Resistance Welding Manufacturers Alliance (RWMA). He was inducted into the Ferris State University Welding Hall of Fame for his contributions to the school's welding engineering program and to the industry. He was also a recipient of the Elihu Thomson Resistance Welding Award. His contributions to the science of resistance welding are numerous, and he was a significant contributor to the industry codes and standards authored by the RWMA and published by AWS. He is survived by his wife of 58 years, Betty Lou, their three children, five grandchildren, brother-in-law, and sister-in-law.

Significant Contributions to the AWS Foundation

- Contributed more than \$50,000 to establish the Dietrich & Betty Roth Scholarship for welding students in West Michigan interested in the field of resistance welding.

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The AWS Foundation received \$889,836 in donations in 2019, and the following companies, members, individuals, and AWS Sections donated over \$1,000 to support scholarships, grants, and other workforce development initiatives.

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Rexnord Industries LLC
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AWS Long Island Section
AWS New Mexico Section
AWS York-Lancaster Section

\$5,000+

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Fluor Corporation
Marie Lipphardt
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AWS Central Michigan Section
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Aecon-Wachs
Josh Armstrong
B & H Rig and Tong Sales, Inc.
Jack & Jo Dammann
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Euroweld Ltd.
Huntington Ingalls Industries-Newport
News Shipbuilding
Hypertherm HOPE Foundation
Mary Ruth Johnsen
Jim & Diane Key
Key Energy Services
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National Oilwell Varco
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Monica Pfarr
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Lawrence & Sarah Cruise
Hyster-Yale Group
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contact Monica Pfarr, Executive Director of the AWS Foundation, at 800-443-9353 Ext. 461 or mpfarr@aws.org.

Choosing the Best Cutting Tool for the Job

This guide breaks down the categories of cutting tools along with their pros and cons

BY TIM LYMAN

Before metal pieces can be joined, they often need to be cut down to specific measurements or angles. Sometimes they are cut just to create a clean surface to guarantee a strong weld. There are multiple ways that welding professionals complete this cutting task, including the use of gas and plasma cutting machines, power tools, and cutting hand tools. This article provides details on many of the specific tools that fall within these categories and the pros and cons that come with each.

While many of these tools are able to achieve the desired cut, they present potential hazards when used improperly with the hope of saving time or money. These cutting tools are powerful and can be dangerous when used incorrectly or by inexperienced professionals. Be sure to consistently use safety equipment, including goggles and gloves, and to always stand to the side of a power saw to prevent injury due to kickback.



Fig. 1 — The Norton mini angle sanders are small and compact, designed to get into hard-to-reach areas, and powerful enough to finish jobs fast and efficiently. (Courtesy of Norton | Saint-Gobain Abrasives.)

Plasma and Gas Cutting

Two of the most commonly used tools by professional welders are the plasma cutting machine and the oxy-acetylene cutting torch. Both are effective options that cut most types and thicknesses of metals. However, they come with some large costs both upfront and in maintaining the necessary parts.

Plasma Cutting Machine

Pros

- Cuts all types of metal
- Higher cutting speeds — great for fast, straight cuts of thin metals
- Dross free — No after treatment required

Cons

- Thickness limitations on most shop plasma cutting machines
- Broader kerf than laser cutting
- Expensive upfront cost and not cross functional

Gas (Oxyacetylene) Cutting Torch

Pros

- Suitable for medium-sized and thick materials
- Bevel cutting with up to three torches on one aggregate
- Cross functional and relatively inexpensive — cut, weld, braze, heat, etc.

Cons

- Suitable for cutting mild steel only
- Low-cut speed and reduced dimensional accuracy when making repeat cuts
- Can cause warpage and partial dross formation, requiring after treatment
- Causes heavy scale on workpiece, which can be a challenge to remove before welding operations can be done effectively

Power Tools

There are many different types of power tools available depending on how much power or precision a job demands. The portability of many power tools also allows for greater convenience and the ability to make cuts in hard-to-reach places.

Angle Grinder

Pros

- Works well in making cuts on most metals — Fig. 1
- Effectively makes quick cuts on bolts, nuts, sheet metal, etc.
- Versatile tool that can also be used to sharpen blades and grind metals

Cons

- Due to various grain compositions, each abrasive has specific material operating parameters and are not universal to all metals
- Sparks are upwards of 1700°C, which are molten metal, and can easily cover more than 15 ft of distance during the operation

Jig Saw

Pros

- Suitable for jobs that require precise and delicate cuts on a flat surface
- Often used to make straight or curved cuts in the middle of a workpiece
- High degree of safety due to ease of use
- Great longevity on lightweight, cordless tools

Cons

- Cannot be used to make flush cuts
- Requires a somewhat even surface for the base to be stable
- Only has a moderate level of power

Reciprocating Saw

Pros

- Ability to quickly cut all types of metals

- Suitable for demolition and quick, rough cuts
- Ease-of-use when reaching into tight or hard-to-reach places
- Great mobility due to design for use on cordless tools

Cons

- Careful user attention is required for consistent, accurate cutting
- Higher skill level is required to make a puncture/cut into a flat surface
- Strong power can be dangerous when used in low-leverage situations

Metal Circular Saw

Pros

- Able to cut in several directions and angles on most types of metal
- Long blade life and portable use
- Can be used as a stationary or mobile tool, allowing users to transport the least amount of mass for any given application

Cons

- Not able to make consistent curved cuts
- Needs a specific blade made for cutting metal
- Can be dangerous — sparks and metal chips will fly during usage

Portable Band Saw

Pros

- Effectively cuts most metals and allows for straight and curved lines
- Powerful and fast cutting. Makes fast cuts with very few sparks
- Versatile and allows for vertical and horizontal cuts

Cons

- Portable band saw blades can wear down quickly if proper operating parameters are not followed to
- Not suited for making thick cuts
- Potentially dangerous if operator does not attend to proper safety and personal protection equipment requirements

Chop Saw

Pros

- Highly accurate in making straight cuts in most materials up to a ½-in. thick
- Convenient when needing to quickly make many similar type cuts
- Cost effective option for cutting many materials

Cons

- Stationary. Only able to move up and down
- Typically used for more specialized, consistent cuts
- Often leaves a burr on the cut, which requires secondary cleanup

Band Saw Blade

Pros

- Can cut all thicknesses of metal, including bundles — Figs. 2 and 3
- Most are programmable, facilitating increased productivity and semiautomation
- Affordable option that operates quietly and cleaner when compared to other options

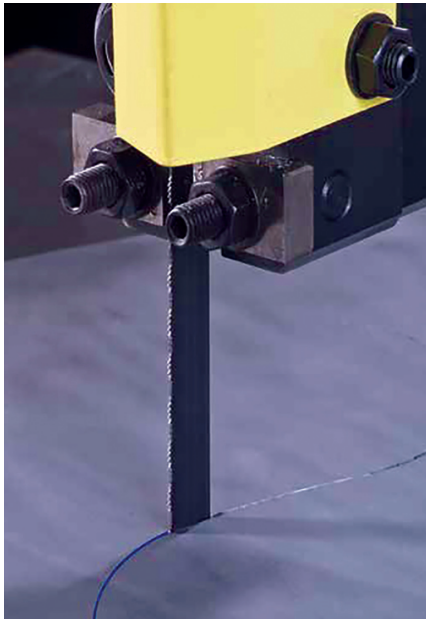


Fig. 2 — The Starrett Bi-Metal Intenss band saw blade has strong tooth geometry and M42 high-speed steel teeth combined with a fatigue-resistant backing. (Courtesy of The L. S. Starrett Co.)

Cons

- Stationary. Saw takes up space in shop
- Requires operator to know how to break in the blade and set saw
- Coolant is required for many applications for ideal operating parameters

Cutting Hand Tools

Simple “old school” cutting tools still get the job done today and can usually be found in your toolbox. These tools are less expensive than power tools and are very useful in making simple, quick straight-line cuts.

Metal Shear

Pros

- Works well on most soft, thin metals
- Ideal for quick, inexpensive straight-line cuts of simply shaped parts
- Produces minimal kerf with virtually no loss of material



Fig. 3 — The Starrett “3X Power” bi-metal reciprocating saw blades feature teeth that cut more efficiently, enabling users to make up to three times the number of cuts than conventional blades, and are engineered for use on corded and cordless saws.

Cons

- Not ideal for cutting harder metals or thick material
- Can only make straight-line cuts
- Often creates burrs and end deformation on cut

Hacksaw

Pros

- Better suited for cutting through thinner materials
- Very safe — poses less risk than power tools because user is in full control
- Size and light weight make it easy to reach awkward cutting places

Cons

- Blades can easily get damaged when cutting thick or hard metals
- Can be a slow cutting process due to small teeth and gullets on blade
- Can be physically draining on projects with a lot to cut — less ergonomic than other available alternatives

Tin Snip

Pros

- Designed for cutting thin sheets of soft metal
- Affordable and very easy to use
- Highly durable tool

Cons

- Low on versatility
- Can be a slow cutting process depending on material and individuals' experience
- Takes extra effort to cut tougher material due to spring-loaded handles

Conclusion

There are other specialty metal cutting tools available, but the ones reviewed in this article are the most commonly found within the welding industry. Using the right tool for the job will help to increase job productivity and personal safety. [WJ](http://www.starrett.com)

TIM LYMAN (tlyman@starrett.com) is welding channel manager, The L. S. Starrett Co., Athol, Mass.

Recommendations for Developing Alternative Flaw Acceptance Criteria for Structural Steel Welds

Learn the benefits of employing an optional strategy to evaluate flaws when welding to AWS D1.1

BY STEVEN ALTSTADT
AND ROBERT WARKE

The challenge of separating steel welds with acceptable flaws and tolerances from those that are unacceptable (defects) is nearly as old as the challenge of welding itself. This challenge will continue to be with us long into the future. Setting limits that are too stringent can cause economic waste, and may even create unanticipated new technical risks when unnecessary modifications are made. Alternatively, setting limits that are too loose increases the risk of fracture.

Across the many industries that use welded joints, there are two different strategies for judging inspection results when addressing this challenge. The first strategy is to use a consensus-based, standardized, codified set of criteria, often referred to as workmanship criteria. In AWS D1.1/D1.1M:2020, *Structural Welding Code*

— *Steel*, Clauses 7 and 8 exemplify this approach. The second strategy is to formulate project-specific acceptance criteria, usually through a combination of fracture mechanics, metallurgy, and performance-based inspection criteria. The strategy goes by many names, including alternate flaw acceptance criteria, engineering critical assessment (ECA), damage-tolerant design, fit-for-purpose assessment, fit-for-service assessment, and performance-based design.

The primary benefit of this approach is flexibility, backed up by technical rigor. Any combination of material properties, applied stresses, residual stresses, and flaw geometry that can be reasonably demonstrated to remain stable throughout the entire service life, or the minimum specified portion of the service life, can be considered acceptable. Subclause 1.5 al-

lows for this approach, and subclause C-8.8 in the Commentary alludes to it. Because the method is free of explicit codified rules, new materials, joining methods, inspection technologies, and novel design applications can be readily addressed, as long as the fundamental technical data sets are available. For well-established materials, joining methods, inspection methods, and design applications, the key benefit is that tradeoffs between these can be explicitly accommodated.

Within the alternative flaw criteria strategy, there are two sub-options. One is based on simple hit/miss detection and the other on flaw sizing. The flaw detection approach is based on choosing a combination of materials, applied stresses, residual stresses, and other considerations that lead to allowable flaw sizes that are larger than the specified inspection method can

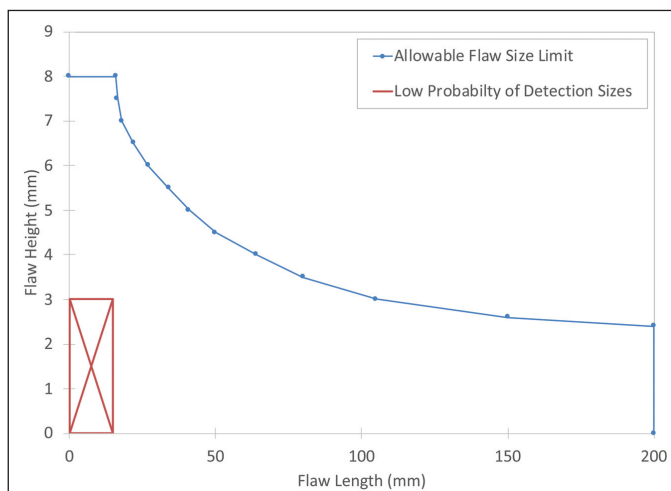


Fig. 1 — Example of flaw acceptance based on detection.

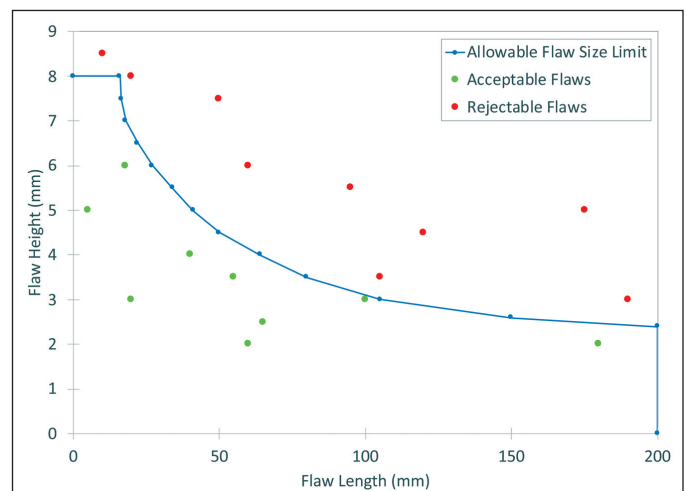


Fig. 2 — Example of flaw acceptance based on sizing.

reliably detect. This is illustrated in Fig. 1. In this approach, a detected flaw is a rejected flaw. The flaw sizing approach is based on choosing a combination of the same factors to create a flaw-size limit curve. This is illustrated in Fig. 2. Here, the rejection of the flaw is based on the measured dimensions, usually flaw length, height, and position. Accompanying rules are usually provided for combining neighboring flaws into a single equivalent flaw.

The selection of codified workmanship vs. the ECA-based strategy varies greatly by industry, even for welded joints of similar construction. There is no simple answer as to why usage trends vary among industries. However, it is likely due to some combination of the respective industry's culture, economic incentives, and regulations.

Historically, for welds fabricated to AWS D1.1, the flaws have been evaluated using standardized workmanship requirements. Some owners, usually large corporations or government agencies, overlay their own internal standards onto the requirements of AWS D1.1. Depending on the application and region, regulators may also have additional requirements. The owner's engineer of record (EOR) may also modify the AWS D1.1 requirements based on the authority granted under subclause 1.5. When this is done, it is usually based on the EOR's qualitative evaluation and not a formal ECA approach. While no formal statistics exist on the choice of coded rules vs. an ECA approach for welded structural steel projects, it is safe to say that some version of the standardized approach is used more than 99% of the time.

For welded structural steel applications, the use of ECAs historically has been reserved for special applications, or as an option of last resort when the standard workmanship criteria could not be satisfied.

Workflow for Establishing Alternative Flaw Acceptance Criteria

The starting point is to form an interdisciplinary technical team. The team's expertise typically spans system design, metallurgy, welding, fracture mechanics, and inspection. A typical step-by-step approach is outlined ahead. For simplicity, in the descriptions we will assume each specialty is

covered by one individual. Since the strategy is flexible, the steps can be conducted in a different order, and iteration between steps also is possible. While the workflow described below is focused on flaws in welded joints, a similar procedure can be followed to determine flaw tolerance in the base metal of castings, forgings, and rolled products.

Step 1: Establish Preliminary Design Drawings and Specifications

The lead design engineer, in consultation with others on the team, assembles a set of preliminary drawings, material specifications, and inspection criteria. The engineer also summarizes the design loads and the peak service conditions (e.g., minimum and maximum service temperatures, dynamic loading rates, and anticipated corrosion environment). Early consultation with the team is important because potential problems can be identified before significant effort is expended. For AWS D1.1 applications, the designed system is typically a structure, and the lead design engineer is most often a civil-structural engineer.

Step 2: Create Representative Test Welds

Representative test welds are fabricated for the purpose of creating material test specimens in Step 3. Creating welds that are reasonably representative and logistically feasible within the project constraints requires input from a metallurgist and welding engineer. Often the procedure qualification test plates form the basis for the material test program, but additional samples or sample preparation may be required. In some cases, additional effort is required to make the welds representative of the final in-service condition. For example, if the welds are to be cold bent during the fabrication process, then the test plates need to be strained a similar amount to capture any changes in the material properties.

Step 3: Test Materials

The material test program typically involves tensile tests, fracture toughness tests, and microhardness traverses across the weld. The fracture tough-

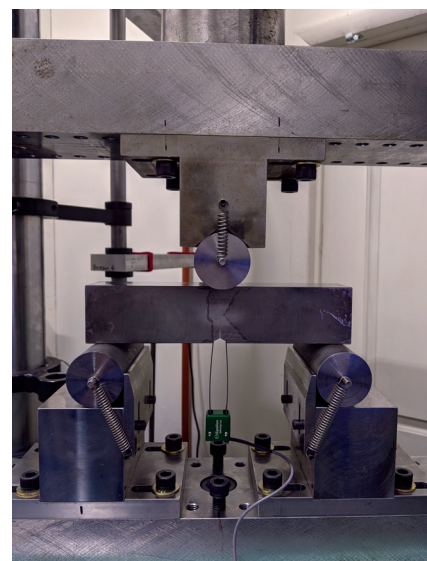


Fig. 3 — Weld metal fracture toughness test setup. (Courtesy of Product Evaluation Systems Inc.)

ness tests include the weld metal, weld interface, heat-affected zone, and base metal. Figure 3 illustrates a typical fracture toughness test setup, in which the precrack was placed in the weld metal. Charpy V-Notch (CVN) tests will sometimes be substituted for fracture toughness tests, often because CVN tests are quicker and cheaper. However, it is important to keep in mind that, at best, CVN results provide an indirect prediction of fracture toughness. As a result, the fracture mechanics specialist typically applies lower-bound empirical relationships to infer fracture toughness values from CVN results. The practical result of doing so is that the allowable flaw sizes are often artificially smaller than if they had been based on direct fracture toughness results, sometimes by a substantial amount.

Step 4: Conduct Fracture Mechanics Calculations to Determine Initial Flaw Sizes

Using the information from Steps 1 and 3, the fracture mechanics engineer calculates a set of flaw size curves, such as those shown in Figs. 1 or 2. Typically, the calculations are based on methods and guidance from one or more of the major flaw assessment guidance documents. For welded carbon and low-alloy steel, the two most commonly used documents are BS7910:2019, *Guide to Assessing the Acceptability of Flaws in Metallic Struc-*

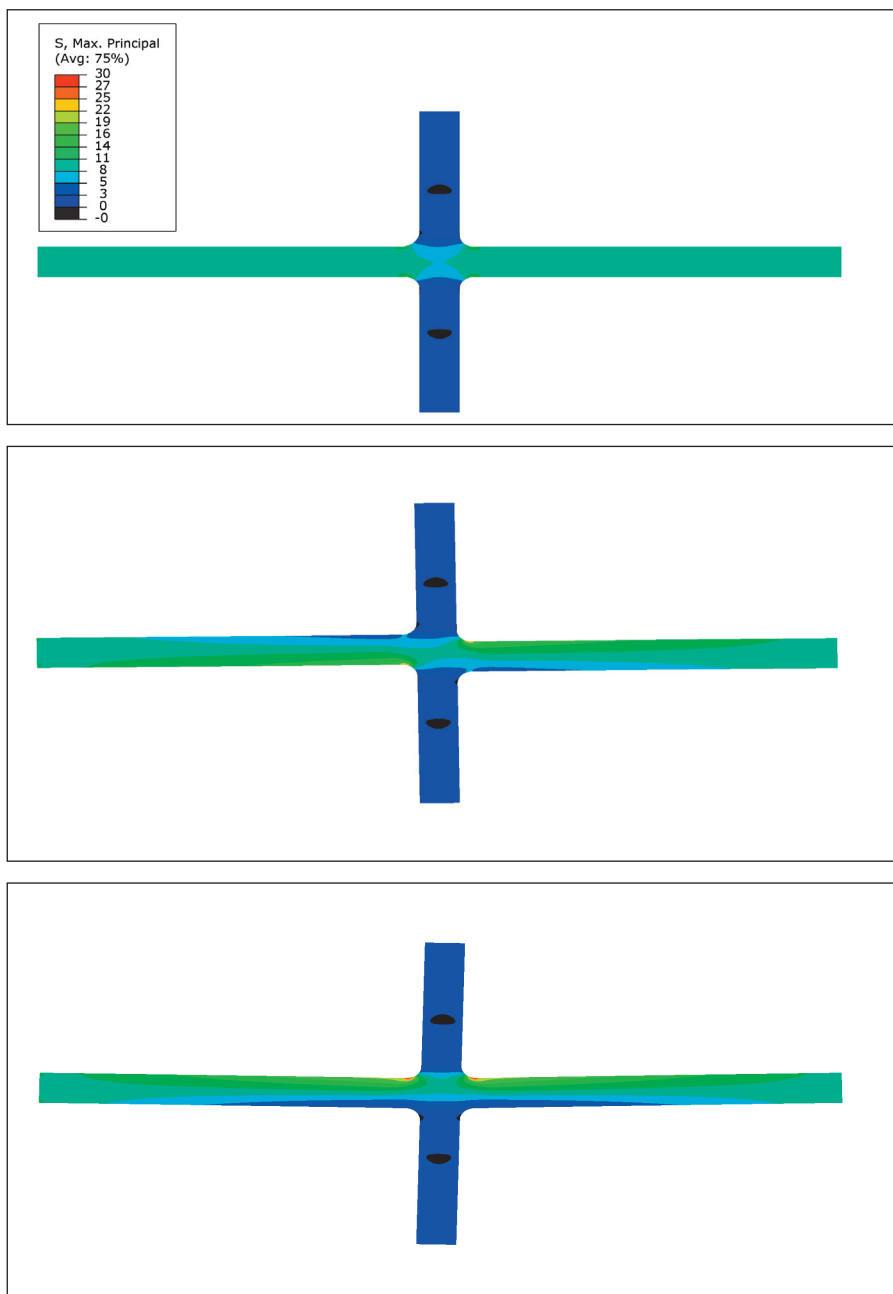


Fig. 4 — Elastic finite element maximum principal stress results for a nominal cruciform joint (top), eccentric parallel plates (middle), and angular misalignment (bottom).

tures, and API 579-1/ASME FFS-1, *Fitness-for-Service*. The fracture mechanics specialist typically can select from relatively simple hand calculation techniques to advanced numerical simulations. Hand calculations are quicker and cheaper. However, they generally result in smaller allowable flaw sizes, due to the conservative simplifying assumptions built into the techniques. More advanced analysis generally allows for removing conservative assumptions. However, this benefit comes with larger budget and schedule requirements.

The fracture mechanics engineer may also provide guidance on the sensitivity of the preliminary solution to various inputs. During a new iteration, this can help decision-making for options such as postweld heat treatment (PWHT) vs. as-welded, as-welded profile vs. ground smooth surface, expanding or tightening fit-up tolerances, changing minimum and maximum material property limits, and modifying the nominal joint geometry. While sometimes not obvious, fit-up tolerances can have a substantial effect on local stresses in the region of

the weld and thus the flaw tolerance. As an example, Fig. 4 illustrates a comparison of simple cruciform joints subject to a nominal tensile stress in the horizontal direction.

Step 5: Determine the Inspection Program

Selecting an inspection program in an ECA strategy requires consideration of the actual ability to detect the flaw sizes, positions, and orientations quantified in Step 4. The most rigorous option is to quantify probability of detection and sizing error through blind testing of the inspector, with the specified inspection technology being used on representative joints with known, representative weld flaws. For the reader who has no familiarity with these blind testing concepts, the book *Fundamentals of Structural Integrity* by A. F. Grandt Jr. is a recommended starting point. In the least rigorous approach, guidance from existing sources in combination with previous knowledge of the inspection team is used.

As a midpoint between the two extremes, a limited blind testing program is used to screen out inspectors or inspection technologies, but the number of specimens used is far less than what is included in a rigorous statistical study. Appendix T of BS7910 provides general guidance on flaw detection and sizing capabilities for various mainstream inspection techniques. This is a helpful reference to use during Step 1. However, readers are cautioned that there is no reasonable assurance that the detection and error numbers are accurate for their project's inspection program.

The inspection expert will review the preliminary flaw size curves from Step 4. If the flaw sizes are judged to be too small for reliable detection or reliable sizing, then either a revision will be suggested, or a decision to modify the inspection strategy will be made.

Step 6: Accept, Refine, or Abandon

After the preceding steps are completed, a decision is made. The lead engineer can accept the proposed alternative flaw acceptance criteria, modify the approach, or go back to the drawing board. An additional benefit of this approach is that the flaw sizes

can be recalculated during the fabrication and installation if an unforeseen issue arises.

Applications Where Developing Alternative Flaw Criteria May Not Be Practically Feasible

One of the most challenging applications for developing alternative flaw acceptance criteria is for designs where environmentally assisted cracking (EAC) is a credible concern. For these applications, typically the specific characteristics of the environment need to be estimated in advance, and the materials need to be tested under a simulated environment in the laboratory to determine representative crack growth rates and fracture toughness. In structural applications, concerns about EAC can often be greatly reduced by selecting materials that are known to not be susceptible in the given service environment.

A notable exception is hot-dip galvanizing (HDG). Any quantitative methodology for predicting crack ex-

tension under the combination of conditions that occur during HDG (e.g., transient hydrogen diffusion, transient thermal stresses, liquid metal-assisted cracking, and rate and temperature dependent material properties) will be fraught with uncertainty. To the authors' knowledge, no consensus methodology has been published for quantifying crack extension during the HDG process. In other words, if HDG is a project requirement, alternative flaw acceptance criteria should be applied with due caution, even healthy skepticism.

Product Management Considerations

Developing a new alternative flaw acceptance program calls for a level of cooperation among the technical disciplines that exceeds what is usually required for a standard codified approach. It is important to set expectations early in the project.

While there is no single method for estimating ECA cost, it will be in the range of \$15,000 to hundreds of thousands of dollars for time and materi-

als, excluding the cost to fabricate the test welds and conduct the inspection evaluation program. Relatively simple geometries, with relatively simple loading schemes, fabricated with well-established materials, and inspected using established methods will tend to be on the lower end of that range. The price tends to rise as complexity increases.

This raises the question of whether an alternative flaw criteria approach makes sense for one's next project. The short answer is that AWS D1.1, subclause 1.5 states that only the person meeting the definition of "engineer" for the project can officially answer that question. That being said, perhaps the discussion provided in this article can help. **WJ**

STEVEN ALTSTADT, PhD, PE (saltstadt@wje.com) and ROBERT WARKE, PE (rwarke@wje.com) are associate principals in the Metallurgy & Applied Mechanics Group of Wiss, Janney, Elstner Associates Inc., Northbrook, Ill.

This article is based on a presentation given at the Inspection Expo & Conference, January 21-23, 2020, Houston, Tex.

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- SAW Fluxes For Stainless Steel



WELDING MACHINES

- MMA
- TIG
- MIG/MAG
- Plasma Cutting
- SAW Welding Machine

Don't Break the News . . . or Your Pipeline

Selective seam weld corrosion can be identified in older pipes using in-line inspection data

BY BERNARDO CUERVO
AND MARK McQUEEN

This article describes a supplemental screening process, called the enhanced filtering analysis technique (EFAT™), that operators can perform as part of their due diligence to verify and validate the in-line inspection (ILI) survey. As a clear and structured protocol, EFAT can be described as a “second set of eyes” to analyze ILI data related to pipeline material, operating conditions, and environment. The process uses ultrasonic testing (UT) or magnetic flux leakage (MFL) data coupled with the ILI vendor’s display software to identify and prioritize potential longitudinal seam weld anomalies related to selective seam weld corrosion (SSWC) in pre-1970s pipe manufactured with low-frequency electric resistance welding (LF-ERW)

as well as pre-1980s pipe manufactured with high-frequency electric resistance welding (HF-ERW). The results of this process deliver a ranking of the anomalies to help operators prioritize integrity management efforts and resources.

Background

On July 8, 1986, an 8-in. pipeline transporting gasoline ruptured in Mounds View, Minn. Vaporized gasoline combined with air and liquid gasoline flowed along neighborhood streets. Approximately 30 min later, a vehicle entered the area, igniting the gasoline vapor. Two people were severely burned and later died.

Jones and Laughlin Steel Co., Pitts-

burgh, Pa., had manufactured the pipe that ruptured using LF-ERW. The pipeline failed at 1434 lb/in.², but had been hydrostatically pressure tested to 1900 lb/in.² just two years prior to this incident. In its accident report, the National Transportation Safety Board (NTSB, Ref. 1) determined the pipe’s susceptibility to SSWC contributed to the incident.

On January 28, 1988, and March 3, 1989, the Office of Pipeline Safety (OPS) issued alert notices (ALN-88-01 and ALN-89-01) to warn the pipeline industry of problems with pipe made with ERW, and the need for an effective means of identifying problems with longitudinal seams on electric resistance welded pipe manufactured before 1970.

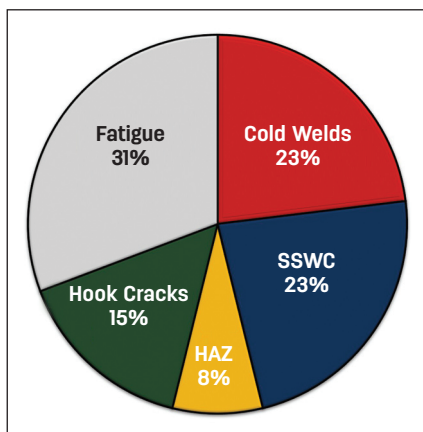


Fig. 1 — Type of seam defects causing in-service hazardous liquid pipeline failures (where metallurgical reports were available) between 1977 and 1988 (Ref. 2).

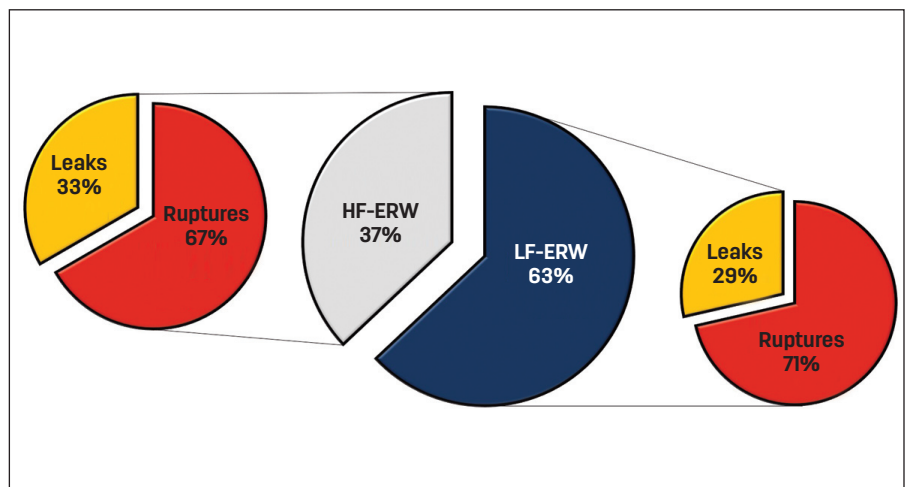


Fig. 2 — This illustration shows the percentage of leaks and ruptures for LF-ERW and HF-ERW failures along with the percentage of failures per type of seam from 2002 to 2007 (Ref. 2).

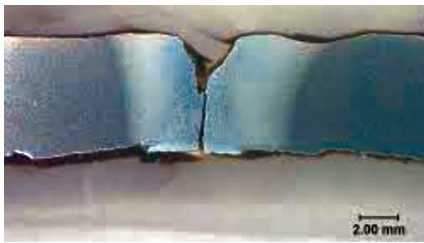


Fig. 3 — Metallographic cross section of a failure in a longitudinal seam weld, which was manufactured with LF-ERW, with SSWC (Ref. 5).

On August 1989, the Department of Transportation, through the Research and Special Programs Administration (later called the Pipeline Hazardous Materials Safety Administration, PHMSA), published a technical report (Ref. 2) that determined a total of 172 failures associated with LF-ERW in hazardous liquid pipelines between 1968 and 1988, as well as 103 seam failures associated with ERW in gas pipelines between 1970 and 1988. The report concluded the failure rate of pre-1970s electric resistance welded pipelines carrying hazardous liquids was about three times that of pre-1970s electric resistance welded pipe carrying natural gas.

Figure 1 shows in-service failures according to the type of defect found in metallurgical examinations. Selective seam weld corrosion represented 23% of all the defects causing failures (where metallurgical reports were available) in hazardous liquid pipelines between 1977 and 1988.

Selective seam weld corrosion anomalies do not need to be relatively large to cause brittle seam failure. Most failures in either LF-ERW or HF-ERW seams are ruptures, and they tend to be catastrophic — Fig. 2.

Following a 2007 pipeline inspection involving a pipe manufactured with LF-ERW by Lone Star Steel Co., Lone Star, Tex., in 1961, the NTSB issued Recommendation P-09-1 on the safety and performance of ERW pipe. In response, PHMSA initiated a study to identify actions that could be implemented by pipeline operators to eliminate longitudinal seam failures in electric resistance welded pipe. The first phase of the study led to 17 reports that documented the outcomes, observations, and recommendations. One of these reports, Subtask 1.3 (Ref. 3), recommended the following:

“The first necessary improvement is for the technologies to be able to

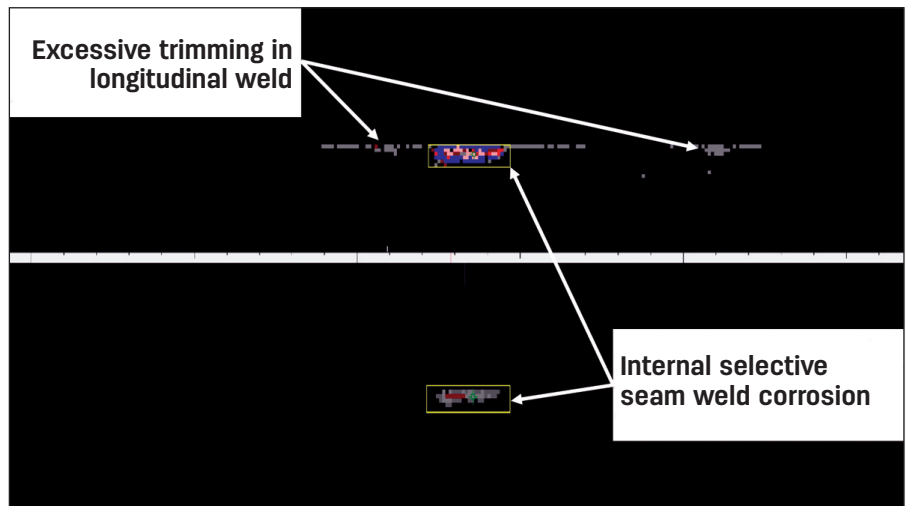


Fig. 4 — Ultrasonic scans of electric resistance welded pipe: Wall thickness scan (above) and stand-off scan (below).

correctly classify the anomalies as cold welds, hook cracks, selective seam weld corrosion, an anomaly that has been enlarged by fatigue crack growth, or some combination of these. These different kinds of defects have different impacts on pipeline integrity. Hook cracks and defects enlarged by fatigue tend to behave in a relatively ductile manner and usually have to be relatively large to cause a pipeline to fail in service. Cold weld defects or selective seam corrosion defects, on the other hand, tend to cause brittle fracture, and they do not necessarily have to be large for that to occur. Even, without improved sizing capabilities, this improvement could lead to more efficient screening of anomalies.”

Metal-Loss ILI Technologies

The application of ILI tools (“smart pigs”) has become an invaluable tool with pipeline operators for determining the integrity of their systems. Data collected from these inspections are widely regarded as reliable, repeatable, and verifiable, and can be applied to more than simply identifying defect locations. In-line inspection is a non-destructive examination technique used to measure the integrity of a pipeline from the inside of the pipe. A process referred to as “smart pigging” uses a device of either magnetic or ultrasonic technology to detect and record signals that are later interpreted for the presence of anomalies.

Both MFL and UT technologies (Ref. 4) have been used to detect and size corrosion of longitudinal welds with limited success. However, narrow

and deep defects in the long seam can be differentiated from imperfections with a detailed analysis of ILI data in context with previous ILI surveys, as well as other relevant information about the pipeline.

EFAT for Longitudinal Seam Weld Corrosion

In-line inspection vendors report all seam anomalies as simply metal-loss features. A metal-loss feature is an ultrasonic or magnetic ILI indication caused by any decrease in the wall thickness with dimensions and orientation within the specifications of the ILI tool. The ability to differentiate SSWC from other forms of metal loss (i.e., grinding, manufacturing anomalies, etc.) can significantly improve the screening of anomalies as well as the calculation of failure stress levels and predicted remaining life. This can help operators choose the correct fracture initiation model to maintain the integrity of their electric resistance welded pipelines.

The EFAT analysis process pertains to the review of ILI raw data for the presence of SSWC anomalies. The purpose of this is to help operators who currently own metal-loss ILI data to verify characterization, as well as discriminate and prioritize injurious anomalies using the ILI vendor’s display software.

The EFAT can be applied to anomalies detected by UT or MFL tools in pipe made using upset autogenous weld seams, specifically electric resistance and flash welded seams. This analysis helps operators to distinguish

between SSWC and ordinary corrosion crossing the seam. Ordinary corrosion generally does not pose an immediate threat to a pipeline's integrity, whereas actual SSWC does.

The information required to perform the EFAT is indicated below:

a) The UT or MFL ILI survey with good quality data (EFAT is not a replacement for a failed survey with sub-par data quality);

b) Information on the pipe that includes size, transported product, coating, pipe grade, seam producer, and year of production or pipeline construction;

c) ILI vendor proprietary display software and list of anomalies (pipeline register);

d) Alignment sheets, cathodic protection information, and any available ILI metal loss survey; and

e) Date of the initial mill or pre-service field pressure test (if any, which for some early construction involved gas tests), and details of last pressure tests.

EFAT requires the review of the UT and/or MFL data using the ILI vendor's proprietary analysis software (usually provided to the pipeline operator with the final ILI report). The data is then reviewed in context with additional information, such as year of pipeline construction, seam producer, alignment sheets, failure history, previous ILI surveys, and other relevant information on the pipeline.

SSWC Signature

In contrast with double submerged arc welded pipe, an electric resistance weld is generated without deposited weld metal. During UT of the longitudinal seam weld, sound can travel through the seam weld and may be reflected back to the sensors not only by internal features but also by metal loss anomalies, such as corrosion, grinding, or gouging. Figure 3 shows a typical failure of a pipe manufactured with LF-ERW affected by SSWC.

Figure 4 shows an internal SSWC anomaly in a section of pipe that also has areas of excessive trim at the longitudinal weld bond line area. The wall thickness C-Scan (upper part of Fig. 4) shows reductions in the wall thickness values. The excess trim is shown in gray, and the SSWC is shown in red

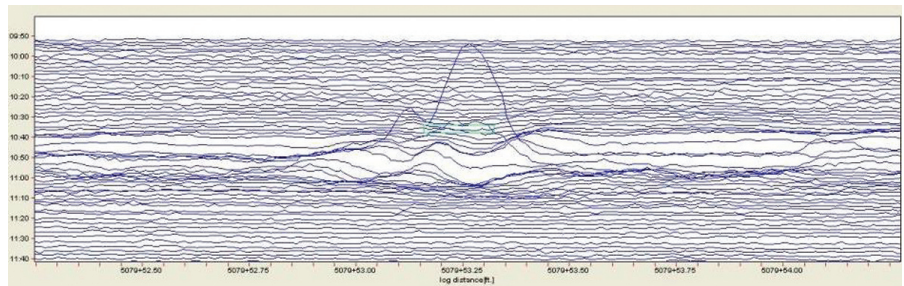


Fig. 5 — Circumferential magnetization indications of longitudinal SSWC.

and pink. The important characteristic of the signature for the enhanced analysis is the profile of the metal loss and the coincidental location of the seam weld anomaly.

Figure 5 shows an A-scan (analogous scan) of a circumferential MFL tool for LF-ERW and SSWC. The signal shows a pattern similar to that of corrosion, and the anomaly is in the longitudinal seam weld visible across the joint.

Conclusion

The following conclusions can be made:

1. An enhanced analysis can help pipeline operators focus on the anomalies that may threaten the integrity of their pipeline.

Not only can current ILI reporting of corrosion anomalies be vague (e.g., metal loss, manufacturing related, etc.) when left to be interpreted by pipeline operators, but they also often mischaracterize the actual anomaly. The use of broad category types makes it harder for field and integrity personnel to understand and prioritize defects for excavation and further investigation. A report with thousands of anomalies, many of them with the comment "at/near/across longitudinal weld" (i.e., a metal loss that may turn to be just an imperfection in the vicinity of the seam weld) does not add the proper value to the integrity program, yet it adds significant costs.

2. Pipeline operators need to use the correct fracture toughness value and the appropriate fracture initiation model for either preferential seam weld corrosion or ordinary corrosion across the longitudinal seam weld.

ILI-reported depths and lengths of metal loss anomalies are not enough to accurately perform remaining life, remaining strength, and burst pres-

sure calculations. General corrosion and defects enlarged by fatigue are prone to fail in a ductile manner. In general, they must be relatively large to cause a pipeline to fail in service. Selective seam weld corrosion anomalies tend to cause brittle fracture, and they don't necessarily have to be large for that to occur.

3. The EFAT can help operators prioritize response to anomalies, therefore optimizing cost and resources without compromising integrity.

In-line inspection surveys provide pipeline operators with a wealth of information, but operators must be willing to look beyond the standard reports. To ensure safety and reliability, PHMSA included section 195.591 ILI of pipelines in the Federal Pipeline Safety Regulations in February 2017 and included section 192.493 to the updated Gas Rule effective on July 1, 2020. This means, when conducting ILI of pipelines, each operator must comply with the requirements and recommendations of three documents incorporated by reference in §195.3. They are API 1163, *In-Line Inspection Systems Qualification*; NACE Standard Practice, *In-Line Inspection of Pipelines*; and ANSI/ASTN ILI-PQ-2010, *In-line Inspection Personnel Qualification and Certification*.

Gas and hazardous liquid operators need to generate quantitative comparisons to determine if critical anomalies have been classified and characterized using an appropriate level of conservatism. This requires for there to be a process in place with a second trained person to review the detailed data the ILI vendor provides.

The EFAT can also unlock the ILI by characterizing reported metal loss anomalies as SSWC, general corrosion, or grinding. After an enhanced filtering analysis, pipeline operators are

able to categorize long lists of anomalies into the following: immediate, near term, and long term.

4. The EFAT provides a means to confirm data quality and reporting of features that potentially impact integrity.

The EFAT will help as a second detailed review of the data, looking to confirm that there are no features or "signals" in the data that warrant additional investigation, like unusual features, signals, or interactions. Some areas of interest include the following:

- Areas of speed excursion and signal degradation,
- Dents that interact with either the long seam or a girth weld,
- Long areas of general corrosion,
- Corrosion around a girth weld (due to shrink sleeves or poor field ap-

plied coating),

- Corrosion in or across a long seam or girth weld, and
- Indications of selective seam corrosion.

5. The EFAT can provide an increased level of confidence in your data.

Managing the integrity of a pipeline is not only about what you found and responded to using ILI results. The true integrity of the pipe is based on how confident you were about the features that remain in the pipe that you decided not to respond to. **WJ**

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BERNARDO CUERVO (bernardo.cuervo@g2-is.com) is a principal integrity consultant and **MARK McQUEEN** (mark.mcqueen@g2-is.com) is an asset integrity risk manager at G2 Integrated Solutions, Houston, Tex.

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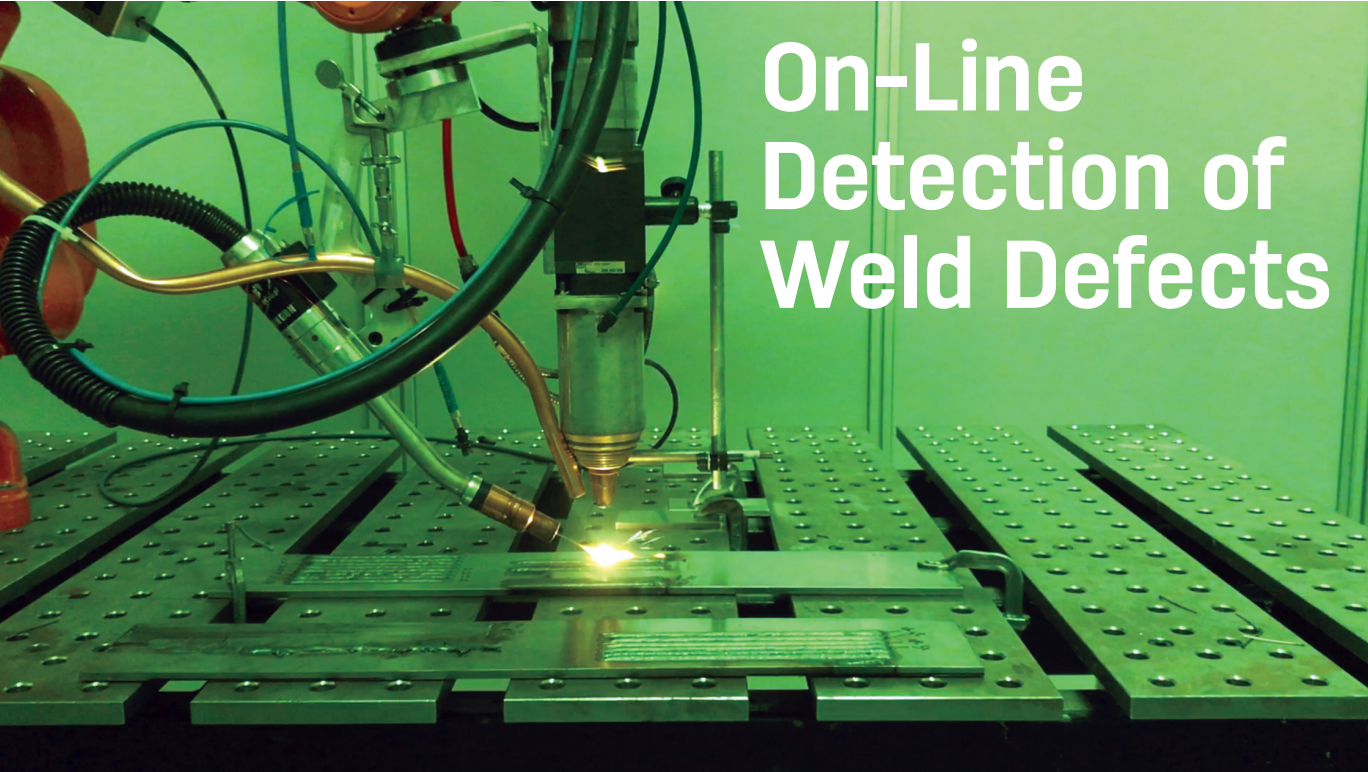
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On-Line Detection of Weld Defects

On-line detection by a smart optical monitoring system during laser hot wire cladding.

A smart optical monitoring system identifies subsurface pores and sudden changes of process parameters

BY J. CHOI AND J. MAZUMDER

The manufacturing industry plays an important role in the economy because of its influence on diverse application sectors, such as engineering, agriculture, automobiles, infrastructure, electronics, and more. Welding also accounts for a large fraction. Fortune Business Insights predicts the worldwide welding market will exceed \$48 billion (Ref. 1).

However, the manufacturing industry is facing challenges, including stringent customer demands, intensified competition to reduce lead and cycle times along with manual labor, and rigorous requirements to eliminate the liability of defective products. The key technical challenge is to obtain a reliable in-process sensor that will predict manufacturing quality, minimize material wastage and lost labor time, and increase long-term product quality. Cost consciousness and global competition raise awareness of the adoption of innovation to reduce manpower and scrap costs and, at the same time, improve product qualities.

The design of a reliable smart sensor is the answer to the technical challenge to guarantee the quality control of manufacturing products for a variety of industries. This article focuses on that topic, with an emphasis on a smart optical monitoring system (SOMS).

Quality Control Techniques Abound

Excess scrap, additional material cost, poor long-term product quality, and lost labor time are concerns for joining industries. So are in-situ quality assurance for welding defects. Joining defects deteriorate the mechanical properties of welded structures and, as a result, increase the risks of part failure. To detect the possible presence of different weld defects, sensing, monitoring, and inspection methods are necessary for quality control.

Table 1 — Comparison among Three Different On-Line Sensing Methods

	Vision-Based System		Acoustic	Plasma-Based System	
	Thermal	CCD/CMOS		Spectrometer	Photo Diode
Noise Rejection	Fair	Fair	Poor	Good	Good
Speed	> 10 ms	> 10 ms	> 1 ms	< 1 ms	< 1 ms
Computation	Heavy	Heavy	Fair	Fair	Minimum
Function/Defects	Temperature	Bead shape	Porosity	Multifunction	Some function
Defect Classification	Limited	Limited	Limited	Good	Limited
Composition Monitor	No	No	No	Yes	No
Microstructure	No	No	No	Yes	No
Prices	Fair	Fair	Fair	Fair	Low

Note: CCD/CMOS stands for charge-coupled device/complementary metal-oxide semiconductor.

In the welding industry, many types of inspection practices are used, including visual inspections by qualified personnel; nondestructive detections like magnetic particle, liquid penetration, radiographic, and ultrasonic testing to inspect external and internal weld defects, such as cracking and porosity, after a weld has been completed (Ref. 2); and a range of destructive tests. Real-time process monitoring presents an option to avoid or minimize defects, as well as reduce repair and quality assurance costs.

Exploring On-Line Methods

Because welding is such a complex process, many different physical phenomena will occur, such as electromagnetic radiation, optical and acoustic emission, and plasma generation. Therefore, different on-line sensing methods have been developed to monitor these in-process signals, detect part defects, and predict part qualities (see lead photo).

Among different methods, vision-based inspection systems, either thermal or charge-coupled device (CCD) based (Refs. 3, 4), acoustic-based inspection systems (Refs. 5, 6), and plasma spectroscopy inspection systems (Ref. 7) are under active use worldwide.

The quality of these on-line inspection methods heavily relies on efficient processing and accurate interpretation of the signals captured from the welding process. Table 1 gives a brief comparison of these three nondestructive on-line inspection methods. As an example, for vision- and acoustic-based systems, inspections are sometimes not reliable because of misinterpretations due to crossed signals by noises in both the process and industrial environment. Most of the real-time vision systems cost more than \$10,000 (Ref. 3).

Particularly promising are the sensors that analyze the behavior of plasmas generated in the arc/laser metal interaction zones. Spectroscopic sensors exhibit some remarkable features, such as immunity to strong electro-

magnetic interference and background acoustic noise associated with the arc welding process.

On the other hand, the analysis offers the possibility of tracing specific elements or species participating in the plasma by a SOMS utilizing spectroscopic sensors. Figure 1 shows an interior look with a digital signal processor (DSP) CCD detector, mirror, and more, then an exterior look of a product by SenSigma LLC, Ann Arbor, Mich.

In addition, by monitoring plasma information (such as line intensity, plasma temperature, or electron density) and by using standard deviation (different signal processing algorithm such as vector machine training or wavelet transforming), welding defects have been detected and classified.

Seeking a Solution

It is evident plasma plume plays an important role in the coupling of plasma radiation or electric discharge with the workpiece. Diagnosis of the plasma plume has been used to detect and categorize weld qualities. We adopt to incorporate the fundamental understanding of the mechanisms into the refined algorithm, to interpret plasma signals for improved weld defect tracking, learning, and detection, as well as classification performance. Reasons that cause different defects were produced, and the plasma characterization for each weld defect was analyzed.

After a basic understanding of different mechanisms on how the defects affect various characterizations of the plasma, an effective algorithm was developed for scenarios of both defect tracking/learning/detection and classification. When some features of the plasma are sensitive to certain types of defects and insensitive to others, they

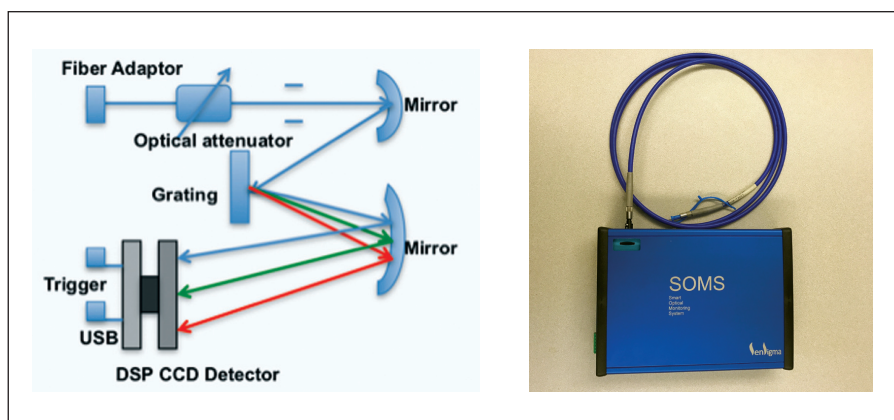


Fig. 1 — SOMS display, with an internal view detailed on the left and an external view of a unit on the right.

Table 2 — Design of Experiments (DOE) for Porosity Analysis

Level	Weld Voltage (V)	Wire Speed (mm/s)	Gun Orientation (deg)	Stickout Length (mm)
1	18	5	-15 (pull)	15
2	21	7.5	0	15
3	24	10	+15 (push)	15

are useful for both defect tracking/learning/detection and classification. These features of plasma parameters are identified and used in this case. Therefore, special attention was devoted to the identification of the spectral line with respect to a defect. Software was also developed to provide a visual marker when such defects were identified through a spectral line.

For porosity identification, it has been demonstrated a SOMS can identify the pore defect in the subsurface during the arc welding process. The spectral signal is often affected by the presence of pores inside the weld due to an instant increase of trapped gases from a shielding gas like argon or evaporated gases like hydrogen, oxygen, and nitrogen. The spectral intensity of those trapped gases, in general, affects the emission spectral signal during the welding process. Other defects, such as incomplete fusion, un-

derfill, and undercut, also affects emission spectral signal intensity during the welding process, varying the spectral intensity of certain metallic elements. Monitoring the variation of the spectroscopic signal of major elements (e.g., Fe, Cr, Ni, and so on), the defect can be classified and identified.

Various Applications

In this section, the application of SOMS for in-situ defect, composition, and process variation are discussed with the help of case studies.

Case 1: Defect Identification/Classification during Arc Welding

A gas metal arc welding (GMAW) machine (Fronius TransSteel 3500 power supply, with VR500 wire feeder,

and Tregaskiss gun, 500 A, air cooled) was utilized on the wrist of an articulated robot (ABB IRB 140 with an IRC5 controller). The substrate material was typical mild steel. The filler wire was from Lincoln Electric, Blue Max® GMAW 308LSi.

To identify defect features, such as voids, pores, and internal cracks during the manufacturing process, the following was carried out: industrial computerized tomography (CT) scans, an x-ray procedure that combines many x-ray images with the aid of a computer to generate cross-sectional views, and if needed, 3D images of the internal structure. A welding test matrix, based on design-of-experiments through the Taguchi method, was also built and performed to make experimental coupons for the CT scan analysis (as shown in Table 2). The porosity analysis was done after analyzing the CT scanned graphic data.

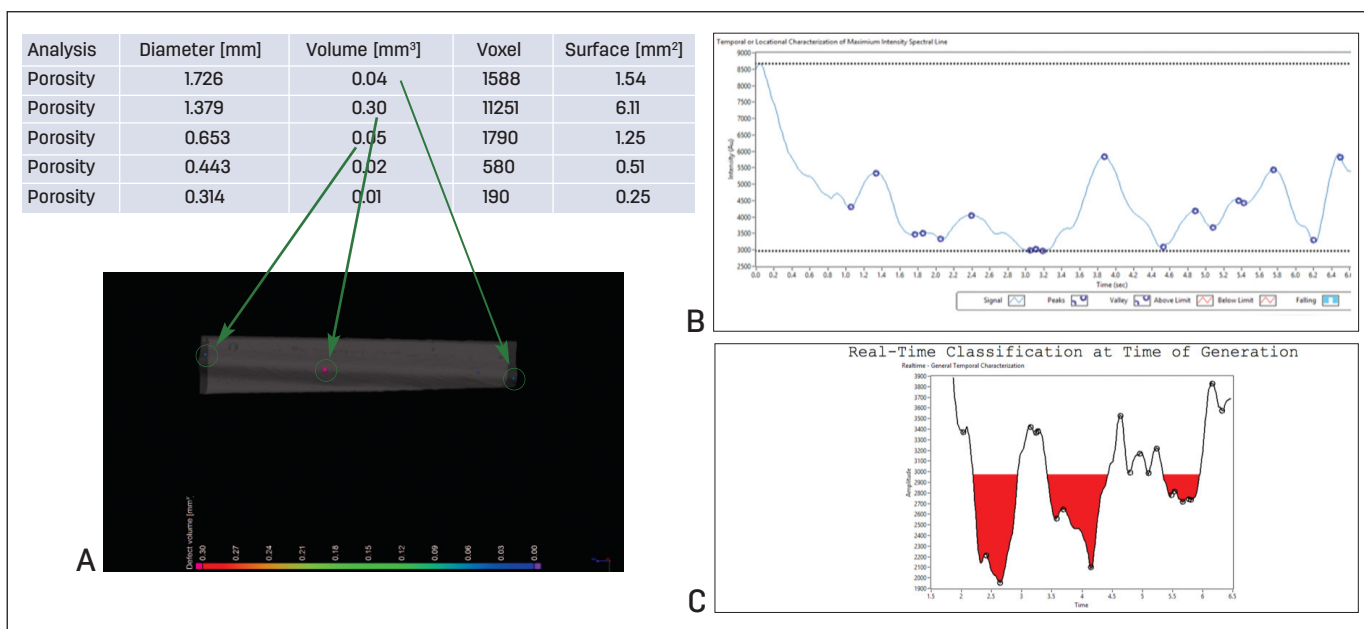


Fig. 2 — Comparison of the CT scanned data with temporal spectral data acquired by a SOMS (process parameters (sample #1): weld volt = 18 V, wire speed = 5 mm/s, gun = -15-deg pull, stickout = 15 mm). A — Data of porosity analysis and graphic image showing the location of pores; B — temporal spectral data before training by a SOMS; C — real-time classification after training by a SOMS (red zone: defect feature identified by a SOMS).

Figure 2 shows the comparison of the CT scanned graphic data with temporal spectral data before and after training by a SOMS. As shown in the graphic image, three circled areas were identified by a SOMS as the “defect zone” (red colored). The porosity analysis, utilizing CT scanned data, identified five different locations of “pores” — Fig. 2A. Three major defects (pore size diameter > 0.5 mm) were captured as a “defect zone” by a SOMS — Fig. 2C. The SOMS was able to capture the defects (pores/voids > 0.5 mm diameter); however, the smaller sizes of pores (< 0.1 mm) were not captured effectively. It should be noted the number of SOMS training (two trainings/each parameter) was not sufficient to identify the smaller size (< 0.1 mm) of pores, even if the CT scanned analysis could identify a minimum of ~ 25 micron size of pore with the weld coupon size of ~ 2 in. length × 0.5 in. width × 0.25 in. thickness. Therefore, until a more rigorous training algorithm is developed, the defect detection resolution is around 100 micrometer. Presently, research effort is underway to improve the resolution.

Case 2: Composition and Process Variation Identification during Laser Hot Wire Cladding

In laser hot wire cladding (LHWC), a hybrid joining process that combines a preheated wire with a solid-state laser using an arc welding controller, these case 2 experiments were carried out.

The LHWC process could provide minimal dilution with the base metal and high deposition rates. The tests were executed using a LHWC system at Lincoln Electric Automation, Cleveland, Ohio. The laser used for the process was Laserline LDF 6000-40 (wavelength 900 to 1070 nm), and the arc welding robot integrated with a gun and filler wire was used. The filler wire used for the test was Lincoln Electric’s Techalloy® 625. A mild steel, 6-in.-diameter round rod was used as a substrate.

To verify if a SOMS can detect the shielding gas fluctuation, another test was performed. As shown in Fig. 3, total spectral intensity was suddenly increased as the shielding gas was turned off. It verifies a SOMS can detect almost instantaneously if/when

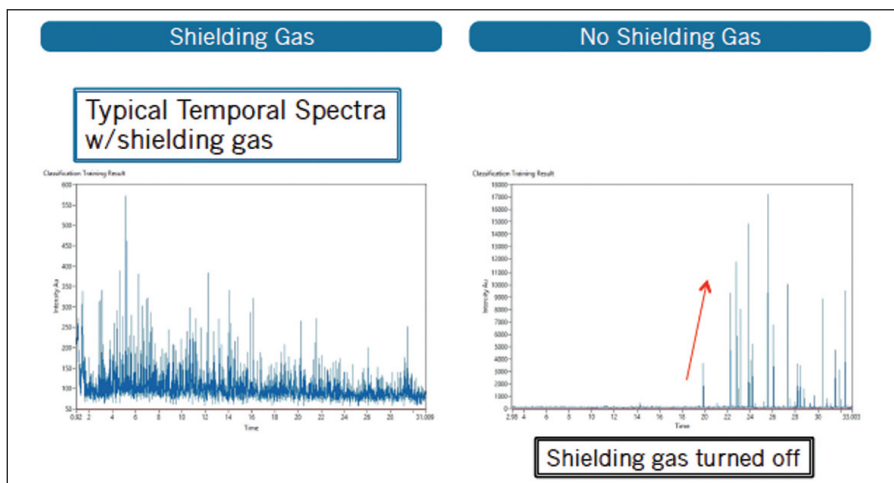


Fig. 3 — Detection of gas fluctuation by a SOMS (material: IN625).

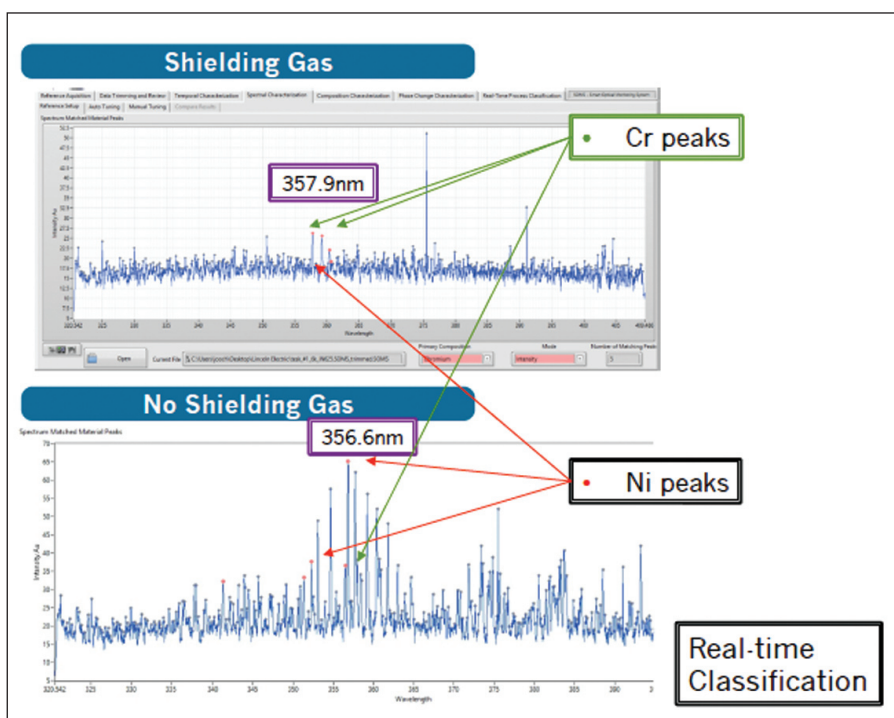


Fig. 4 — Comparison of shielding gas on and off on the element spectra (material: IN625).

shielding gas runs out or is turned off.

Figure 4 shows the comparison of element spectral intensity change between shielding gas on and off. It is noted without shielding gas, element peak intensity (Ni, Cr) increased. It means a SOMS can detect the absence/fluctuation of shielding gas.

Summary

A SOMS, when installed on a welding robot or additive manufacturing

machine, observes the plasma generated in real-time during a welding or material deposition operation. It uses optical emission spectroscopy to improve manufacturing quality and to increase no-defect product throughput in metal manufacturing processes. It also has fast signal processing capability. For sudden changes (weld power, wire feed rate, and shielding gas flow rate) of arc welding process parameters, a SOMS can monitor and identify the spectral intensity change. Additionally, it has a

capability to identify subsurface defect features, such as voids, pores, and internal cracks.

In conclusion, a SOMS is a technology for in-situ monitoring and control of phase transformation and composition by systematic diagnosis of the laser-induced plasma; is an advanced technology to detect and categorize manufacturing defects through understanding the affects of different defects on plasma and designing effective algorithms to interpret plasma signals; and has the potential to influence the metal manufacturing and materials processing industries. **WJ**

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J. CHOI (jchoi@sensigmallc.com) and J. MAZUMDER (mazumder@umich.edu) are with SenSigma LLC, Ann Arbor, Mich. MAZUMDER is also with the University of Michigan, Ann Arbor, Mich.



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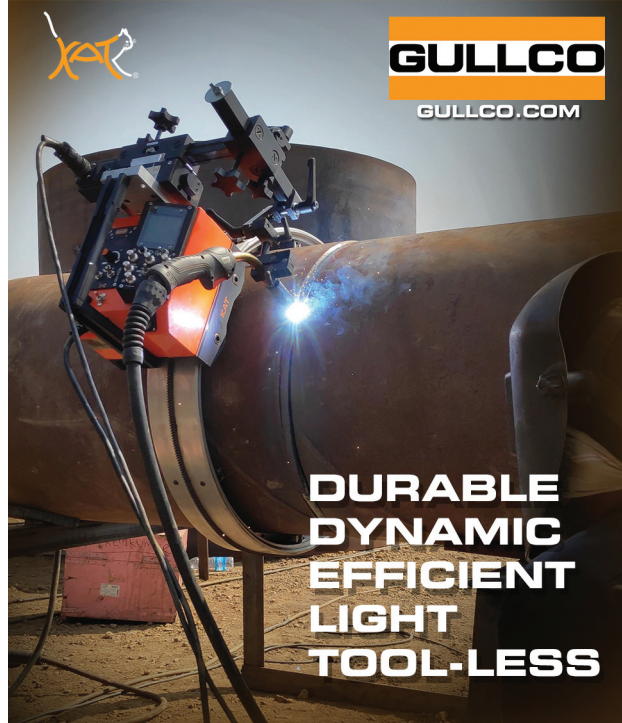


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☐ 1 Year-Digital *Welding Journal* \$15

☐ 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* \$171

\$ _____

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* \$171

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

☐ 2 Year - Print and Digital *Welding Journal* \$271

\$ _____

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 | P Engineering & Architectural Services (Including Assns.) | S Other |
| C Petroleum & Coal Industries | H Transport Equip. — Air, Aerospace | L Utilities | Q Misc. Business Services (Including Commercial Labs) | |
| D Primary Metal Industries | I Transport Equip. — Automotive | M Welding Distributors & Retail Trade | | |
| E Fabricated Metal Products | | N Misc. Repair Services (Including Welding Shops) | | |

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 | 20 Engineer — Design | 13 Research & Development | 09 Welder, Welding or Cutting Operator | 16 Student |
| | 21 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: _____

National and District Officers Nominated for 2021

The 2019–2020 Nominating Committee has announced its slate of candidates who will stand for election to American Welding Society (AWS) national offices for the 2021 term, which begins January 1, 2021.

Nominated are the following candidates: W. Richard Polanin for president; Dennis K. Eck, Michael A. Krupnicki, and Richard L. Holdren for vice presidents; and Michael M. Skiles and Nicholas Peterson for directors-at-large. One president, three vice presidents, and two directors-at-large are to be elected.

The National Nominating Committee was chaired by Past President Dale A. Flood. Serving on the committee with Flood were D. Joshua Burgess, David J. Landon, Duane K. Miller, Howard W. Record, J. Jones, John R. Bray, Kenneth Temme, Phillip I. Temple, Robert G. Pali, Shawn McDaniel, Tony H. Brosio, and William A. Rice. Chelsea L. Steel served as secretary.

The Nominating Committees for Districts 3, 6, 9, 12, 15, 18, and 21 have selected the following candidates for election/re-election as District directors for the three-year term Jan. 1, 2021–Dec. 31, 2023. The nominees

are Sean Moran, Dist. 3; Ronald H. Stahura, Dist. 6; Calvin E. Pepper, Dist. 9; Dale H. Lange, Dist. 12; Michael R. Hanson, Dist. 15; Thomas S. Holt, Dist. 18; and Jeff Davis, Dist. 21.

W. Richard Polanin, nominated to serve as president, is a retired professor and program chair of the manufacturing engineering technology and welding technology programs at Illinois Central College. He is currently coprincipal investigator for Weld-Ed, chair of the AWS Peoria Section, and vice-chair elect of the International Institute of Welding Commission XIV. He is also an active member of several AWS committees.

Dennis K. Eck, nominated to serve as vice president, is general sales manager for Praxair in the greater Houston area. He has been involved with the AWS Houston Section for 28 years, serving as chair, first and second vice chair, treasurer, and secretary. He was also a part of the AWS Membership Committee for seven years, and has been recognized with multiple AWS awards.

Michael A. Krupnicki, nominated to serve as vice president, is owner and president of Mahany Welding Supply

Co. Inc.; founder and executive director of Rochester Arc + Flame Center LLC; and founder and managing member of Molecular Independence LLC and Capricorn Ventures LLC. His 32-year involvement with AWS has included serving as Dist. 6 director as well as chair and treasurer of the Rochester Section.

Richard L. Holdren, nominated to serve as vice president, is president and principal welding engineer of Welding Consultants LLC, as well as senior welding engineer for Arc Specialties Technical Services. With more than 40 years' experience in welding engineering, he has served as member, advisor, and chair to numerous AWS certification, education, and technical committees. He is also an AWS Life Member.

Michael M. Skiles, nominated to serve as director-at-large, is retired from Airgas LLC. He has been active in AWS for more than 38 years, achieving both Silver and Life Member status. He has chaired the New Orleans and Acadiana Sections several times, as well as served two terms as Dist. 9 director. He currently sits on numerous AWS committees and the advisory board of six Louisiana community colleges.



W. Richard Polanin
president



Dennis K. Eck
vice president



Michael A. Krupnicki
vice president



Richard L. Holdren
vice president



Michael M. Skiles
director-at-large



Nicholas Peterson
director-at-large



Sean P. Moran
Dist. 3 director



Ronald H. Stahura
Dist. 6 director



Calvin E. Pepper
Dist. 9 director



Dale H. Lange
Dist. 12 director



Michael R. Hanson
Dist. 15 director



Thomas S. Holt
Dist. 18 director



Jeff Davis
Dist. 21 director

Nicholas Peterson, nominated to serve as director-at-large, is a welding engineer/curriculum developer for Miller Electric Mfg. LLC, faculty adviser at Arizona State University, and director/corporate secretary for NOCTI Business Solutions. Having joined AWS in 1990, he currently serves as vice chair of the Skills Competition Committee and member of the Education Committee. He is also an AWS Certified Welding Inspector (CWI) and Certified Welding Supervisor.

Sean P. Moran, nominated to serve as Dist. 3 director for a second term, is a welding engineer for American Hydro Corp. His 35-year involvement with AWS has included serving as Dist. 3 director from 2018 to 2020; Dist. 12 director from 2006 to 2010; and two terms as director-at-large from 2011 to 2015. He has served as chair, vice chair, and member of numerous AWS committees, subcommittees, and task groups. He is also a Senior CWI.

Ronald H. Stahura, nominated to serve as Dist. 6 director, is a strategic account manager for ESAB Welding & Cutting Products. A 36-year Life Mem-

ber of AWS, he has served the Niagara Frontier Section in various capacities, including chair from 1987 to 1988 and treasurer from 2015 to 2019. He is also an AWS CWI and Certified Welding Educator (CWE).

Calvin E. Pepper, nominated to serve as Dist. 9 director, is with DOT Quality Systems. An AWS Life Member, he served as director-at-large from 1996 to 1999, and has received various awards during his 42 years of service. He is presently a member of the AWS Qualification & Certification Committee and the Handbook Committee, both of which he previously served as chair. He has produced more than 20 publications on quality, inspection, nondestructive examination, and project management.

Dale H. Lange, nominated to serve as Dist. 12 director, is an AWS CWI and CWE, a Wisconsin State Weld Test Conductor, and an industrial consultant. He has taught welding, metallurgy, and metal fabrication at Northeast Wisconsin Technical College for 40 years. He has also received the AWS Dist. 12 Educators Award, the Howard

Adkins National Educator of the Year Award, and the Dist. 12 Dalton E. Hamilton CWI Award.

Michael R. Hanson, nominated to serve as Dist. 15 director, is a plant maintenance supervisor with Compass Electronics Solutions and an AWS CWI. An AWS member for more than 20 years, he has served the Northwest Section in multiple capacities, including chair in 2000 and 2004–2006. He is also the recipient of the AWS Section and District Meritorious, Section and District CWI of the Year, and District Director Certificate awards.

Thomas S. Holt, nominated to serve as Dist. 18 director, has been regional manager for TechCorr USA Management for 13 years. He is also active in his local Port Neches and Port Arthur Chamber of Commerce. He has been an AWS member since 1997 and has held many positions within the Sabine Section, including chair and vice chair. He has been assisting the AWS CWI seminar and proctoring the part A and C exams for more than a decade. He has also chaired several AWS committees.

Jeff Davis, nominated to serve as Dist. 21 director, a position he has held since 2016, has been retired from a large public agency since 2017. He has been active in the AWS San Diego Section for several years, holding the offices of chair, first vice chair, and second vice chair. He has also served as a member of various AWS technical committees. In addition to AWS activities, he sits on several high school and community college advisory committees for their welding programs. [WJ](#)

Nominations Sought for National Offices

American Welding Society (AWS) members who wish to nominate candidates for President, Vice President, Treasurer, and Director-at-Large on the AWS Board of Directors for the term starting Jan. 1, 2022, may either

1. Send their nominations electronically by Sept. 30, 2020, to Chelsea L. Steel at csteel@aws.org, c/o Thomas J. Lienert, chairman, National Nominat-

ing Committee, or

2. Present their nominations in person at the open session of the National Nominating Committee meeting scheduled for 2:00 to 3:00 p.m., Thursday, Nov. 19, 2020, at the Las Vegas Convention Center, Las Vegas, Nev., during the 2020 FABTECH Show.

Nominations must be accompanied by biographical material on each can-

didate, including a written statement by the candidate as to his or her willingness and ability to serve if nominated and elected, letters of support, and a 5- × 7-in. head-and-shoulders color photograph.

Note: Persons who present their nominations at FABTECH must provide 20 copies of the biographical material and written statement.

AWS Bylaws Article IX, Section 3

Section 3. Nominations.

Nominations, except for Executive Director and Secretary, shall proceed as follows:

(a) Nominations for District Directors shall be made by the District Nominating Committees [see Article III, Section 2(c)]. The National Nominating Committee shall select nominees for the other offices falling vacant. The names of the nominees for each office, with a brief biographical sketch of each, shall be published in the July issue of the *Welding Journal*.

The names of the members of the National Nominating Committee shall also be published in this issue of the *Welding Journal*, along with a copy of this Article IX, Section 3.

(b) Any person with the required qualifications may be nominated for any national office by written petitions signed by not less than 200 members other than Student Members, with signatures of at least 20 members from each of five Districts, provided such petitions are delivered to the Executive Director and Secretary before August 26 for the elections to be held that year. A biographical

sketch of the nominee (and acceptance letter) shall be provided with the petition. Any such nominee shall be included in the election for such office. A District Director may be nominated by written petitions signed by at least ten members each from a majority of the Sections in the District, provided such petitions are delivered to the Executive Director and Secretary before August 26 for the elections to be held that year. A biographical sketch and acceptance letter of the nominee shall be provided with the petition. Any such nominee shall be included in the election.

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, shorrero@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. **Orbital 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. **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). **High energy beam welding and cutting**, C7 Committee (C, E, G). **Hybrid welding**, C7D Subcommittee (G). **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). **Robotic and automatic welding**, D16 Committee (C, E).

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.

Aug. 4–6. B2 Committee and Subcommittees on Procedure and Performance Qualification. San Diego, Calif. Contact: J. Rosario, jrosario@aws.org, ext. 308.

Aug. 11, 12. D15 Committee and Subcommittees on Railroad Welding. Columbus, Ohio. Contact: J. Rosario, jrosario@aws.org, ext. 308.

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.

A5.11/A5.11M:20XX, *Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielding Metal Arc Welding*. This specification prescribes the composition, dimensions, soundness, and properties of weld metal for more than 40 classifications of nickel and nickel-alloy-covered electrodes. Major topics include general requirements, testing, manufacturing, identification, and packaging. A guide to using the specification is included in Annex A. Stakeholders: Nickel filler metal manufacturers, welding educators, welding designers, fabricators, consultants, and professionals with a general interest in welding with nickel electrodes. Revised Standard. Contact: R. Gupta, ext. 301, gupta@aws.org.

A5.13/A5.13M:20XX, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*. This specification prescribes the requirements for classification of surfacing electrodes for shielded metal arc welding. Classification is based upon the chemical composition of the deposited weld metal except for tungsten carbide electrodes, where classification is based on the mesh range, quantity, and composition of the tungsten carbide granules. A guide is appended to the specification as a source of information concerning the classification system employed and the intended use of the classified electrodes. Stakeholders: Producers of surfacing electrodes, welding educators, welding consultants, fabricators, welding designers, welding inspectors, and professionals with a general interest in shielded metal arc welding. Revised Standard. Contact: R. Gupta, ext. 301, gupta@aws.org.

A5.32M/A5.32:201X (ISO 14175:2008 MOD), *Welding Consumables — Gases and Gas Mixtures For Fusion Welding and Allied Processes*. This standard prescribes the requirements for the classification of gases and gas mixtures used in fusion welding and allied processes. Classification is based on the chemical compositions of the more popular single- and multicomponent

gases. Additional requirements are included for purity and moisture of individual gas components, testing, retesting, packaging, and cylinder or container labeling. An annex is appended to the standard as a source of information concerning the classification system and the intended use of gases and gas mixtures. Stakeholders: the welding industry. Revised Standard. Contact: R. Gupta, gupta@aws.org, ext. 301.

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.

B2.5/B2.5M:20XX (ISO/TR 18491:2015 MOD), *Specification for Measurement and Calculation of Arc Energy*. New Standard. \$25.00. ANSI public review expired 6/22/2020. Contact: J. Rosario, jrosario@aws.org, ext. 308.

C3.8M/C3.8:20XX, *Specification for the Ultrasonic Pulse-Echo Examination of Brazed Joints*. Revised Standard. \$40.00. ANSI public review expires 7/6/2020. Contact: K. Bulger, ext. 306, kbulger@aws.org.

C3.9M/C3.9:20XX, *Specification for Resistance Brazing*. Revised Standard. \$34.00. ANSI public review expires 7/6/2020. Contact: K. Bulger, ext. 306, kbulger@aws.org.

Revised Standard Approved by ANSI

D1.5M/D1.5:2020, *Bridge Welding Code*. Approval date: 4/24/2020.

AWS D1.2/D1.2M:2014 Errata

The following errata have been identified and will be incorporated into the next reprinting of this document.

AWS Standard: D1.2/D1.2M:2014,

Structural Welding Code — Aluminum
p. xi, Table of Contents: Delete line "Foreword . . . 179."

p. 67, 4.6: Change "A gas or gas mixture used for shielding shall comply with AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*" to "A gas or gas mixture used for shielding shall comply with AWS A5.32/ A5.32M, *Welding Consumables — Gases and Gas Mixtures for Fusion Welding and Allied Processes*."

p. 71, 4.21.5: Change "in conformance with 4.20" to "in conformance with 4.24."

p. 78, Figure 4.2: Change "TABLE 4.6" to "TABLE 5.3."

p. 81, 5.7.2: Change "in conformance with 4.21" to "in conformance with 4.24."

p. 84, 5.11: Change "in conformance with 4.21" to "in conformance with 4.24."

p. 102, 6.14.1: Change the reference from "Table 6.3" to "Table 6.2."

pp. 106–111, Clause 7: Change page header from "CLAUSE 7. STRENGTHENING AND REPAIR OF EXISTING STRUCTURES" to "CLAUSE 7. FRIC-TION STIR WELDING."

p. 174, Annex I: Change page header from "ANNEX K" to "ANNEX I."

p. 176, Annex J: Change page header from "ANNEX L" to "ANNEX J."

p. 210, Index: Change "Repairs, 4.21 & 4.21.5" to "Repairs, 4.24."

p. 210, Index: Change "Repairs, . . . of welds, 4.21.5" to "Repairs, . . . of welds, 4.24.5."

AWS D1.4 Intent Interpretation

Subject: Use of Essential Variables for Welding Procedure Specification Qualification

Code Edition: 2018

Code Provisions: Table 8.2, Essential Variable 11, Table 8.3

AWS Log: D1.4-18-I01

Inquiry 1: Is position an essential variable in D1.4/D1.4M:2018, Table 8.2?

Interpretation 1: Yes

Inquiry 2: Is it the intent of D1.4/D1.4M:2018, Table 8.2, item 11 "A change in groove type (e.g., flare-V to flare-bevel groove)" to actually refer as "A change in type of joint (e.g., direct butt to indirect butt) of D1.4/D1.4M:2018, Table 8.3?"

Interpretation 2: Yes

Inquiry 3: Must the test assemblies and the production joint being qualified in D1.4/D1.4M:2018 conform to one another within the limits of the essential variables?

Interpretation 3: See inquiry and response to Question 2 and answer of the D1.4-98-I02 interpretation.

Inquiry 4: Do direct butt welds (Fig. 8.5A) in D1.4/D1.4M:2018, Table 8.3 qualify single-V-groove, double-V-groove, single-bevel, and double-bevel groove welds as shown in D1.4/D1.4M:2018, Fig. 5.2?

Interpretation 4: Yes

Disclaimer: AWS D1.4/D1.4M:2018, *Structural Welding Code—Steel Reinforcing Bars*, is being revised to appropri-

ately address the concerns of this intent interpretation. A new code will be published as an amendment (AWS D1.4/D1.4M:2018-AMD1).

AWS D1.6/D1.6:2007 Interpretation

Subject: Welding Procedure Specification

Code Edition: 2007

AWS Log: D1.6-07-I08

Inquiry: Is macroetch testing for size required for both partial joint penetration (PJP) and fillet weld procedures that are qualified by complete joint penetration weld tests in accordance

with Table 4.2?

Interpretation: Yes, see subclause 4.1.7, Complete Joint Penetration Weld Qualification Limitations. Macroetch tests are still required to verify the design weld size and penetration for PJP and fillet welds (see 4.3.2 and 4.4).

AWS D1.1:2020 Errata

Errata have been identified and will be incorporated into the next reprinting of AWS D1.1/D1.1M:2020, *Structural Welding Code—Steel*. To view the errata, visit aws.org/standards/page/errata?#d1_2020.

MEMBERSHIP ACTIVITIES

2020 Membership Challenge

Listed here are the members participating in the 2020 Membership Challenge — point standings as of May 14. 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 41 of this *Welding Journal* or call the AWS Membership Dept. at (800) 443-9353, ext. 480.

J. W. Fregia, Houston — 95
A. D. Dillon, Detroit — 38
S. A. Milner, San Francisco — 36
B. J. Cain, Los Angeles/Inland Empire — 34
J. P. Theberge, Boston — 31
J. C. Durbin, Tri-River — 30
D. L. Galiher, Detroit — 29
T. A. Uff, Lehigh Valley — 29
D. P. Thompson, SW Virginia — 29
A. P. Duris, NW Ohio — 26
R. Young, Iowa — 24
T. Edwards, Tulsa — 20
H. J. Merrill II, Louisville — 20
W. H. Wilson, New Orleans — 17
B. A. Cheatham, Columbia — 17

O. Ortiz, Los Angeles/Inland Empire — 16
G. J. Smith, Lehigh Valley — 15
C. W. Gilbertson, Northern Plains — 14
V. O. Harthun, Northern Plains — 13
T. A. Harris, Altoona — 13
S. Silverstein, Milwaukee — 12
M. D. Stein, Detroit — 11

New AWS Supporters

Affiliate Corporate Members

Advanced Welding Technologies Inc.
3110 Pearl Ave.
Erie, PA 16510

Grip-Tite Mfg. Co.
505 E. Madison St.
Winterset, IA 50273

Heat Treating Inc.
6740 SE 110 St.
Bellevue, FL 34420

Mechanical Industries Inc.
314 Yampa St.
Bakersfield, CA 93307

North Alabama Fabricating Co. Inc.
1540 County Rd. 222
Cullman, AL 35057

Peak Architectural Metals
50 Co. Rd. 110,
Bldg. A
Glenwood Springs, CO 81601

Studwelding Solutions
P.O. Box 444
Pennington, NJ 08534

TruVision Solutions LLC
8350 W. Grandridge Blvd.,
Ste. 200
Kennewick, WA 99336

USA Sanlaser Co.
342 Broad St.
P.O. Box 3482
Fitchburg, MA 01420

Valkyrie Enterprises
4460 Corporation Ln.
Virginia Beach, VA 23462

Worldwide Welding & Fabrication LLC
424 Berlin St.
East Berlin, CT 06023

Supporting Company Members

Amfabsteel Inc.

100 Calle Industrial
Bernalillo, NM 87004

Erie Industrial Products

248 Artino St.
Oberlin, OH 44074

KairosPower

707 W. Tower Ave.
Alameda, CA 94501

PSS Professional Subsea Service

4 Diagorou St., Kermia House Office 203
Nicosia 1097 Cyprus

Raser Industries

1630 N. 9 St.
Reading, PA 19604

Sustaining Members

Exelon Nuclear Corp — West

4300 Winfield Rd.
Warrenville, IL 60555

Knight Construction & Supply Inc.

2601 E. 6 St.
Deer Park, WA 99006

Lake Air Products

385 90 Ave. NW
Coon Rapids, MN 55433

Educational Institution Members

East Central College

1964 Prairie Dell Rd.
Union, MO 63084

Farmersville High School

631 E. Walnut Ave.
Farmersville, CA 93223

George County Center — Mississippi Gulf Coast Community College (MGCCC)

11203 Old Hwy. 63 S.
Lucedale, MS 39452

Jackson County Campus — MGCCC

2300 Hwy. 90
Gautier, MS 39552

Learn Well Management and Technical Training Center LLC

Al Fahim Tower, Sheikh Rashid St.
Abu Dhabi, United Arab Emirates

Lincoln Electric Co.

22800 St. Clair Ave.
Cleveland, OH 44117

Newaygo County Career Tech Center

4645 W. 48 St.
Fremont, MI 49412

Paul D. Camp Community College

100 N. College Dr.
Franklin, VA 23434

Perkinston Campus — MGCCC

51 Main St.
Perkinston, MS 39573

Poudre High School — Technology Education

201 Impala Dr.
Fort Collins, CO 80521

Spark Welding Academy

6030 Brittmoore Rd. #A1
Houston, TX 77041

West Harrison County Center — MGCCC

21500 B St.
Long Beach, MS 39560

AWS Member Counts June 1, 2020

Sustaining	584
Supporting	360
Educational	839
Affiliate	609
Welding Distributor	64
Total Corporate	2456
Individual	56,683
Student + Transitional	10,695
Total Members	67,378

Technical Advisory Group Formed for ISO Underwater Welding

A new U.S. Technical Advisory Group (TAG) for the ISO/TC 44/SC 15 standard on underwater welding has been created. The scope of the new group is standardization of all aspects of underwater welding, including pro-

cedure and performance qualification in wet and dry hyperbaric environments, as well as classification of welding electrodes for underwater welding.

The American Welding Society is

actively looking for TAG members to participate and review ISO draft standards for underwater welding.

For more information, contact U.S. TAG Secretary Andrew Davis at adavis@aws.org.

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. Kevin Roossink is profiled on the following page.

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.

AWS Member Profile



Kevin Roossinck

Growing up on an apple orchard in Fremont, Mich., Kevin Roossinck's high school dreams involved being a pilot. However, his life would take a different route after his father, John, suggested he enroll in a two-year welding program at a nearby career center. Beginning in his junior year of high school, Roossinck continued with the program until he graduated high school.

"My father knew the head of the welding program at the local career tech center and encouraged me to attend the welding classes as a way of learning a skill that could help pay my way through college," he recalled. "We learned the basic welding processes and welded coupons of carbon and stainless steels, various joint designs, and welding positions."

The welding program also unveiled to him other career paths within the welding industry, such as welding engineering. After a tour of the welding engineering program at Ferris State University, Big Rapids, Mich., Roossinck began to reconsider his original plan to become a pilot.

"My instructor at the career tech center had attended Ferris State University's welding engineering program and arranged a tour of the facility, guided by Ken Kuk, the program coordinator at the time," he said. "It was my first exposure to any engineering program and opened up my eyes to

"What I like best about my job is working with different organizations to solve big problems. It's a big shipyard with lots of interesting and unique challenges."

the career possibilities if I obtained a welding engineering degree. I had already been starting to question whether or not an airline pilot was a realistic career goal for me, and after spending a summer in a welding shop, a career as a welding engineer had a lot of appeal to me."

Soon after, Roossinck became a welding engineering student at Ferris State University. In his last two years of college, he worked as an intern at a small, Tier 3 automotive supplier.

Before graduating with his bachelor's degree, Roossinck was offered a job as an associate welding engineer with Ingalls Shipbuilding, a shipyard located in Pascagoula, Miss. Nearly 16 years later, Roossinck is still with the company. He is presently manager of the company's welding engineering department.

"I am responsible for all of our internal procedures related to welding and ship construction. In addition, the welding engineering department is responsible for facilitating the approval of vendor procedure qualifications," he explained. "We support production and engineering in all aspects of the shipbuilding process and are involved in productivity improvement initiatives, capital equipment purchases, and installation, as well as failure analysis."

Roossinck's job permits him to work with a diverse group of professionals to brainstorm solutions to challenging issues.

"What I like best about my job is working with different organizations to solve big problems. It's a big shipyard with lots of interesting and unique challenges. It's a lot of fun to work through challenges with the skills and abilities of individuals in other departments," he said.

Roossinck's job also allows him to be involved with one-of-a-kind, large-

scale projects. One such project involved the installation of a "multimillion dollar, state-of-the-art panel line."

"I worked with a team on the project start to finish, from developing the specifications to overseeing the installation, commissioning and turnover to production," he said.

Projects such as these give him the opportunity to learn new things and branch out as a professional.

"I learned so much about many aspects that had nothing to do with my education, such as getting imported equipment classified for customs purposes and what kind of infrastructure has to be in place prior to heavy equipment installation," he said. "Most of the equipment came from a company in Finland called Pemamek, so I got to meet a lot of interesting people and was faced with a diverse set of challenges associated with getting extremely heavy equipment shipped across the Atlantic Ocean."

Looking to the future, Roossinck hopes to continue to hone his skills at Ingalls Shipbuilding, while also helping to grow the department he is so proud of.

"My goal is to continue the respected reputation that the welding engineering department at Ingalls Shipbuilding enjoys, which was developed by my mentor Lee Kvidahl. He retired from this job after more than 40 years spent building that reputation," he affirmed. "I want to build a deep and strong bench of welding engineers, and then potentially move on to roles of increasing responsibility within the company if the opportunity presents itself."

When he's not working, Roossinck enjoys spending time on Gulf Coast beaches with his wife and four children. He also likes golf and other outdoor activities.

District 1

Douglas A. Desrochers, director
(508) 763-8011
dadaws@comcast.net

District 2

Harland Thompson, director
(631) 546-2903
harland.w.thompson@ul.com

District 3

Sean Moran, director
(717) 885-5039
sean.moran@ahydro.com

District 4

Mr. Lynn Showalter, director
(757) 848-8029
lynneshowalter@gmail.com

District 5

Howard Record, director
(352) 816-0835
howard@rtdtools.com

District 6

Ronald Stahura, director
(716) 207-7869
rstahura@esab.com

District 7

Roger E. Hilty, director
(740) 317-9073
rhilty@comcast.net

District 8

James Thompson, director
(256) 347-6481
jim.thompson@wallacestate.edu

District 9

Michael Skiles, director
(337) 501-0304
michaelskiles@cox.net

District 10

Mike Sherman, director
(216) 570-9348
mike@shermanswelding.com

District 11

Phillip Temple, director
(734) 546-4298
nwcllc_ptemple@att.net

DETROIT February 28

Location: Muskegon Community College, Sturuss Technology Center, Muskegon, Mich.
Summary: Deputy District Director Mark Rotary attended the 3rd Annual Muskegon Community College Welding Competition. He awarded two \$1000 scholarships to exemplary graduating seniors. Welding students from Muskegon Tech Center, Newaygo County Regional Educational Service Agency and Greenville High School participated in the competition.

District 12

Dale Lange, director
(715) 732-3645
dale.lange@nwtc.edu

District 13

Ronald Ashelford, director
(815) 218-8766
r.ashelford@rockvalleycollege.edu

District 14

Tony Brosio, director
(765) 215-7506
tbrosio@yahoo.com

District 15

Michael Hanson, director
(763) 221-5951
mikhan318@comcast.com

District 16

Karl Fogleman, director
(402) 677-2490
fogleman3@cox.net



DETROIT — Deputy District Director Mark Rotary awarded Welding Competition Scholarships of \$1000 each to two students.

District 17

J Jones, director
(832) 506-5986

District 18

Thomas Holt, director
(409) 721-5777
tholt@techcorr.com

District 19

Shawn McDaniel, director
(509) 793-5182
shawnm@bigbend.edu

District 20

Denis Clark, director
(208) 357-6626
denis.clark.51@gmail.com

District 21

Sam Lindsey, director
(858) 740-1917
slindsey@sandiego.gov

District 22

Robert Purvis, director
(916) 599-5561
purviswelds@gmail.com



COLORADO — Kyle Moorehead from WJMG (center) received the Section Meritorious Award. Pictured with him (from left) are Jesse Grantham, WJMG; Jeremy Mowry, shop foreman BSM; Bob Teusher, AWS past president and president of AJAX Industries; and Tom Keinbalm.

COLORADO

April 18

Location: E. B. Rains Jr. Memorial Park, Northglenn, Colo.
Summary: Section members held a lunch meeting to discuss monthly business and hand out awards.

May 6

Location: Welding & Joining Management Group, Frederick, Colo.
Summary: A dinner meeting was held to discuss Section business and present awards.



COLORADO — Seen at the April meeting are Jeremy Mowry, Jim Cade, and Bob Teusher.



COLORADO — AWS Past President Bob Teusher (far left) and Vice Chair Jeremy Mowry (far right) with award recipients (from left) Jim Jones, Colorado Department of Transportation; Steve Pinero, Colorado Department of Transportation; Ariel Black Greening; and Jim Cade.

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American Welding Society®

8669 NW 36 St., #130
Miami, FL 33166-6672
(800/305) 443-9353
Phone extensions are in parentheses.

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Gesana Villegas.. gvillegas@aws.org(252)

Senior Vice Presidents

Cassie Burrell.. cburrell@aws.org(253)
Research, Strategy, and Membership

John Gayler.. gayler@aws.org(472)
Welding & Technology

Vice President

Annette Alonso.. aalonso@aws.org(299)
Publishing

EXECUTIVE OFFICE

Associate Director
Chelsea Steel.. csteel@aws.org(294)

Program Administrator, National Awards

Malisa Mercado.. mmercado@aws.org(293)

HUMAN RESOURCES

Director
Alex Diaz.. adiaz@aws.org(209)

GOVERNMENT LIAISON SERVICES

Hugh Webster.. hwebster@wc-b.com
Webster, Chamberlain & Bean, Washington,
D.C. (202) 785-9500; Fax: (202) 835-0243
Monitors federal issues of importance to the
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CONVENTION AND EXPOSITIONS

Director, Expositions
Matthew Rubin.. mrubin@aws.org(239)

Senior Sales Executive, Expositions

Sarah Dickson.. sdickson@aws.org(297)

ITSA — INTERNATIONAL THERMAL SPRAY ASSOCIATION

Program Manager
Alfred Nieves.. anieves@aws.org(467)

RWMA — RESISTANCE WELDING MANUFACTURING ALLIANCE and WEMCO — ASSOCIATION OF WELDING MANUFACTURERS

Program Manager
Adrian Bustillo.. abustillo@aws.org(295)

INFORMATION SYSTEMS

Managing Director
John Perry.. jperry@aws.org(247)

PUBLISHING & EDITORIAL

Dept. information(275)

Welding Journal Publisher/Editor

Annette Alonso.. aalonso@aws.org(299)

Managing Editor

Kristin Campbell.. kcampbell@aws.org(257)

Society News Editor

Katie Pacheco.. kpacheco@aws.org(275)

Section News Editor

Cindy Weihl.. cweihl@aws.org(256)

Inspection Trends Editor

Carlos Guzman.. cguzman@aws.org(348)

MEMBER SERVICES

Dept. information(480)

Director, Membership

Nici Banks.. nbanks@aws.org(270)
Serves as a liaison between members and
AWS headquarters.

Senior Manager, Sections and Student Chapters

Darrill Gaschler.. dgaschler@aws.org(260)

CERTIFICATION SERVICES

Dept. information(273)

Managing Director

Denny Smith.. dsmith@aws.org(263)

ACCREDITATION

Senior Manager
Emil Pagoaga.. epagoaga@aws.org(448)

EDUCATION & TRAINING

Director
Alicia Garcia.. agarcia@aws.org(229)

CONFERENCES & EVENTS

Dept. information(213)

SALES & CUSTOMER SERVICE

Managing Director
Michael Walsh.. mwalsh@aws.org(350)

Senior Sales Executive, Corporate

Sandra Jorgensen.. sjorgensen@aws.org(254)

STANDARDS DEVELOPMENT

Dept. information(340)

Director — Standards Development

Peter Portela.. pportela@aws.org(311)
Technical Committee Activities, Additive
Manufacturing, Structural Subcommittees on
Bridge Welding and Titanium

Director — International Activities

Andrew Davis.. adavis@aws.org(466)
International Standards Activities, American
Council of the International Institute of Welding

Program Managers

Stephen Hedrick.. steveh@aws.org(305)
Metric Practice, Safety and Health, Joining
of Plastics and Composites, Personnel and Faci-
ilities Qualification, Mechanical Testing of Welds,
Welding in Sanitary Applications

Stephen Borrero.. sborrero@aws.org(334)
Definitions and Symbols, Structural Sub-
committees on Reinforcing Steel and Stainless
Steel, Joining of Metals and Alloys, Piping and
Tubing

Rakesh Gupta.. gupta@aws.org(301)
Filler Metals and Allied Materials, Interna-
tional Filler Metals, UNS Numbers Assignment,
Computational Weld Mechanics

Jennifer Molin.. jmolin@aws.org(304)
Structural Welding, Sheet Metal Welding

Mario Diaz.. mdiaz@aws.org(310)
Automotive, Resistance Welding, Resistance
Welding Equipment, Welding and Brazing in
Aerospace, Friction Welding

Kevin Bulger.. kbulger@aws.org(306)
Brazing and Soldering, Methods of Weld In-
spection, High-Energy Beam Welding, Welding
in Marine Construction, Welding of Machinery
and Equipment

Jennifer Rosario.. jrosario@aws.org(308)
Oxyfuel Gas Welding and Cutting, Railroad
Welding, Robotics Welding, Thermal Spraying,
Welding Iron Castings, Welding Qualification

Welding Handbook Editor

Kathy Sinnes.. ksinnes@aws.org(255)

CUSTOMER SERVICE & SUPPORT

Customer Service.. customerservice@aws.org (280)

AWS FOUNDATION INC.

aws.org/w/a/foundation
General Information
(800/305) 443-9353, ext. 212, jdouglass@aws.org

Chairman, Board of Trustees

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Associate Director, Foundation Services

John Douglass.. jdouglass@aws.org(212)

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American Welding Society

Note: The 2020 schedules for all certifications are posted online at 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
Los Angeles, CA	Aug. 2-7	Aug. 8
Hutchinson, KS	Aug. 2-7	Aug. 8
Beaumont, TX	Aug. 2-7	Aug. 8
Denver, CO	Aug. 9-14	Aug. 15
Philadelphia, PA	Aug. 9-14	Aug. 15
Salt Lake City, UT	Aug. 9-14	Aug. 15
San Diego, CA	Aug. 16-21	Aug. 22
Miami, FL	Aug. 16-21	Aug. 22
Chicago, IL	Aug. 16-21	Aug. 22
Charlotte, NC	Aug. 16-21	Aug. 22
Sacramento, CA	Aug. 23-28	Aug. 29
Des Moines, IA	Aug. 23-28	Aug. 29
Chattanooga, TN	Aug. 23-28	Aug. 29
Miami, FL	Sept. 13-18	Sept. 19
Houston, TX	Sept. 13-18	Sept. 19
Seattle, WA	Sept. 13-18	Sept. 19
Benicia, CA	Sept. 20-25	Sept. 26
Louisville, KY	Sept. 20-25	Sept. 26
Minneapolis, MN	Sept. 20-25	Sept. 26
New Orleans, LA	Sept. 27-Oct. 2	Oct. 3
Boston, MA	Sept. 27-Oct. 2	Oct. 3
Nashville, TN	Sept. 27-Oct. 2	Oct. 3
San Antonio, TX	Sept. 27-Oct. 2	Oct. 3
Miami, FL	Oct. 4-9	Oct. 10
Long Beach, CA	Oct. 11-16	Oct. 17
Detroit, MI	Oct. 11-16	Oct. 17
Tulsa, OK	Oct. 11-16	Oct. 17
Atlanta, GA	Oct. 18-23	Oct. 24
Las Vegas, NV	Oct. 18-23	Oct. 24
Houston, TX	Oct. 18-23	Oct. 24
Kansas City, MO	Oct. 25-30	Oct. 31
Pittsburgh, PA	Oct. 25-30	Oct. 31
Orlando, FL	Nov. 1-6	Nov. 7
Indianapolis, IN	Nov. 1-6	Nov. 7
Reno, NV	Nov. 1-6	Nov. 7

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	July 15-17	July 18
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
Albuquerque, NM	July 26-31
Houston, TX	Aug. 9-14
Indianapolis, IN	Aug. 16-21
Orlando, FL	Sept. 13-18
Sacramento, CA	Oct. 4-9
Dallas, TX	Oct. 11-16
Denver, CO	Oct. 25-30
St. Louis, MO	Nov. 1-6
New Orleans, LA	Nov. 8-13
Miami, FL	Dec. 6-11

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 Resistance Welding Technician

A comprehensive two-day seminar to arm attendees with the knowledge needed to take the exam with confidence.

Location	Seminar Dates
Cleveland, OH	July 13-14
Nashville, TN	Oct. 27-28

Certified Welding Supervisor (CWS)

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

Location	Seminar Dates
Atlanta, GA	Dec. 6-11

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.org/certification/detail/certified-radiographic-interpreter.

Location	Seminar Dates	Exam Date
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 [WJ](http://www.wj.com)

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.org/certification/docs/schedules.html. For information on AWS seminars and certification programs, or to register online, visit aws.org/certification or call (800/305) 443-9353, ext. 273 for Certification; or ext. 455 for Seminars.

Eriez® Appoints CEO and President



L. Guenthardt

Eriez®, Erie, Pa., a separation technologies provider, has selected Lukas Guenthardt as president and CEO. Guenthardt joined the company's board of directors in 2011 and was named executive vice president of global strategy and development in 2014. Previously he was with K-Tron International for 20 years, serving in various executive capacities during that time. He started in K-Tron's research and development department and then relocated to Switzerland to direct European and Asian operations. He later moved back to the United States to head the company's strategy and acquisition activities and subsequently was named president of K-Tron's Size Reduction Group.

Arc Specialties Hires Sales Application Engineering Representative



J. Stoll

John Stoll has joined Arc Specialties, Houston, Tex., a supplier of automated manufacturing systems and custom equipment for joining, as an outside sales application engineering representative. Stoll previously served as an application engineer and strategic accounts manager at voestalpine Bohler North America for five years. This is preceded by his 27 years of service with Lincoln Electric Metrode Products Ltd. from which he retired as the North American manager of alloys. He is a life member of the American Welding Society (AWS) with more than 40 years of continuous service, and a past AWS District 18 di-

rector. He was elected and served on the executive committee of the AWS board of directors in 2016. He is also a member of NACE and ASME, where he serves on several API committees, including A582 and A934G. He has served on the advisory boards for both San Jacinto College and Tulsa Welding School — Houston campus. He has been a judge for the Houston Livestock Show's Ag-Mechanics contest for the past 20 years. He has also developed, produced, and conducted yearly welding symposiums for the greater Gulf Coast area.

Lincoln Electric Announces Retirement of Executive Vice President



G. D. Blankenship

Lincoln Electric, Cleveland, Ohio, designer, developer, and manufacturer of arc welding products, automated joining, assembly and cutting systems, plasma, and oxyfuel cutting equipment, has announced George D. Blankenship, executive vice president and president of the Americas welding segment is retiring. Blankenship joined the company in 1985 as an engineering trainee and held various engineering and product development management positions until 2009, when he was promoted to senior vice president and president North America. In 2016, he was named executive vice president and president of Americas welding. During his 35-year tenure, his technical, strategic, and operational contributions have advanced the company's competitive position.

Emerson Makes Leadership Promotions

Emerson, Elyria, Ohio, has appointed Justin King as vice president of engineering and Rob Trefz as vice president of marketing within its Professional Tools business to create synergies between the RIDGID and Greenlee



J. King



R. Trefz

brands. Both King and Trefz bring leadership skills and experience working for the company's brands to their new roles. In his role, King will lead the development and evolution of the entire Professional Tools line of pipe and electrical products, including RIDGID and Greenlee. He has worked with Greenlee since 2007, joining the company as country manager for China. He then held various roles in strategy and business development, product management, and engineering. Following Emerson's acquisition of Greenlee in 2018, he became director of engineering and innovation for Greenlee within the Professional Tools business.

Trefz will oversee all product management, product marketing, and marketing strategy; assuring the products meet the needs of tradespeople worldwide and that the benefits are effectively communicated. Trefz has worked with the company since 2004, joining as a global commodity manager. He held procurement roles for Emerson and its motor division before moving into various marketing and business development roles at RIDGID. He most recently held the position of vice president of marketing for Greenlee.

Test Equipment Distributors Adds Sales Representative

Test Equipment Distributors, Troy, Mich., a provider of equipment, supplies, service, and repair needs of non-destructive examination (NDE), has appointed Jeff Sengenberger as sales representative for NDE equipment and services. He will be responsible for sales and technical support in the midwest, including Iowa, Illinois, Minnesota, Missouri, and Wisconsin. Sen-



J. Sengenberger

genberger has nearly 40 years of NDE experience. Prior to joining the company, he was vice president of quality solutions at System One Holdings, where he managed their quality programs group serving organizations in the govern-

ment, nuclear, gas, and petrochemical industries. Previously, he was director of quality programs at AECOM, managing a staff of more than 400 NDE and quality assurance/quality control professionals.

Obituary

Ruben Burks



R. Burks

Ruben Burks, former secretary-treasurer of The International Union, United Automobile, Aerospace, and Agricultural Implement Workers of America (UAW) passed away on April 6. He was 86. Burks' long history of unionism and ad-

vocacy for social justice started in 1955 when he began working as an assembler at the former General Motors Fisher body plant 2 in Flint, Mich., where he joined UAW Local 598. He steadily rose through the ranks of the Local, serving in various leadership posts, including shop committee person and executive board member. In 1970, he was appointed as the international representative in Region 1C. By 1989, he was the director of Region 1C and held that position for three terms. He restructured the community action program to emphasize issue education and recruiting and training UAW members to work as volunteers in campaigns in the region. In 1998, he became the first African American International UAW secretary-treasurer, a post he held until 2002.

He was very active in the Flint com-

munity, holding a leadership post in Flint Genesee County Economic Development, and becoming the first labor leader to chair the Board of Trustees of the United Way of Genesee and Lapeer counties in 1991. He also was director of the Flint Urban League, director of Goodwill Industries of Flint, an advisory board member of the University of Michigan-Flint, and a leader with the UAW-General Motors Community Health Care Initiative in Flint. He received an honorary degree in community development from Mott Community College, in recognition and appreciation of his contributions to the Flint community. In December 2017, Local 598 renamed its union hall Ruben Burks Hall to honor his decades of leadership.

Charles Roland Credicott



C. R. Credicott

Charles Roland Credicott died on May 9, in Fort Worth, Tex. He was 76. Born in Breckenridge, Tex., Credicott graduated in 1963 from Breckenridge High School where he played football, basketball, and ran track. He later attended and graduated from East Texas State University. He was called the "Encyclopedia of Welding" and was well respected for his knowledge. He taught welding at a high school in Plano, Tex., followed by Brazosport College, then Tarrant County Community College in Fort Worth, Tex., where he retired after more than 40 years in education. He continued to work parttime conducting welding inspections and certifications throughout the state. An AWS Certified Welding Educator since the 1970s, Credicott was recently nominated and chosen for the District 17 AWS Certified Welding Inspector of the Year Award upon his passing. He is survived by his wife of 50 years, Jean Ann; brother; brothers-in-law; and nine nieces and nephews. Donations can be made in Charles's memory to either the Pellizzari Youth Fund, Breckenridge Meals on Wheels, or the Swenson Memorial Museum. 



American Welding Society

Authors: Submit Research Papers Online

Peer review of research papers is now managed through an online system using Editorial Manager software. Papers can be submitted into the system directly from the *Welding Journal* page on the AWS website (aws.org) by clicking on "submit papers." You can also access the new site directly at editorialmanager.com/wj/. Follow the instructions to register or log in. This online system streamlines the review process, and makes it easier to submit papers and track their progress. By publishing in the *Welding Journal*, more than 70,000 members will receive the results of your research.

Additionally, your full paper is posted on the American Welding Society website for FREE access around the globe. There are no page charges, and articles are published in full color. By far, the most people, at the least cost, will recognize your research when you publish in the world-respected *Welding Journal*.



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The easy-to-use app includes past issues of the magazine, features various viewable formats and a search option, and offers download choices.

Inspection and NDE Terms

The term *inspection* denotes an all-encompassing quality control or quality assurance activity that includes numerous steps applied at different stages during a component's fabrication and service life. Therefore, this term describes activities that are performed not only at the time of manufacture but also after the component has been subjected to service. While the types of discontinuities revealed during these varying stages may differ, the basic principles governing inspection activities are essentially the same, making them applicable to new manufacture, repair operations, erection, or evaluation of components that have already been subjected to their intended service conditions.

Many of the same methods used for welding inspection are also used to determine the quality of components joined by brazing or soldering. However, because of the physical nature of brazed and soldered joints (e.g., dissimilar materials, thinness of the joint, and so forth), some techniques may be inappropriate for use with the inspection of brazed and soldered joints.

Welding Inspection Terms

Members of the quality control and quality assurance community often utilize the terms *examination*, *evaluation*, and *testing* to convey a meaning similar to that of inspection. These terms are defined as follows:

Examination. An activity that results in indirect measurement or determination of the quality of a material or component. Examinations can be performed without causing destruction of the test object;

Evaluation. Consideration of examination and test results to determine suitability of a component in terms of its quality or performance;

Testing. An activity that results in the direct measurement or determination of the suitability of a material or component for a prescribed service. Because a test involves the application of an actual or simulated service condition, the test object may be destroyed as a result of this process; and

Inspection. The overall quality control and assurance activity that encompasses other elements, including examination, testing, and evaluation.

With respect to welding inspection, the terms discontinuity, flaw, and defect are defined as follows:

Discontinuity. An interruption in the typical structure of a weldment, consisting of a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the base metal or the weld metal. A discontinuity is not necessarily a defect;

Flaw. A term nearly synonymous with discontinuity, but with the connotation of undesirability; and

Defect. A discontinuity that, by nature or effect, renders a weldment unable to meet specifications or acceptance standards. This term designates a condition that necessitates rejection.

Nondestructive Examination Terms



Fig. 1 — A technician performs ultrasonic testing on a welded pipe. (Credit: Olympus Scientific Solutions of America.)

The term *nondestructive examination* (NDE) is used to designate those inspection methods that allow materials to be examined without changing or destroying their usefulness. The terms nondestructive testing, nondestructive evaluation, and nondestructive inspection are sometimes used interchangeably with the term NDE and are generally considered synonymous. NDE is performed on a weldment to verify that the weld quality meets the specification. It is also conducted to determine whether the weld has degraded during service or exhibits quality issues.

A number of different NDE methods may be employed in welding inspection. Despite their differences, many NDE methods have certain similarities. These include 1) a source of probing energy, 2) a test component with discontinuities capable of causing an alteration of the probing energy, 3) a device capable of detecting the differences in or the effects on the probing energy, and 4) a means of displaying the results of the test to allow for the interpretation and evaluation of discontinuities.

The following NDE methods are most commonly used for the inspection of weldments:

- Visual examination,
- Radiographic testing,
- Ultrasonic testing — Fig. 1,
- Magnetic particle testing,
- Liquid penetrant testing,
- Electromagnetic testing, and
- Acoustic emission testing.

Other NDE methods, such as thermographic and ferrite testing, exist for special types of examination. [WJ](#)

NEWS OF THE INDUSTRY

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Each winning team member and individual essay winner member took home a \$250 cash prize in addition to a Victor Medalist 350 outfit, while each winning school received a cutting and welding package valued at more than \$8400.

KV Tooling Earns First Place at ANCA Tool of the Year



As an industry, #ANCATooloftheYear celebrates the knowledge and imagination of cutting tool craftsmen.

KV Tooling, Augusta, Maine, won first place in ANCA's industry first competition, titled ANCA Tool of the Year. The cutting tool industry has cultivated and refined its craft over the years to design beautiful tools, applying science to achieve a submicron surface finish and more.

"All finalists were of a very high standard and demonstrated a deep understanding for tool geometry, as well as taking full use of ANCA's software to design unique and special cutting tools," said Pat Boland, the company's cofounder.

"Our entry was a very complex tool with many features incorporated into one tool. We designed the cutting tool to satisfy a customer's problem, where our one tool replaced a machining requirement that previously required six tools..."

said Brian Beland, president, KV Tooling Systems.

In addition, runner up Eshed Tools, located in Israel, entered the competition to share its tool manufacturing skill set with ANCA users. Zakłady Mechaniczne Kazimieruk, based in Poland, won the most creative tool, which was motivated to inspire the grinding community.

Industry Notes

- **Metabo Corp.**, West Chester, Pa., an international manufacturer of professional grade cordless and corded hand-held power tools and accessories, has a new Factory Service site at metabousafactoryservice.com. According to Carlos Gregory, the company's area service manager for North and South America, the site allows increasing its overall repair efficiency, repair service time, and ability to deliver timely information; your tool is not just repaired, it is fully serviced; and everything that is worn is replaced, not only what's broken.

- Spencer Ashton, CEO of **Ashton Sawing and Drilling**, has opened a new location outside of New Orleans, La. It will offer the same level of commercial concrete services the company has demonstrated in the Houston and Dallas, Tex., markets for 20 years. The office will be run by Daniel Giles, a veteran in the concrete services industry.

- **United Performance Metals** has achieved ISO 13485:2016 certification from **NSF International Strategic Registrations**, Ann Arbor, Mich. This approval will allow the company's South Windsor, Conn., branch to provide materials and processing services for the medical industry.

- **Cincinnati Incorporated**, Harrison, Ohio, a build-to-order machine tool manufacturer, recently announced a distribution partnership with **BASF 3D Printing Solutions**, Heidelberg, Germany. Its high-temperature small area additive manufacturing machine will offer BASF's ABS plastic, carbon fiber PET, and recycled PET materials. These three provisions add new manufacturing possibilities to the machine.

- **Paperless Parts**, Boston, Mass., has partnered with **Online Metals**, Seattle, Wash., to combine its understanding of how part geometry drives materials selection with Online Metals' instant materials pricing to provide engineers and custom part manufacturers with the ability to streamline materials pricing, which is one of the first steps in every quoting process. [WJ](http://wj.com)

PRODUCT & PRINT SPOTLIGHT

— continued from page 16

settings to the harsh environments of foundries. To produce clean breathing air, it uses a high-efficiency filter media that removes 99.9999% of particulates at 0.12 microns. To improve safety, the filter door cannot mount to the unit unless a filter is fixed in place. Additionally, the lightweight, 2.55-lb PAPR distributes weight through its vertical mounting, which is supported



by the company's flexi-belt. This allows the system to contour to the user's body, thus maximizing comfort and stability. Some of the PAPR's other

features include a quick-release mount lock system to facilitate decontamination; a long-life lithium-ion battery that is sealed inside the unit; a LED user interface that indicates airflow, fan speed, and battery level; and visual, audible, and vibrating alarms to alert the user of low-battery level or when airflow falls below minimum requirements. The PAPR is certified to a IP65 rating in use, and a IP67 rating with the cleaning kit in place.

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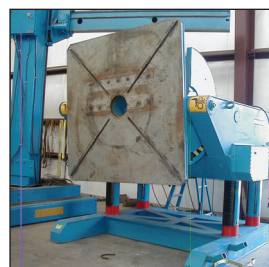


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Effect of PWHT on Laser-Welded Duplex Stainless Steel

The effects of postweld heat treatments on the microstructure, tensile behavior, and corrosion resistance of laser-welded duplex stainless steel were investigated

BY A. S. MAGALHÃES, C. H. X. M. MAGALHÃES, M. S. F. DE LIMA, J. CRUZ, L. B. GODEFROID, R. BERTAZZOLI, AND G. L. DE FARIA

ABSTRACT

The welded joints of duplex stainless steels (DSSs) have been widely used in petrochemical, nuclear, pulp, and paper industries. Welds require a good, superficial finishing and a combination of mechanical and corrosion properties in these types of high-quality, demanding applications. Even though laser welding promotes narrow weld beads and a small heat-affected zone, when it is applied to DSSs, it can produce dangerous microstructural discontinuities. In this context, the effects of subsequent heat treatments on the microstructure, corrosion resistance, microhardness, and tensile properties of DSS laser-welded joints are investigated. In this study, samples of UNS S32304 DSS were submitted to two different conditions of laser welding. Subsequently, the plates submitted to the best welding condition were subjected to isothermal heat treatments at different temperatures (850°, 950°, 1050°, and 1150°C) for 10 min. Then they were microstructurally characterized. Phase fraction measurements and microhardness tests were performed. Based on the obtained results, postweld heat-treated samples at 1150°C, which is the best condition, were subjected to corrosion and tensile tests. It was possible to conclude the corrosion properties of the welded joint were significantly improved after the heat treatment. However, the mechanical behavior was strongly influenced by the presence of volumetric discontinuities and intermetallic compounds, which considerably deteriorated the mechanical strength of the material.

KEYWORDS

- Laser Welding • Duplex Stainless Steel • Corrosion
- Postweld Heat Treatment

Introduction

Duplex stainless steels (DSSs) are dual-phase alloys based on the Fe-Cr-Ni system, whose microstructure consists of

similar volume ferrite and austenite fractions, containing approximately 50% of each phase (Ref. 1). DSSs have advantages over austenitic and ferritic stainless steels because they have a favorable property combination of both steels: good toughness, high mechanical strength, good corrosion resistance in different environments, excellent fatigue strength, and stress corrosion cracking resistance (Ref. 2). Due to their properties, DSSs have been used in the petrochemical, oil and gas, pulp, and other types of industry. Furthermore, they are commonly used in aqueous and chloride-containing environments, and as a substitute for austenitic stainless steels, which may suffer chloride corrosion under stress or pitting in service (Ref. 3).

In most applications, DSSs must undergo a welding process. During this process, the microstructure and properties of the DSSs can be significantly changed. The volume fractions of ferrite/austenite phases become unbalanced when close to the heat-affected zone (HAZ), and a structure constituted for almost 100% of ferrite can be formed near the fusion central line. In addition, precipitation of intermetallic compounds may occur (Refs. 1, 3). The effects of these structural changes on the mechanical and corrosion properties of DSSs can be deleterious (Ref. 4). According to Nilsson (Ref. 5), the chromium nitride precipitation in the ferrite decreases the material pitting corrosion resistance. Kordatos et al. (Ref. 6) claim these precipitates also contribute to the toughness decrease in samples that are fast-water cooled after the welding procedure. Consequently, welding processes have been extensively analyzed to minimize the deleterious effects on the mechanical properties and corrosion resistance of DSSs due to the welding thermal cycles (Ref. 7).

Laser welding has proven to be an attractive process for the joining of thin steel plates because it has high productivity. In addition, it is characterized by its small HAZ, deep penetration, narrow weld bead, low-heat input per volume unit, and high degree of automation. However, laser welding in DSSs promotes the presence of a metastable structure al-

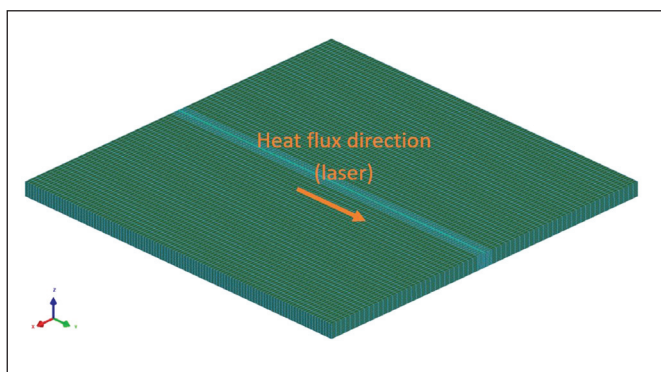


Fig. 1 — Three-dimensional model employed at SYSWELD.

Base Metal	Fusion Zone	Base Metal
6 measurements with spacing of 0.1mm between them	Measurements in the whole fusion zone with spacing of 0.1mm between them	6 measurements with spacing of 0.1mm between them

Fig. 2 — Microhardness measurement scheme.

Table 1 — Chemical Composition of UNS S32304 Steel (wt-%)

C	Mn	Si	Cr	Ni	P	S	Cu	Mo	N
0.01	1.34	0.31	22.23	4.10	0.025	0.0004	0.09	0.32	0.10

most completely ferritic in the fusion zone (FZ), consisting of elongated ferrite grains with a small amount of allotriomorphic and Widmanstätten austenites, and abundant precipitation of chromium nitrides due to the high cooling rates arising from the procedure (Refs. 8, 9).

According to previous studies, an effective way to improve the DSSs weldability is to adjust the austenite volumetric fraction in the FZ, reformatting the austenite and, if possible, reestablishing its morphology (Ref. 10). The laser welding procedure and the postweld heat treatments (PWHTs) applied to DSSs are not as well studied as the other usual welding methods (Refs. 11–15). Even so, there is an indication that the correct planning and use of PWHT can be a powerful tool for this purpose, resulting in desirable mechanical and corrosion properties in the FZ. In this context, this study aims to evaluate the effects of PWHTs on the microstructure, tensile behavior, and corrosion resistance of laser-welded UNS S32304 duplex stainless steel.

Experimental Procedure

Material

The as-received UNS S32304 duplex stainless steel plates were supplied by Aperam South America. Table 1 shows the chemical composition provided by the manufacturer. The samples were taken from a cold-rolled sheet with a 48% area reduction and a 2.5-mm final thickness, annealed and pickled with 2B finishing rolling (dimensional fine adjustment and strain hardening rolling).

Plates of UNS S32304 duplex stainless steel, with dimensions of 6.5 × 6.5 cm, were laser welded in a butt joint configuration in the rolling direction. A high-powered fiber laser, manufactured by IPG Photonics Ltd., model YLR-2000W was used. This laser has a maximum power of 2000 W in continuous operation. Argon and nitrogen were used as the shielding and process gas, respectively. The flow rate of argon gas was 8 L/min. The plates were placed under the welding table with a computer numerical control managed

by the software EMC² operated by the Linux system (Ref. 16), which allows for variation in the speed and position of the laser. The studied welding conditions were as follows: 1) AT50, performed at a speed of 2400 mm/min and a power of 2000 W, and 2) AT100, performed at a speed of 600 mm/min and a power of 1000 W.

Computational Simulation of the Welding Thermal Profile

Because there is great difficulty in measuring temperatures during laser welding, it was necessary to use numerical methods to evaluate the thermal gradients to which the plates were subjected during the process. In the present study, ESS Group's SYSWELD software was used to investigate the effect of the welding conditions on the thermal cycling imposed on the plates (Ref. 17).

The SYSWELD software has an extensive database of metallic material properties, which allows an estimation of the thermometallurgical and mechanical characteristics of the component during and after welding. The thermal properties of the UNS S32304 DSS are not part of the software database, so it is necessary to use the material whose thermal conductivity, specific heat, and density are as close as possible to the studied material. In this case, the properties of 316L stainless steel were used.

The simulation was based on a three-dimensional finite element model in which a mesh was constituted of 140,000 nodes with tetrahedral elements, and was inserted, as presented in Fig. 1. Note that the mesh is refined around the path of the heat source to improve the resolution where the thermal gradient is larger. As the thermal transfer is performed through the nodes between each element of the mesh, the minimum distance between the nodes was 0.03 mm in the x-axis and 0.25 mm in the z-axis, around the heat source.

For the computational simulation, the same values for the welding power and speed used in the already described physical experiments, and a laser beam absorptivity of 65%, were used (Ref. 18). It must be noted that the ab-

Table 2 — Heat Treatment Temperatures

Temperature of Isothermal Heat Treatment (10 min)	Identification
850°C	L1
950°C	L2
1050°C	L3
1150°C	L4

sorptivity was a fit for the simulation and not based upon any experimentally determined data. This absorptivity was estimated/ fit in a way that the simulated shape of the melt pool corresponded to the dimensions experimentally verified. The calorimetric procedure for estimation of the absorptivity could not be applied in the current setup due to the dimensions of the sample (Ref. 19). In the present study, the output data of the computational simulation were the temperature profiles as a function of the time for both studied experimental conditions, which are called AT50 and AT100.

Because it is difficult to monitor the temperature in laser welding processes, the measured width of the FZ as a validation parameter for the computational model was utilized as it will be shown in the results.

PWHT

For PWHTs to be practical and economically feasible in the industrial manufacturing routine, it is important that a relatively short time be adopted during this procedure. Thus, some plates welded using the AT100 condition were subjected to isothermal heat treatments for 10 min in a furnace manufactured by the Instituto de Aeronáutica e Espaço, AMR — Divisão de Materiais. Then, they were cooled in water at room temperature. Table 2 presents the temperatures used and the sample identification nomenclature.

Microstructural Characterization and Phase Fraction Measurements

Samples of the welded plates were examined in the transverse direction (through thickness) of the weld bead for analysis by the optical microscope (OM). The samples were prepared for metallographic examination, according to the ASTM E3-11 standard recommendations (Ref. 20). For phase volume fraction quantification, the samples were etched by Beraha II etchant (20-mL HCl, 80-mL H₂O, 1-g K₂S₂O₅, 2. [Refs. 21–26]). The volumetric fractions of ferrite and austenite were determined by automatic image analysis software LAS-LEICA by a complete scan of the FZ image (200× magnification). The characterization of the FZ and base metal (BM) was carried out by the OM. For this purpose, the samples were electrolytically etched with the KOH solution (100-g KOH and 900-mL deionized water) by applying 3 V for 30 s. Then, some samples were electrolytically etched by using a 10% oxalic acid solution by applying 3 V for 30 s to reveal chromium nitrides. Additionally, the following three techniques were also performed to enhance the microstructural characterization and phase quantification.

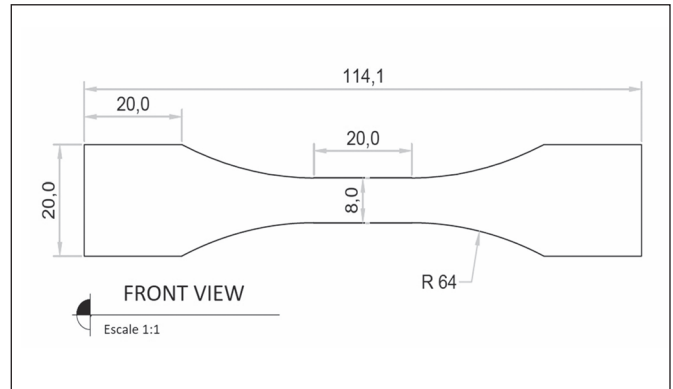


Fig. 3 — Dimensions of the specimens used in the tensile tests (in mm).

Electron Backscatter Diffraction Analysis

To confirm the phase identification (austenite and ferrite) performed in the previous procedure and to compare the phase quantification performed by the OM and electron backscatter diffraction (EBSD), as-received AT100 and L4 samples were analyzed via EBSD. For analyses via EBSD, the samples followed the same procedures of metallographic sample preparation for the OM with an additional 1.5 h of polishing with 0.02 μ m colloidal silica on a Minimet Buehler polishing machine. EBSD analysis was performed on the Vega 3 – Tescan scanning electron microscope (SEM) and the analysis software was AZtec Oxford.

SEM Analysis

For further investigation of precipitation of chromium nitrides in the ferritic grain boundaries in the FZ of the AT50 sample, SEM analyses were executed by a Vega 3 – Tescan SEM. The sample was prepared following the same metallographic procedures for the OM. Then, based on literature data and on ASTM A1084, *Standard Test Method for Detecting Detrimental Phases in Lean Duplex Austenitic/Ferritic Stainless Steels*, two etchants were adopted to reveal evidences of the presence of chromium nitrides precipitates: 10% oxalic acid solution by applying 3 V for 30 s (indirect evidence due to sensitization occurrence where chromium nitrides precipitate) and Beraha II etchant (20-mL HCl, 80-mL H₂O, 1-g K₂S₂O₅, 2.4-g (NH₄)HSO₄) for 10 s (direct evidence due to the revelation of nanostructured chromium nitrides) (Refs. 27, 28).

Transmission Electron Microscopy Analysis

To verify the presence of chromium nitrides, transmission electron microscopy (TEM) analysis was performed. For that, the FZ of the AT100 sample was previously prepared by the focused electron beam (FIB) technique in a Quanta 3D field emission gun FEI SEM. Through the cut performed by the FIB, a wedge-shaped sample was obtained in the dimensions of 4 × 2 mm and thickness of less than 200 nm, hence the TEM analysis could be performed. TEM was carried out with the aid of the Tecnai G2-20 SuperTwin FEI, 200-kV TEM.

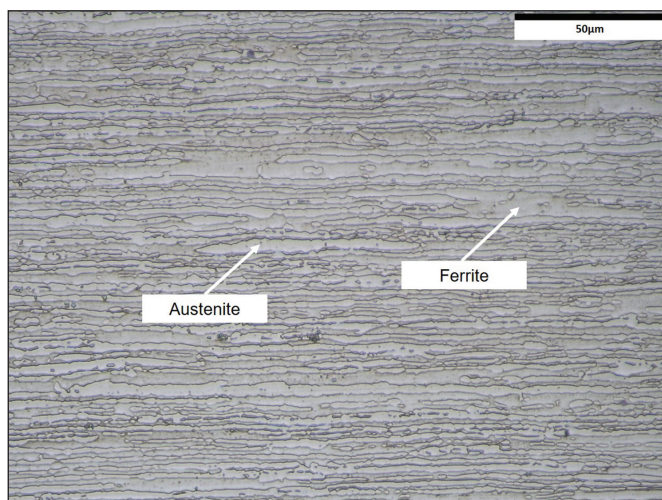


Fig. 4 — Microstructure of UNS S32304 DSS. KOH electrolytic etching. OM-500×

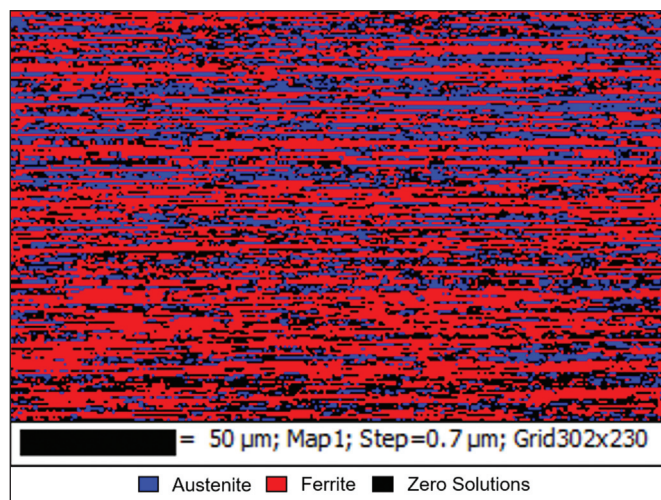


Fig. 5 — EBSD map confirming the phase identification determined by the OM in the as-received sample.

Porosity Measurement in the Fusion Zone

The used measurement method was the light OM cross sections. Several OM images of the FZ cross section were submitted to image analyses, and the total pore area, in μm^2 , were measured (S_p), as well as the FZ total area (S_{FZ}). This method consisted of calculating the average relative pore area in relation to the FZ area [P (%)] (Eq. 1). Qualitative sampling ensured a R.A. value, i.e., relative accuracy of less than 5% (Ref. 29).

$$P (\%) = S_p / S_{FZ} \quad (1)$$

Vickers Microhardness and Ultramicrohardness Measurements

To evaluate the effects of welding and the PWHT on FZ and BM, Vickers microhardness measurements were performed on the etched cross section of the welded samples AT100, L1, L2, L3, and L4. For this, a Pantec digital microhardness tester was used with a load of 0.1 kgf holding for 5 s. The hardness of the BM and FZ were considered as the average values calculated from several measurements performed in each area. Figure 2 shows a schematic figure that highlights the hardness profiles planning for all studied samples.

To verify the differences between ferrite and austenite specific hardness values and to evaluate if there is some influence of welding and heat treatment performed at 1150°C on the phase hardness, Vickers ultramicrohardness measurements were performed on AT100 and L4 samples. These samples were selected because they presented the most appropriate microstructure, considering the need and the desire to obtain similar amounts of austenite and ferrite as the main criterion. The test was performed by a Shimadzu DUH-211/DUH-211S dynamic ultramicrohardness tester with a load of 0.005 kgf holding for 5 s. The average values were calculated from five measurements performed in each phase.

Corrosion Tests

The samples AT100 and L4 were submitted to a corrosion test with microarea analyses. The potentiostat used to measure the open circuit potential (OCP) curves and polarization curves was the Metrohm Autolab model PG-STAT204. Three electrodes were used in the investigation: the working electrode (the specimen), the tungsten reference electrode with a 125 μm diameter and oxidized in 0.1 mol/L solution of sulfuric acid from potentials, 0.954 to 1.854 V in relation to the saturated Ag/AgCl electrode, and the platinum counter electrode with a 100 μm diameter. The tests were carried out under a controlled atmosphere with a relative humidity of $78 \pm 4\%$. All analyses were performed in a Faraday cage.

A precision syringe was used to deposit about 30 μl of 3.5% NaCl solution under a PET laser-cut adhesive mask to demarcate the analyzed area. The exposed surface area analyzed was approximately 0.077 mm^2 , corresponding to a radius of approximately 157 μm . The BM and the FZ of each sample were analyzed. The samples underwent OCP stabilization for 30 min, followed by a polarization test starting from -0.1 to 1.2 mV in relation to the oxidized tungsten electrode -243 mV vs. Ag/AgCl at a potential scanning rate of 1 mVs^{-1} and with a step size of 0.2 mVs^{-1} .

Tensile Tests

Three conditions were chosen for the tensile test: as-received steel, laser welded (AT100), and postweld heat treated at 1150°C (L4). The tensile test specimens were adapted from a fatigue test specimen standard (ASTM E466-15, *Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials*) by conventional machining. The dimensions of the specimens (in mm) are shown in Fig. 3.

The tensile tests were performed on a MTS servohydraulic machine using displacement control with a displacement rate of 5 mm/min at room temperature until the specimen fractured. Three specimens were used for each sample.

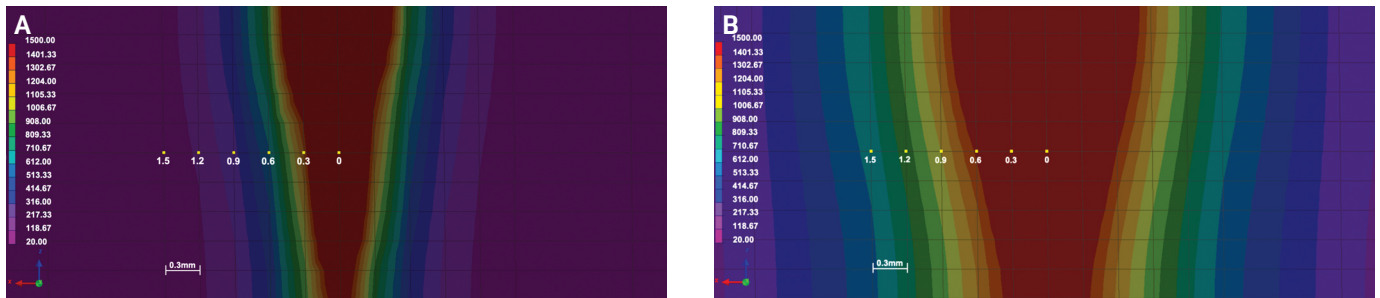


Fig. 6 — Temperature profile (in °C) as a function of the displacement relative to the center of the FZ: A — AT50; B — AT100.

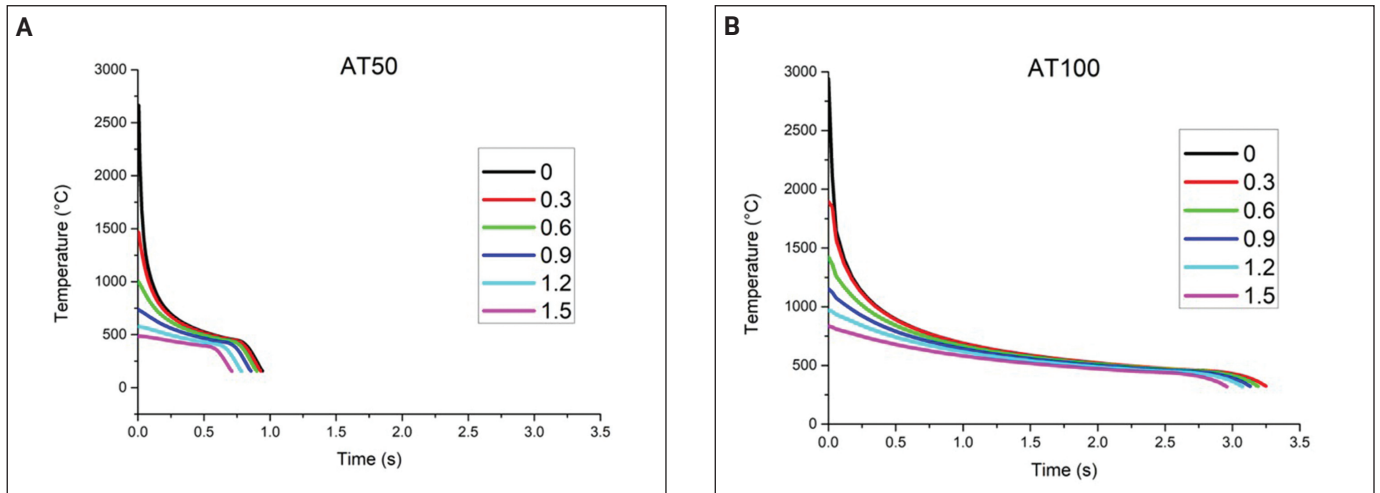


Fig. 7 — Cooling curves as a function of the position in relation to the center of the FZ obtained by SYSWELD software: A — AT50; B — AT100.

condition, and the average values, of each measured parameter, were taken for the result analyses. The fractured surfaces of the tensile test specimens were examined by a Vega 3 – Tescan SEM.

Results

As-Received Microstructural Characterization

The microstructural analysis of the as-received UNS S32304 DSS (Fig. 4) showed that the structure is lamellar with grains aligned in the rolling direction, composed of austenite islands in a ferritic matrix. The phase fraction measurements, using the quantitative metallography method, highlighted a microstructure constituted of $55 \pm 5\%$ of ferrite and $45 \pm 5\%$ of austenite.

The EBSD image of the as-received sample confirmed that the phases indicated as ferrite (darker phase) and austenite (lighter phase) analyzed by the OM was accurate, as shown in Fig. 5.

Computational Simulation

The characteristics of the weld bead, such as penetration depth, FZ width, and cooling rate in laser welding, are dependent on the speed and power of the process. Figure 6 shows the temperature distribution as a function of the po-

sition relative to the center of the weld bead estimated by the SYSWELD software.

The yellow dots indicate the fixed points in relation to the center of the weld bead for which the temperature variation as a function of time was calculated during the laser passage. The mesh width is 0.3 mm, as shown in Fig. 6. The point in the center of the weld bead is the distance 0, the second point indicates the distance of 0.3 mm, and so on to the last point (1.5 mm). Figure 7 shows the result of the computational simulation obtained using the SYSWELD software. Time 0 represents the time at which the laser focus was on the FZ at the position 0. In this way, the temporal evolution of the temperature at these fixed points after the passage of the laser can be observed. Figure 6 considers the melt bath above 1500°C , while in Fig. 7 the temperature curves at point 0 extend to the vaporization limit.

According to the simulations done in the SYSWELD, the average cooling rate at the center of the weld (distance 0), from the maximum temperature to around 500°C , in the AT50 sample was roughly 3870°C/s . The AT100 sample cooling rate was approximately 1105°C/s , about 3.5 times lower than the one calculated for the AT50, as may be observed in Fig. 7.

Fusion Zone Characterization

As shown in Fig. 6, the FZ and HAZ are smaller in the welded joint manufactured with a speed of 2400 mm/s and a laser power of 2000 W (AT50) than in the one with a speed

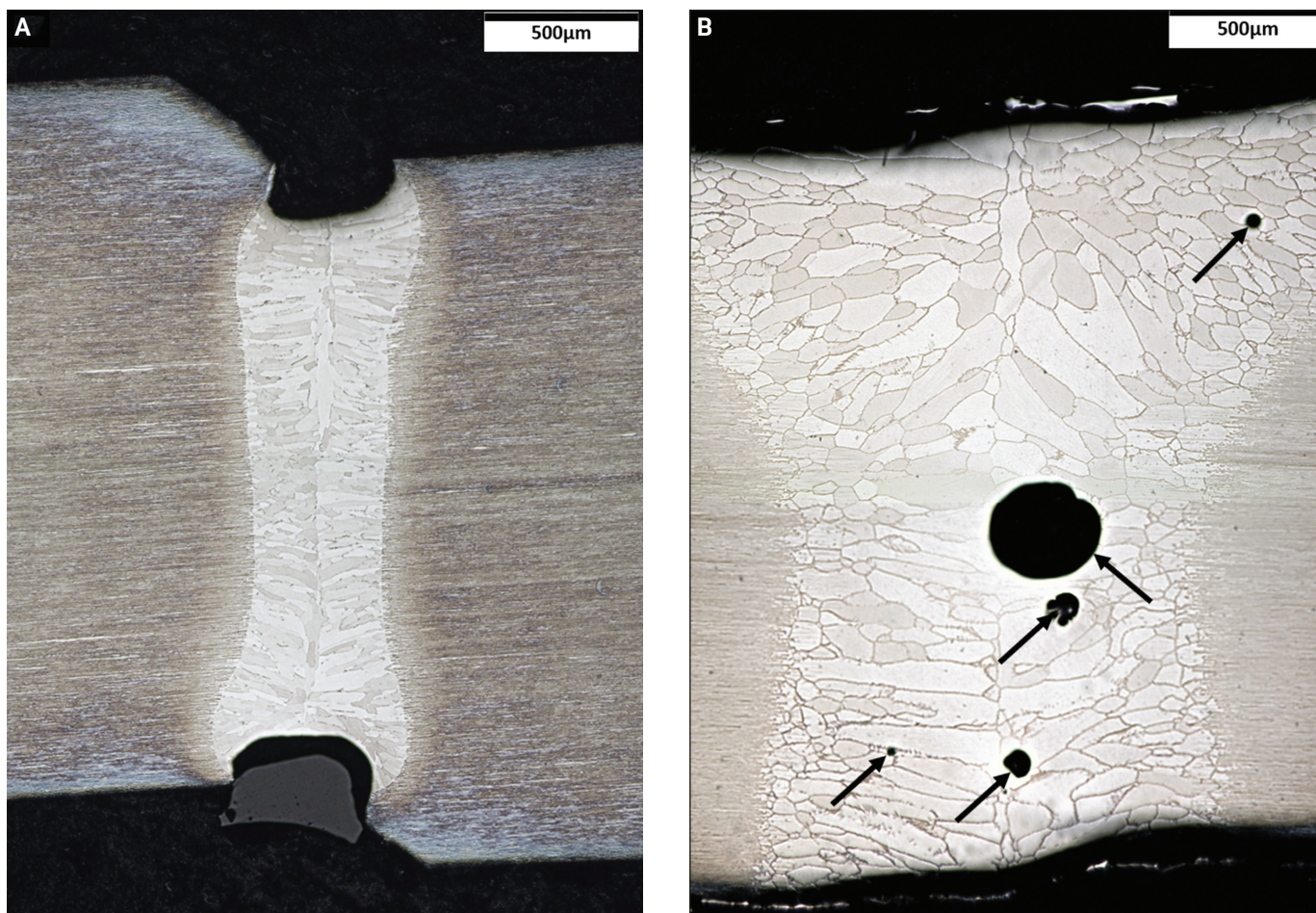


Fig. 8 — Micrographs of FZs: A — AT50; B — AT100. KOH electrolytic etching. OM-50×.

of 600 mm/s and a laser power of 1000 W (AT100). For the abovementioned welding conditions, a heat input of 50 and 100 J/mm is generated, respectively.

Figure 8 shows the micrograph of the weld bead of plates that were welded applying the same simulating conditions. The welds exhibited a typical keyhole shape. Comparing the results presented in Figs. 6 and 8, it is possible to verify that the morphology of the weld beads is consistent with that predicted by the simulation. The width of the FZ in sample AT50 and AT100 was approximately 444 and 1376 μm in the center of the weld bead, respectively. These values were similar to those calculated by the simulation; that is, 400 and 1000 μm , which validate the computational model. Figure 8B shows the presence of porosity in the FZ. These porosities were observed recurrently in the laser-welded joints, some of which had a small fraction of pores (considered in this study as around $0.4 \pm 0.2 \text{ mm}^{-2}$) and other higher fractions (considered in this study as around $1.0 \pm 0.2 \text{ mm}^{-2}$).

The solidification process in the FZ involves epitaxial growth from the BM to the weld interface. The initial dendritic growth is oriented toward the direction of the thermal gradient and produces a columnar ferritic structure. From this structure, the other transformations in the solid state are obtained after the cooling (Ref. 1), as can be seen in Fig. 8. The initial lamellar structure, typically observed in DSSs, was replaced by elongated ferritic grains with columnar

growth oriented in the direction of the heat flow, whereas the austenite concentrated in the ferrite grain boundaries in both welding conditions. The volume fraction of austenite in the samples AT50 and AT100 were 1.8 and 3.5%, respectively, indicating that a small amount of austenite was reformed during the cooling stage, as shown in Fig. 9.

The electrolytic etching with oxalic acid evidenced the presence of chromium nitrides (Fig. 10), as well as in the work of Ramirez et al. (Ref. 9). The chromium nitrides precipitated in the ferrite grain boundaries in both samples. However, chromium nitrides were concentrated within ferrite grains in the AT100 sample, as observed in Fig. 10B.

For a further investigation, aiming to confirm the precipitation of chromium nitrides at some ferrite grain boundaries in the FZ, the AT50 sample was analyzed by SEM submitted to two different etchants: oxalic acid and Beraha II. The first one was adopted to indicate the indirect effect of sensitization, that is, chromium-depleted zones that are susceptible to preferential corrosion during the etching (Refs. 27, 31, 32). The second one was applied to reveal directly the chromium nitrides as a mean of confirmation. In both etchings, indirectly or directly, it was possible to obtain evidences of the chromium nitrides precipitation along the α/α grain boundaries, as indicated in Fig. 11. It was not possible for the precipitation of Cr_2N within ferrite grains to be observed neither by OM nor SEM in the AT50 sample because of the limitation of the later-

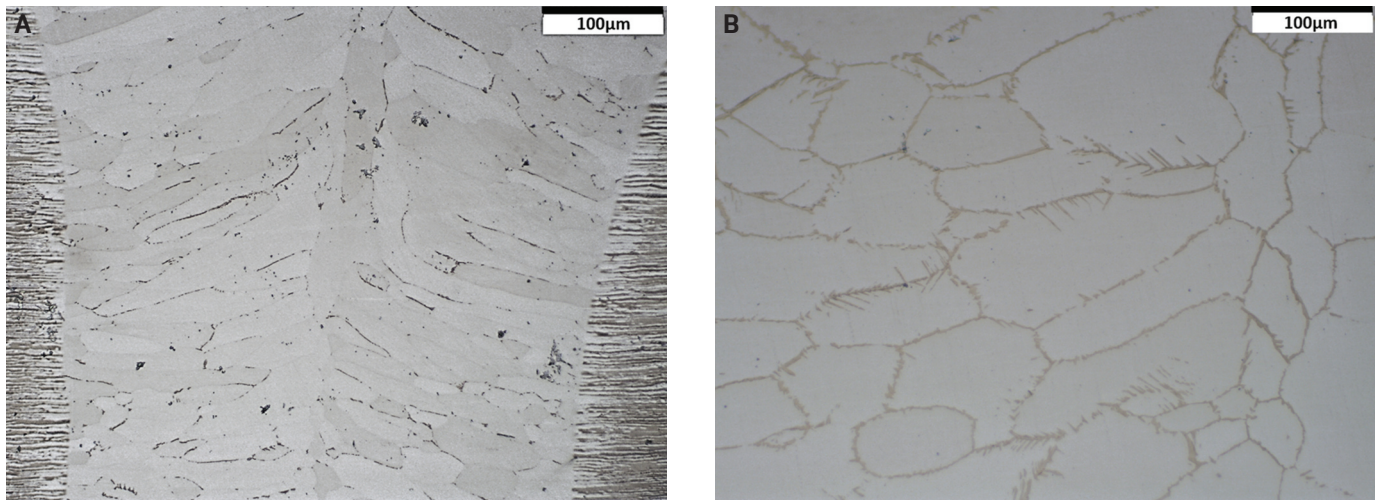


Fig. 9 — Detailed micrographs of FZs: A — AT50; B — AT100. KOH electrolytic etching. OM-200 $\times$.

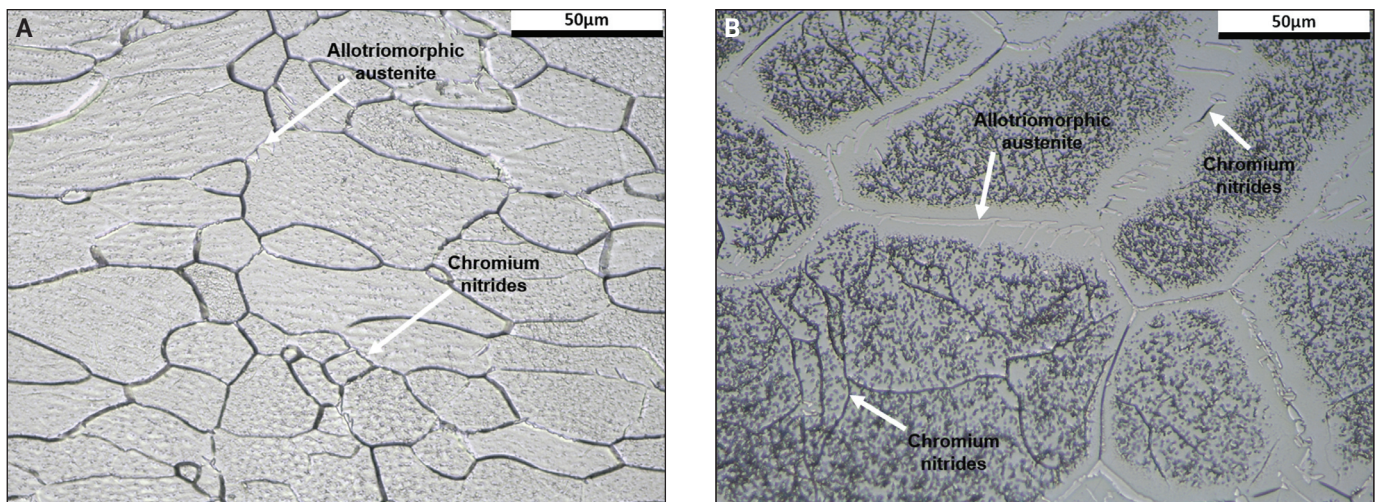


Fig. 10 — Micrographs of FZs (A) AT50 and (B) AT100, indicating the precipitation of chromium nitrides and austenite. KOH electrolytic etching followed by oxalic acid etching. OM-500 $\times$.

al resolution of these techniques.

Complementary analyses were performed in a TEM with the aim to confirm the presence of chromium nitrides within ferrite grains. The TEM analyses confirmed the presence of tiny needles precipitates in the AT100 sample, typical of chromium nitrides precipitated within ferrite grains (Fig. 12), as observed in a previous study by Yang et al. (Ref. 33). Due to the size of the TEM sample prepared in FIB, the tangle of lines in Fig. 10B could not be observed.

Effects of PWHTs on the Microstructure

The effects of laser PWHTs on the microstructure will be presented only for the AT100 condition, since this was the condition of greater representativeness because it presented the greatest amount of reformed austenite in the FZ just as welded and had fewer defects in the welded joint.

Heat treatments had a significant effect on the fraction and morphology of the austenite found in the FZ, as shown in Fig. 13A–D. In the sample heat treated at 850°C, the microstructure consisted of a ferritic matrix with the reformed

austenite concentrated mainly in the ferrite grain boundaries. Widmanstätten austenite formation was also observed, nucleating from the reformed austenite in the ferrite grain boundary — Fig. 13A. At 950°C, there was a significant increase in the amount of intragranular austenite and in the nucleation and growth rate of Widmanstätten austenite from the reformed austenite in the ferrite grain boundary — Fig. 13B. An increase in the amount of Widmanstätten austenite was noticed, as well as the presence of intragranular austenite at 1050°C — Fig. 13C. In the isothermal heat treatment at 1150°C, a refined structure with the predominance of intragranular austenite and the spheroidization of some austenite particles were observed — Fig. 13D.

Table 3 shows the volumetric fraction of austenite/ferrite phases for the different heat treatment temperatures. Notice when increasing temperature from 850° to 1150°C, the austenite fraction also increased. It is important to emphasize only the volumetric fraction of austenite/ferrite phase was evaluated in this work. The PWHT did not have the aim to reach the thermodynamic equilibrium condition, or to reestablish the prior weld phase chemical composition, but

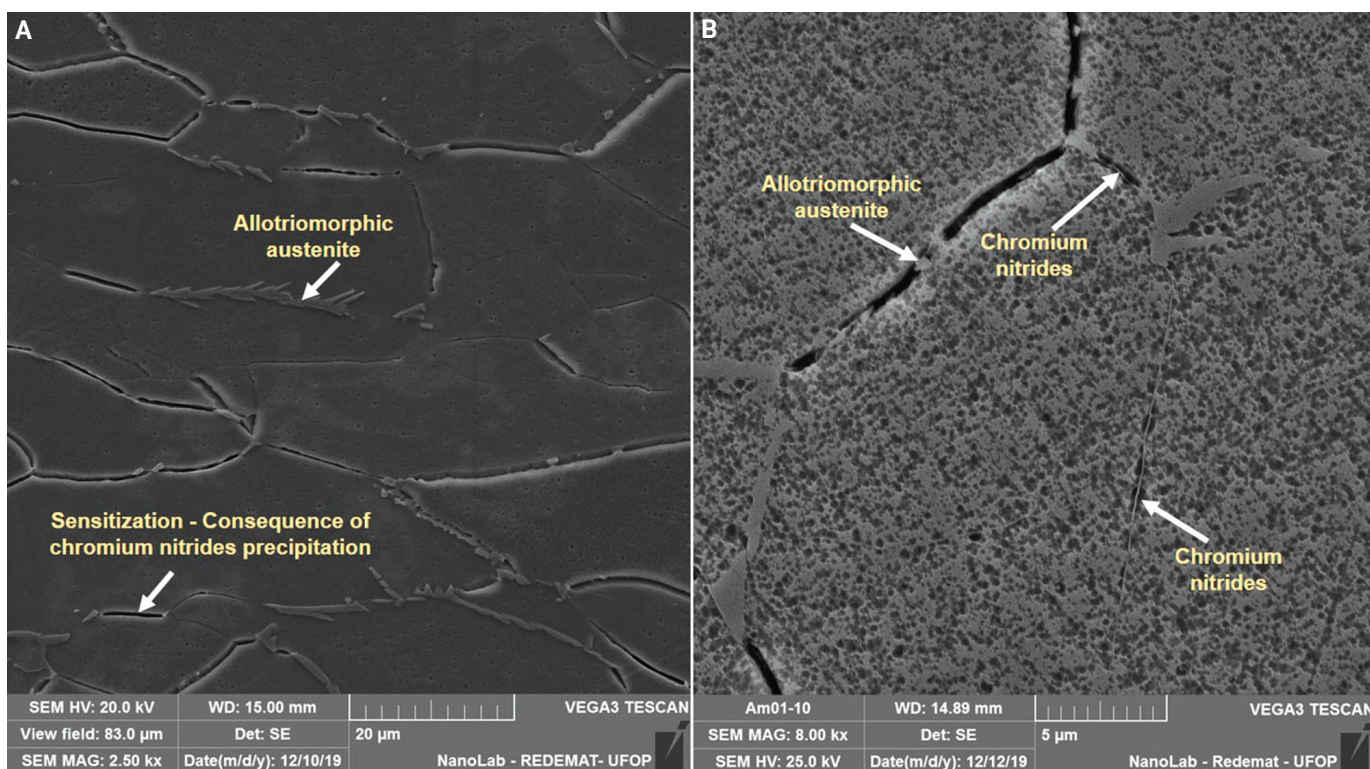


Fig. 11 — SEM micrographs of FZ of AT50 sample: A — Oxalic acid; B — Beraha II etchings.

Table 3 — Volume Fractions of Austenite and Ferrite at Different Heat Treatment Temperatures

Sample	% Austenite	% Ferrite
L1	18, 7	81, 3
L2	37, 0	63, 0
L3	38, 0	62, 0
L4	44, 2	55, 8

just to readjust the phase fraction balance and dissolve deleterious precipitates in a relatively short time that makes its use economically and operationally feasible (Ref. 24). Due to that, the chemical composition in the weld was not estimated, but according to the literature, it is possible to affirm that the ferrite phase is richer in Cr and Mo while the austenite is richer in Ni and N during the short-time PWHT (Ref. 34).

It is well known that nitrogen plays an important role in the austenite formation in the FZ during cooling of DSS. In welding processes, there is a tendency of nitrogen loss, and it can affect the amount of austenite precipitated in the weld metal. According to the literature (Ref. 35), nitrogen depletion in the FZ of DSS welds is most seriously observed in gas tungsten arc welding. In laser welding, the nitrogen depletion in the FZ occurs in a smaller magnitude when compared to other welding processes. Due to the complexity of the characterization techniques to perform an accurate measurement of nitrogen in such a narrow region as in the FZ of laser welding, the nitrogen amount was not measured in this work, but in the scientific literature, there are some studies showing the loss of nitrogen in the weld pool. For example, Lai et al. (Ref. 36) measured the nitrogen content

in the weld pool by the oxygen and nitrogen analyzer, LECO TC-436 in a 2205 DSS fiber laser welded with 100% Ar as a shielding gas. The percentage of nitrogen in the as-received sample was 0.16 wt-%, while the amount of nitrogen in the weld pool was 0.085 wt-% in the center section of the weld and 0.095 wt-% in the upper section of the weld. According to them, the decrease of nitrogen content can lead to dropping the amount of austenite reformed in the FZ during the FZ cooling.

As shown in Fig. 14, in addition to the readjustment of the austenite fraction, the L4 sample had the chromium nitride fraction considerably decreased, and it was not possible to observe this via the OM.

The EBSD images of the FZ of the samples AT100 and L4 (Fig. 15) present the evolution of austenite growth, from the as-welded condition to PWHT at 1150°C for 10 min. Thus, the higher amount of reformed austenite among the temperatures of the heat treatments evaluated was obtained.

The EBSD phase quantification analysis of AT100 and L4 samples was 96.2 and 61.2% of ferrite and 1.8 and 27.8% of austenite, respectively. The fraction of points that were not indexed in the EBSD analysis was presented as zero solu-

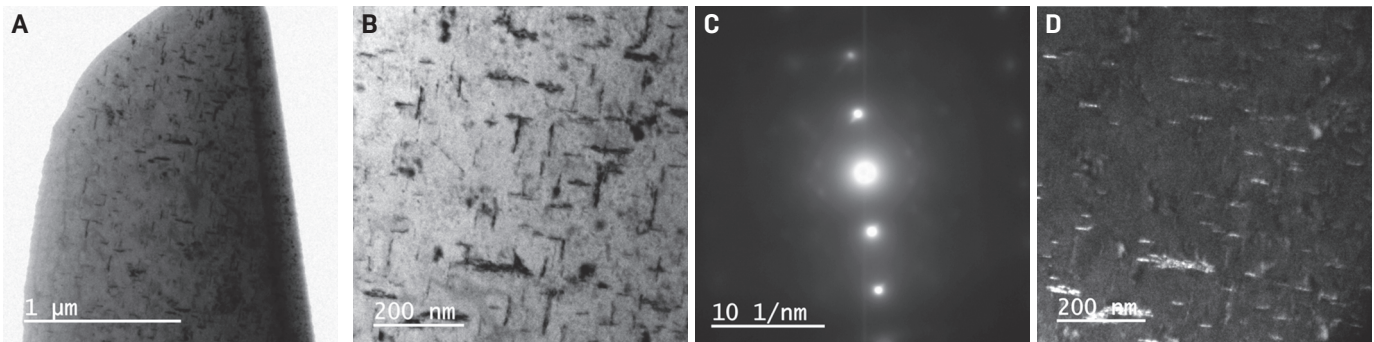


Fig. 12 — TEM analyses of AT100 sample: A — TEM micrograph; B — TEM micrograph showing in detail the chromium nitrides as a needle morphology; C — diffraction profile of ferritic matrix coincident with Cr_2N ; D — elastic scattering image correspondent to C.

Table 4 — Vickers Microhardness and Volume Fraction of Austenite in the Fusion Zone

	BM	FZ	% Austenite (FZ)
AT50	263 ± 4	319 ± 8	1, 8
AT100	250 ± 8	272 ± 5	3, 5
L1	235 ± 4	219 ± 7	18, 7
L2	237 ± 5	234 ± 7	37, 0
L3	240 ± 5	237 ± 8	38, 0
L4	232 ± 8	238 ± 8	44, 2

Table 5 — Vickers Hardness

	BM		FZ	
	Austenite	Ferrite	Austenite	Ferrite
AT100	339 ± 10	264 ± 16	***	272 ± 5
L4	298 ± 9	267 ± 10	304 ± 7	268 ± 5

tions: 2.0 and 11.0% for each sample. It should be highlighted that in the EBSD analysis, the indexing routine is a challenge for accurate data (Ref. 37). Taking this into consideration, and also that phase measurement by the OM for DSS is a consolidated technique in the literature (Refs. 21, 22, 25), the discussion of the results was made considering the phase amounts obtained via OM analysis. Hosseini et al. (Ref. 26) stated the most accurate method to measure the phase amounts of DSS welds was the etching with modified Beraha followed by image analysis software.

Vickers Microhardness and Ultramicrohardness

The results obtained from the microhardness tests are presented in Table 4. The samples AT50 and AT100 had the highest hardness values in the FZ, 319 ± 8 and 272 ± 5 HV, respectively.

The ultramicrohardness of the specific phases (ferrite and austenite) were evaluated only for the extreme conditions (AT100 and L4), shown in Table 5. Because of the AT100 condition, the microstructure is mostly ferritic; as a result, the hardness measurement of austenite was not performed. Instead of the ferrite hardness, the measured microhardness for the FZ was applied. The theory guarantees the load of the hardness test on the Vickers scale does not significantly change the hardness values.

Corrosion Tests

Samples AT100 and L4 were subjected to a corrosion test with microarea analysis to examine the effects of welding

and PWHTs on the corrosion resistance of the FZ and BM. These conditions were chosen based on the results obtained by the microscopic analysis related to the weld quality and the austenite/ferrite adequate ratio. Figure 16 shows the BM and FZ polarization curves for each condition.

In the as-welded sample (AT100), there was a marked decrease in the corrosion resistance for the FZ in relation to the BM, whereupon the BM of the AT100 sample had a behavior that was similar to the as-received material. The values of E_{corr} (corrosion potential) and j_{corr} (corrosion current density), listed in Table 6, show that the BM had a more noble potential than the FZ under this condition (AT100).

Although the analysis indicated a pitting potential near 0.9 V, in the FZ of the postweld heat treated sample (L4), the pits did not become stable in the studied potential range up to 1 V. As both samples had low and very close corrosion current values, of the order of $10^{-7} \text{ A} \cdot \text{cm}^{-2}$, it is possible to affirm the heat treatment did not significantly affect the corrosion current density of the samples.

Tensile Tests

The stress-strain curves for as-received, laser-welded (AT100), and postweld heat-treated (L4) samples are shown in Fig. 17. The tests were conducted for condition L4, considering two specimen groups classified in function of their porosity: one with a relatively low fraction of pores ($0.4 \pm 0.2 \text{ mm}^{-2}$) and another with a relatively high fraction ($1.0 \pm 0.2 \text{ mm}^{-2}$). As the porosity of the weld bead was recurrent, considering the laser welding condition applied to the studied DSS, this was done to evaluate the effect of the pore fraction on the tensile behavior of the postweld heat-treated samples.

Table 7 shows the parameters measured in the tensile test. From the first analyses, it can be seen that the as-received specimen presented the highest yield strength (578 MPa), followed by the AT100 condition, L4 with higher porosity on the fractured surface (Fig. 18A), and L4 with lower porosity

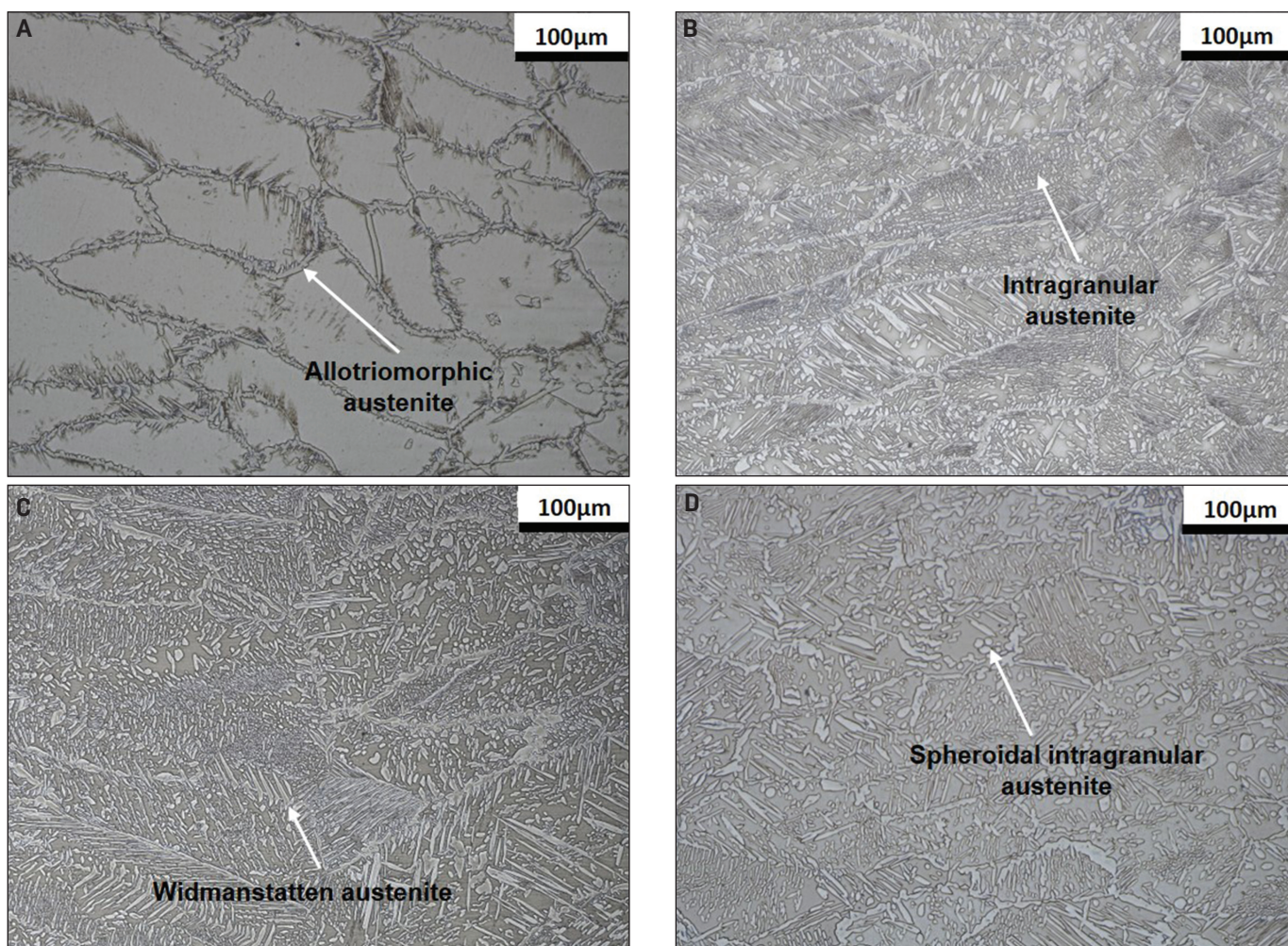


Fig. 13 — Micrograph of the FZ after isothermal heat treatment at different temperatures for 10 min: A — 850°C; B — 950°C; C — 1050°C; D — 1150°C. KOH electrolytic etching. OM-200×.

— Fig. 18B. Comparing the ultimate strength of the samples, the as-received specimen had the highest value (729 MPa), followed by the AT100 condition, L4 with lower porosity, and L4 with higher porosity (605 MPa). The as-received and AT100 conditions had higher tensile strength than the heat-treated samples of both groups. Also, the as-received specimen was the one that deformed the most (52%), presenting greater ductility. Then, the specimen, postweld heat treated at 1150°C and with lower porosity exhibited a greater plastic elongation (30%). While as-welded and L4 with higher porosity were the least plastic deformed, both presented a total deformation of 22%. In all specimens, the fracture occurred in the weld bead.

The as-received sample had a completely ductile fracture surface (Fig. 19A), while the as-welded specimen revealed a semiductile fracture. The fractured surface of this sample was subjected to electrolytic etching with oxalic

Table 6 — Potential and Corrosion Current Density

	AT100		L4	
	BM	FZ	BM	FZ
$E_{corr} (V_{Ag/AgCl})$	-0,181	-0,187	-0,145	-0,137
$j_{corr} (A/cm^2)$	$1,50 \times 10^{-7}$	$1,38 \times 10^{-7}$	$1,90 \times 10^{-7}$	$2,13 \times 10^{-7}$

Table 7 — Yield Strength (σ_{ys}), Ultimate Strength (σ_{ult}), Total Strain (ϵ_r), and Reduction Area (R.A.) of the Tensile Test Specimens Evaluated

Condition	σ_{ys} (MPa)	σ_{ult} (MPa)	ϵ_r (%)	R.A. (%)
As-received	578	729	52	50
AT100	485	675	22	29
L4 (higher porosity)	462	605	22	30
L4 (lower porosity)	426	666	30	37

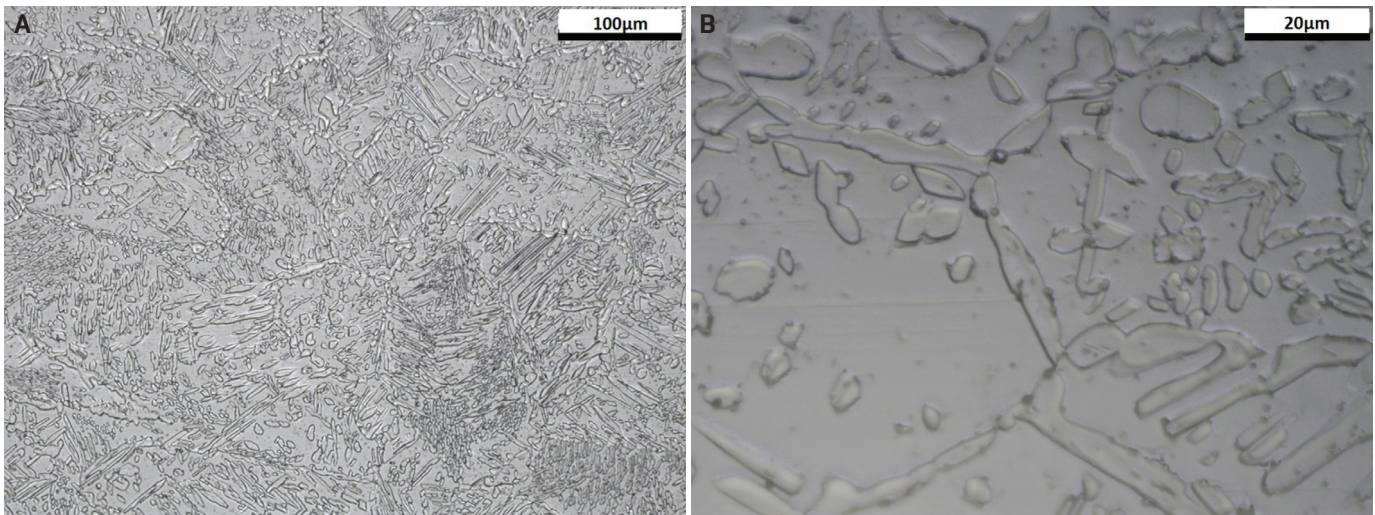


Fig. 14 — Micrographs of FZ of L4 sample indicating the dissolution of chromium nitrides: A — OM-200x; B — OM-1000x. KOH electrolytic etching followed by oxalic acid etching.

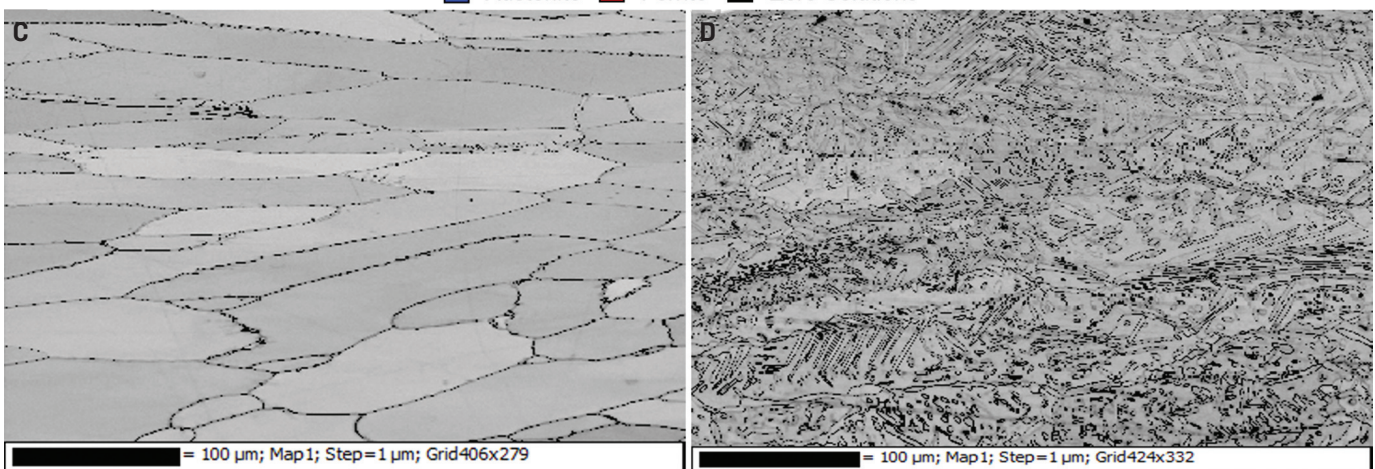
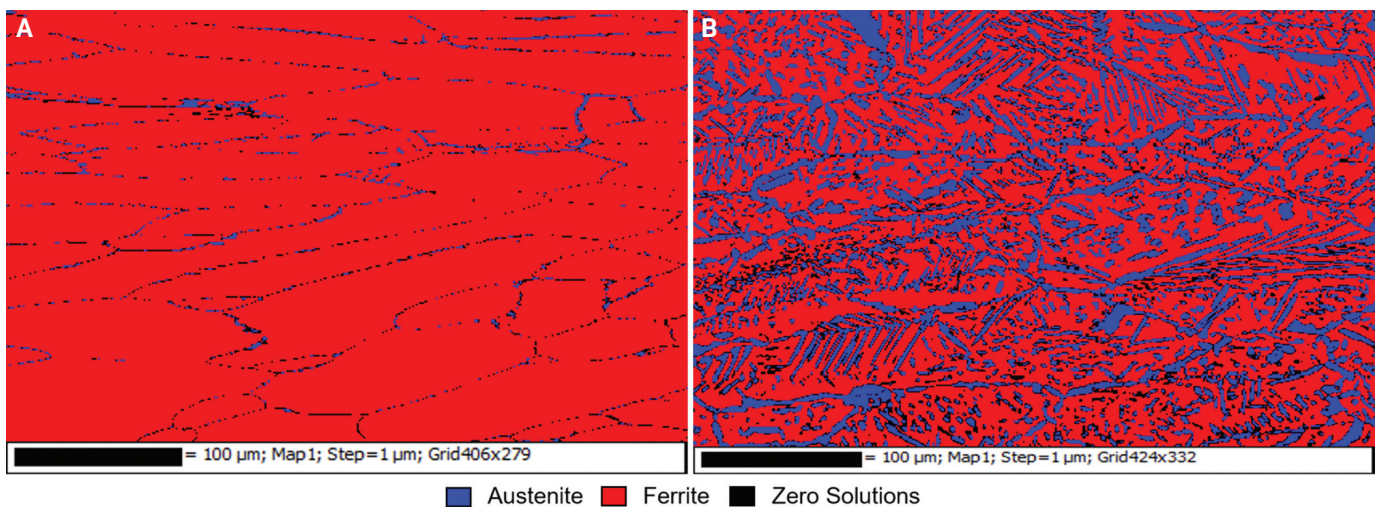


Fig. 15 — EBSD maps: FZ phase distribution of the samples: A — AT100; B — L4. Band contrast: C — AT100; D — L4.

acid, so the presence of chromium nitrides inside the cleavage facets was revealed — Fig. 19B. The heat-treated specimens presented a semiductile fracture, and the sam-

ple with the highest porosity presented a smaller extent of ductile fracture (presence of dimples) (Fig. 20A) than the one with lower porosity in the FZ — Fig. 20B.

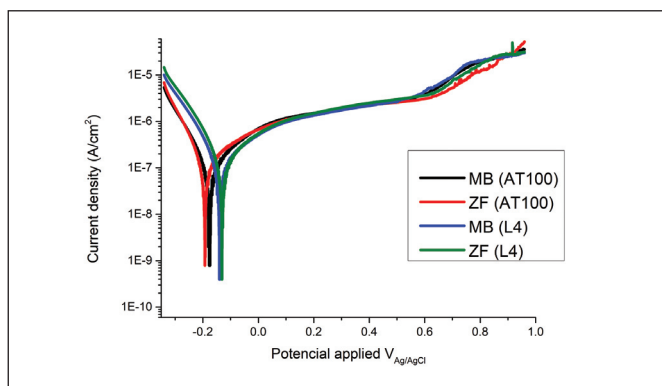


Fig. 16 — BM and FZ polarization curves of samples AT100 and L4, set up by a potentiostatic test performed in an aerated aqueous solution with a nitrogen flow in 3.5 wt-% NaCl at room temperature.

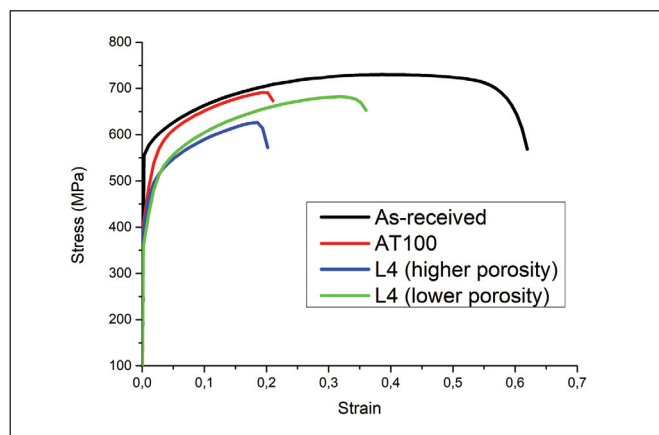


Fig. 17 — Stress-strain curves obtained in the tensile tests for different conditions.

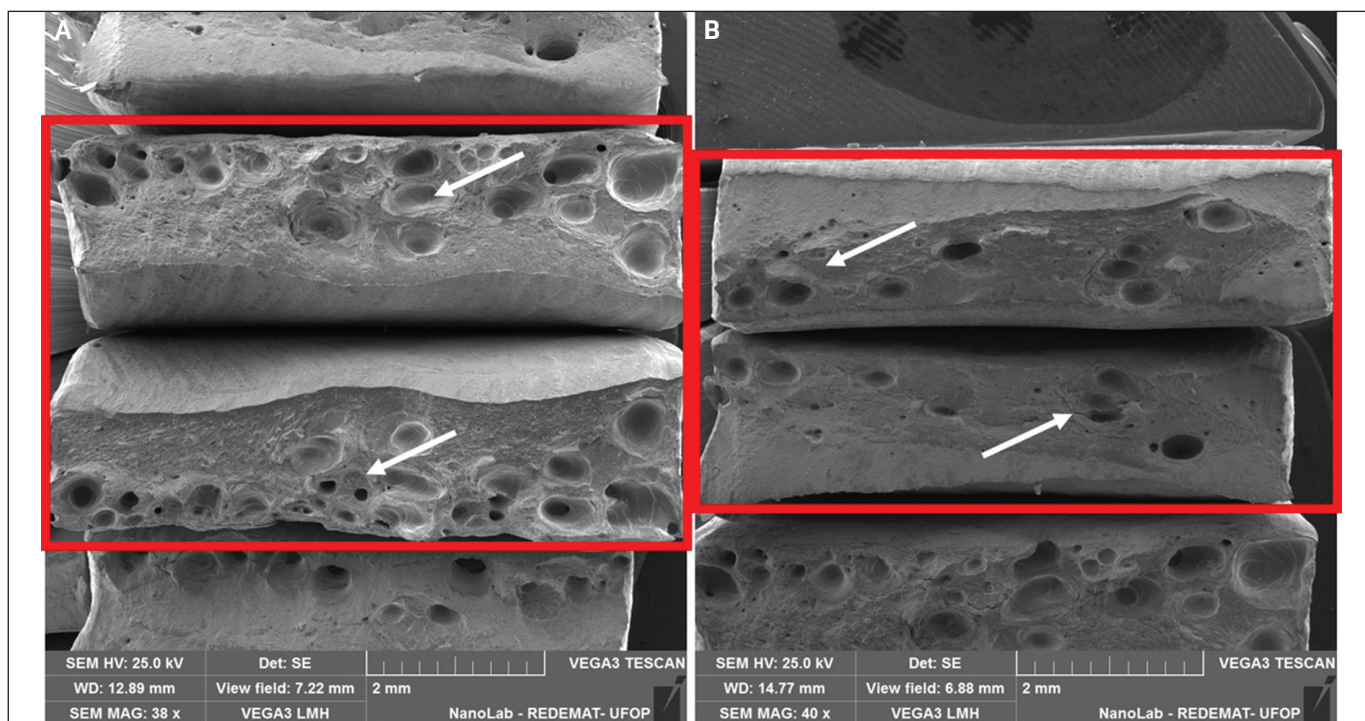


Fig. 18 — SEM surface images of tensile test specimens heat treated at 1150°C, indicating the presence of pores (white arrows): A — High porosity; B — low porosity.

Discussion

Simulation and Laser Welding

Under both welding conditions, the FZ reached a temperature above 1500°C. Ramirez et al. (Ref. 9) found that at 1350°C, there is a complete dissolution of austenite in UNS S32304 DSS, and the FZ becomes completely ferritic in the solidification. The austenite is reformed only during the welded joint cooling to room temperature, if there is enough time for the diffusional processes to occur. It was also noticed that the cooling rate was higher in the first welding condition (AT50) than in the second (AT100), as presented in Fig. 7. Induced by laser welding, the high cooling rates cause the formation of an

almost completely ferritic structure in the FZ after cooling (Ref. 8). If the cooling is fast, the time is insufficient for austenite nucleation and growth. The cooling rate is fundamental to the extent of the transformation (Ref. 1). The austenite precipitation is a nucleation and growth process controlled by diffusion. The reformed austenite is controlled by a paraequilibrium transformation mechanism, whereby the diffusion of the interstitial elements (carbon and nitrogen) is the process controller (Refs. 1, 38). Thus, increasing the cooling rate will reduce the diffusion of austenite stabilizing elements, such as N and Ni, and few austenite will be transformed from supersaturated ferrite (Ref. 39).

The heat input is an effective parameter to judge the quality of the weld surface and the properties of the welded material (Ref. 40). According to Zhao et al. (Ref. 41), the lower the

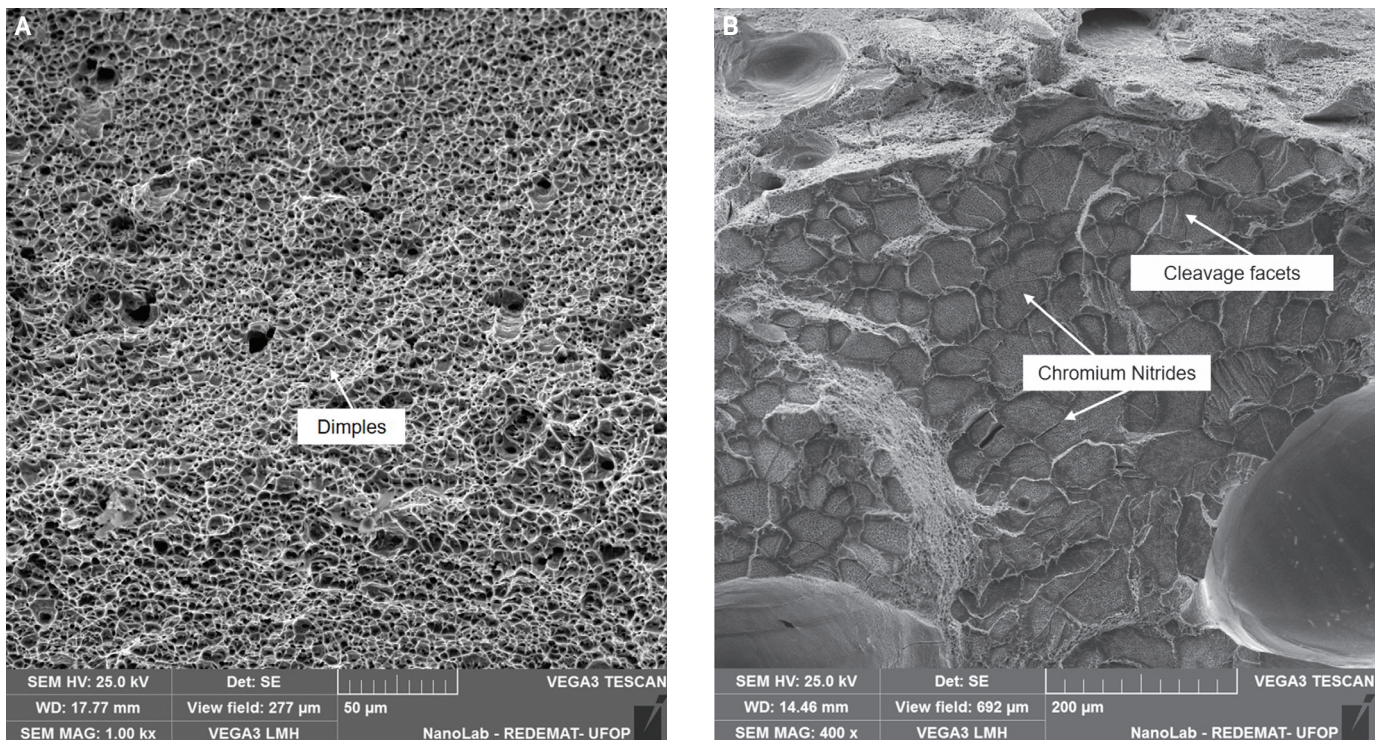


Fig. 19 — Fractography (A) as-received and (B) AT100 indicating the presence of chromium nitrides. KOH electrolytic etching followed by oxalic acid etching, applying 3 V for 30 s.

heat input, the lower the weld bead width because a smaller amount of material is molten. Therefore, the weld bead is narrower, as shown in Fig. 8 and in the computer simulation — Fig. 6. The following is another important consideration: The lower the heat input, the higher the cooling rate, and hence, the lower the amount of reformed austenite during the welded joint cooling.

Regarding the as-received condition, besides the intense modification in the austenite and ferrite volume fractions, there may also be intense chromium nitride precipitation due to the rapid supersaturation of nitrogen in the ferrite during the fast cooling (Ref. 42).

According to Perren et al. (Ref. 43), Cr_2N is rarely found close to the ferrite/austenite grain boundaries because, during the quenching, the nitrogen that is close to the α/γ interface migrates to the adjacent austenite, which has a higher solubility by nitrogen than ferrite. In Fig. 11A, where there is secondary austenite along the grain boundaries, no preferential corrosion areas could be observed after the oxalic acid etching. This is because the nitrogen probably dissolved in austenite and the Cr_2N did not precipitate along the γ/α grain boundaries. Otherwise, where there is a preferential corrosion at α/α grain boundaries, i.e., sensitization occurrence, it is possible to affirm it is an indirect indication of chromium nitride precipitation at the grain boundaries, responsible for chromium-depleted regions (Refs. 27, 28, 31, 32). Because the cooling rate in the AT50 sample is higher than in the AT100 sample, and a small amount of austenite had been reformed, the chromium nitrides were mainly concentrated in the ferrite grain boundaries — Fig. 10A. Bettini et al. (Ref. 44) also detected the presence of chromium nitrides along the α/α boundaries. No chromium nitrides pre-

cipitates were observed in the austenite phase as well, which is in accordance with this work — Fig. 11.

Magalhães et al. (Ref. 45) observed in a UNS S32304 DSS with a completely ferritic structure and fast cooled that there was precipitation of chromium nitrides in the form of black needles in the ferrite grains, similar to that verified in this study for the AT100 condition, as shown in Fig. 10B. The supersaturation of nitrogen in ferrite and the alignment of discordances favor the formation of chromium nitrides in subgrain boundaries, exhibiting this structure in the form of a tangle of lines (Refs. 22, 39, 43).

The suppression of austenite transformation in a high cooling rate condition propitiates a scenario that is favorable for obtaining a microstructure constituted of a high fraction of ferrite and chromium nitrides, which can result in the degradation of corrosion and mechanical properties of a welded joint (Ref. 9), as will be presented later.

Additionally, the presence of porosity found in the solidification of laser-welded joints are consistent with other studies (Refs. 46–51). Previous articles affirm that the porosity formation in laser welding will occur, if the solidification rate of the molten metal exceeds the backfilling speed of the liquid-metal during the keyhole collapse and solidification processes. Porosity formation is even more serious in laser welding, mainly because of the high cooling rates, as shown in the computational simulation. The porosity may cause damage to the quality of the weld, deteriorating its mechanical properties (Ref. 52).

Effects of PWHT on the Microstructure

Two types of secondary austenite (γ_2) can be observed in

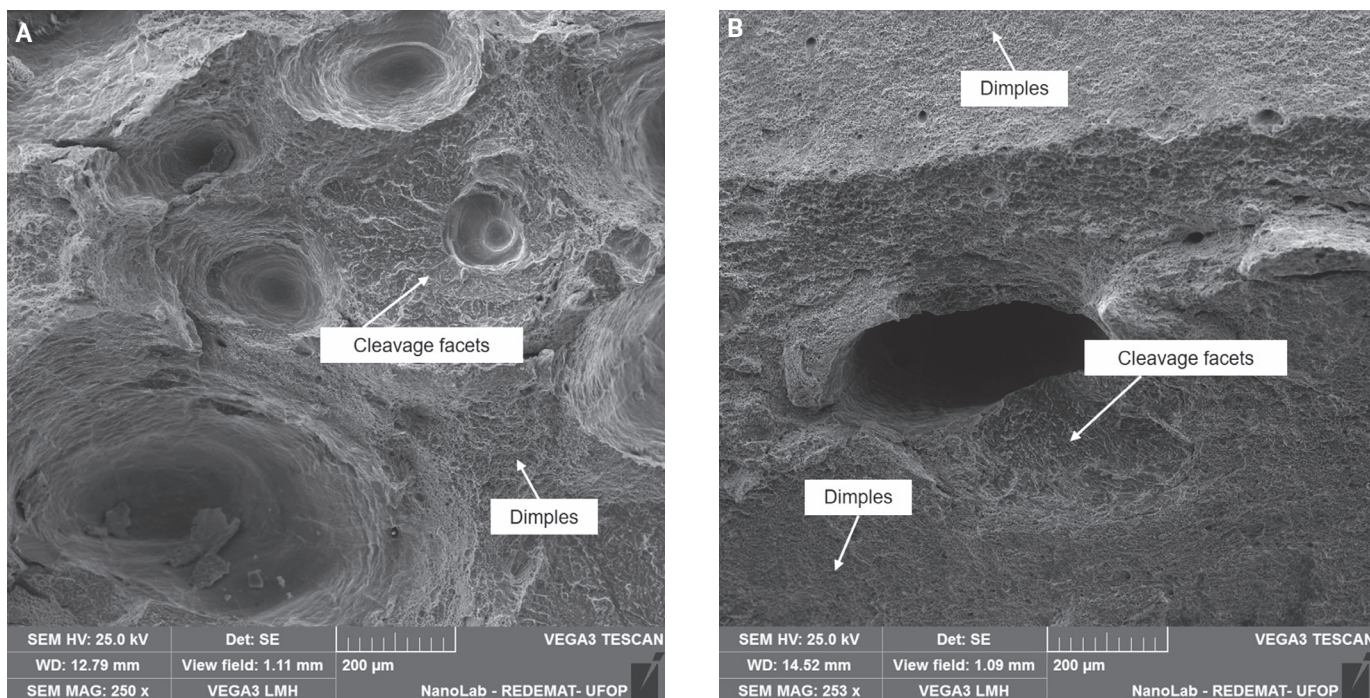


Fig. 20 — Fractography of L4 sample: A — High porosity; B — low porosity in the FZ.

DSSs based on their morphology and site of precipitation criteria. The first type is formed at the α/γ interfaces, denominated intergranular austenite. It is a result of the growth from the preexisting austenite particle toward the ferrite. The second type is intragranular γ_2 , which nucleates and grows intragranularly in the ferrite (Refs. 9, 53). Within these two types, there are subclassifications of the morphology of γ_2 , which are observed in Fig. 13 as the following: A) allotriomorphic along the ferrite grain boundaries, B) Widmanstätten, and C) intragranular austenite. Intragranular austenite particles assume a spheroid shape because they do not have a preferential orientation during their growth (Ref. 54). Zhang et al. (Ref. 53) reported the increase of the heat treatment temperature from 1020° to 1050°C promoted the growth of austenite, the formation of intragranular austenite, and the complete dissolution of chromium nitrides. When the temperature increased from 1080° to 1100°C, the intragranular austenite particles were spheroidized, and the amount of secondary austenite decreased due to more rapid diffusion, and thus, it is in accordance with the present study.

Magalhães et al. (Ref. 45) used the Thermo-Calc software to simulate under thermodynamic equilibrium conditions and the austenite/ferrite fraction ratio as a function of the temperature for the UNS S32304 DSS. For this particular steel, at temperatures above 1250°C, a completely ferritic microstructure can be obtained (during the laser welding process, temperatures reach around 1500°C at the fusion zone), and at temperatures around 800° or 1050°C, the 50% fraction for each phase is obtained. However, the sample that had the austenite fraction closest to 50% was the one submitted to 1150°C for 10 min, approximately 44% (the value close to the amount of austenite in the as-received condition). This proportion in a relatively short time and at a temperature higher than that predicted by Magalhães et al. (Ref. 45) can be ex-

plained by the fact that the simulation was done at equilibrium, and kinetic aspects were not considered.

In equilibrium phase diagrams, at temperatures around 1150°C, there is a tendency for ferrite formation. However, the microstructure of the laser-welded FZ is almost completely ferritic as the cooling is extremely fast and there is not enough time for austenite precipitation during cooling. Thus, there is a driving force for the formation of austenite if the material is reheated, as this is a nonequilibrium condition. Therefore, if the laser-welded plate is heated at any temperature in the range studied in this paper, there will be a predisposition for austenite to be precipitated because they are postweld heat treated for a short time. It was noticed the higher the temperature, the kinetics of austenite formation was favored for this DSS. Therefore, the temperature of 1150°C was more suitable for the phase fraction readjustment in the fusion zone. Thus, it is important to emphasize the optimum heat treatment temperature is a variable, and it depends on the chemical composition of the steel and microstructural condition of the FZ. Austenite formation is a time-dependent diffusional process. According to Magalhães et al. (Ref. 45), the residence time at the treatment temperature proved to be a parameter of great influence on the transformation of ferrite into austenite.

Moreover, the dissolution of Cr_2N at 1150°C PWHT can be attributed to a cooperative mechanism of precipitation of intergranular nitrides and γ_2 , as explained by Ramirez et al. (Ref. 9). The precipitation of Cr_2N at $\alpha/\gamma_{\text{primary}}$ precedes the growth of the secondary austenite. The low-energy interfaces formed between Cr_2N , ferrite, and austenite, along with the diffusion processes, are the factors that control this phase transformation. In the case of intragranular nitrides, they serve as heterogeneous nucleation sites of intragranular γ_2 . It was also verified the dissolution of chromium ni-

trides is favored at temperatures from 1000° to 1200°C (Refs. 24, 53).

Vickers Microhardness and Ultramicrohardness

The highest hardness values in the as-welded samples can be associated with the fact that the low fraction of austenite causes the supersaturation of nitrogen in the ferrite grain, promoting the Cr₂N precipitation (Ref. 45), as seen in Fig. 10B. These particles significantly increase the hardness in the FZ, even with the presence of large ferrite grains and few reformed austenite grains (Ref. 55). In the heat-treated samples, the hardness values are close in both the FZ and BM. The decrease in the FZ hardness after the heat treatments was due to the relief of welding stress, the globularization of the intragranular austenite particles (Ref. 54), and the dissolution of the chromium nitrides. On the other hand, the hardness decreases in the BM of the heat-treated samples, which was caused by the increase of the ferrite interlamellar spacing and by the relief of stress due to dislocation density decrease. According to Muthupandi et al. (Ref. 54), the microhardness reduction cannot be explained by the α/γ ratio changes.

As also verified in previous studies, including Muthupandi et al. (Refs. 54, 56), ultramicrohardness measurements of the ferrite and the austenite in this study have shown that austenite is only slightly harder than ferrite (Table 5). Therefore, a significant difference of hardness in the treated samples was not noticed, even when there was an increase of the austenite fraction with the increase of the heat treatment temperature, because the specific hardness variation of each phase was small. Therefore, the proportion of ferrite and austenite has little effect on the microhardness of the material, as observed in Table 4 for samples L1, L2, L3, and L4. Gunn (Ref. 1) reported that ferrite and austenite do not differ much in composition because the substitutional elements do not have enough time to perform a significant partition during thermal processing. Thus, only the amount of austenite varies, but not the hardness of the γ phase.

Corrosion

As shown previously, the AT100 sample presented a small amount of reformed austenite and abundant precipitation of chromium nitrides — Fig. 10B. It may have caused a chromium depletion around these precipitates and compromised the formation of passive film, which caused a deleterious effect on pitting corrosion resistance in the FZ (Refs. 24, 39, 57).

The results show the heat treatment at 1150°C for 10 min significantly increased the corrosion potential in both the BM and FZ, making the entire weld more noble. This can be explained by the increase in the efficiency of the passive film by the dissolution of the chromium nitrides, which releases the chromium to form the protective oxide by the precipitation of the intragranular austenite, which increases the solubility of N and C, and by the redistribution of the alloying elements by diffusion (Ref. 7).

Tensile Test

Some authors claim that welding has a great influence on the mechanical properties of DSSs because of the phase disproportion produced in the procedure and the specific properties of each phase. By comparing the as-received condition with the as-welded sample (AT100) in the tensile tests, this could be observed (see Fig. 17 and Table 7). Some authors have verified an increase of ductility of heat-treated welded joints, and this was observed in this study for the L4 sample with lower porosity. Muthupandi et al. (Ref. 54) suggested the differences in ductility of as-welded and PWHT samples of DSS joints could not be explained only by changes in the ratio of the two phases in the FZ. Possible reasons for significant toughness improvements in PWHT samples, as in the case of hardness, would be stress relief and spheroidization of intragranular austenite particles. In their research, Zhang et al. (Ref. 58) stated that heat treatment at 1080°C for 3 min increased the impact toughness at -40°C of the welded joint of the UNS S32750 DSS. This improvement in ductility was attributed to the fact that PWHT helped to restore phase balance, as well as to relieve residual stresses in the weld.

Furthermore, the decrease in mechanical strength and ductility in the AT100 and L4 conditions can be accredited to the ferritic grain growth and changes in austenite and ferrite morphology. De Lacerda et al. (Ref. 59) evaluated the effects of annealing heat treatments on the fatigue behavior of a UNS S31803 DSS at different temperatures (1060°, 1200°, and 1300°C). The authors reported that, as the annealing temperature increased, the hardness of the ferrite increased, mainly due to the precipitation of chromium nitrides in ferritic grains. Fatigue crack growth was facilitated in the ferritic phase due to its hardening and the reduction of α/γ interfaces with the increase in grain size of the two phases (Ref. 59).

In addition to the fraction and morphology phases, literature points out the presence of porosity due to the welding process can also influence the mechanical properties of the workpiece. In this study, in addition to the mechanism that causes the recurrent formation of porosities in the laser welding process as mentioned in the item FZ characterization, the pores may have been formed by poor preparation of the edge, causing an inconsistent weld. If the two plates are not in juxtaposed contact, there is not enough material, and the liquid metal covers the pore, resulting in porosities such as those observed in Fig. 8B. Defects in the weld are one of the main reasons to decrease the mechanical strength of the material (Ref. 40). However, pores are stress concentrators, and, thus, for the same applied engineering stress, the real stress around the defects is considerably higher, so the yield and ultimate strength (which use the concept of engineering stress) are smaller. The porosity is a defect in the weld bead, deteriorating its mechanical properties and decreasing its plastic strain capability. In Fig. 20, it is noticed that around the pores, the fracture presented a brittle behavior (presence of cleavage facets). This could explain the poorer performance of the specimen with higher porosity in the weld. Because the pores are sources of stress concentration, this justifies the brittle behavior in the vicinity of pores and the overall ductility loss of the sample.

The material in the as-received condition presented the best tensile behavior in relation to the as-welded material and the heat-treated material. The AT100 sample, which has a predominantly ferritic microstructure with the presence of Cr_2N precipitates, attained higher values of yield strength and lower values of total strain (Refs. 59, 60) than the L4 sample with lower porosity. Moreover, the fact that ferrite hardness is lower than austenite hardness in the as-welded sample (see Table 5), mainly the ferritic phase, contributed to the reduction of the mechanical strength of the material. The decrease in the tensile properties of the as-welded specimen can be attributed to the large volumetric fraction of ferrite, the change in the morphology of the two phases, and the precipitation of chromium nitrides (Refs. 59, 60).

When comparing the samples L4 (with higher porosity) and L4 (with lower porosity), they presented significantly different yield and strength limits, area reduction, and total strain, even though they have a similar proportion of ferrite and austenite phases. These results indicate that even if there is an adequacy of the austenite and ferrite fraction, and the dissolution of chromium nitrides during the heat treatment, the specimens in which the weld presented a higher porosity in the fractured surface presented a behavior close to the specimen without PWHT. When comparing the L4 sample (with lower porosity) with the as-received condition, despite having similar ferrite and austenite proportions, the mechanical properties are different (see Fig. 17 and Table 7). Thus, despite the similar phase fractions, the grain size, phase morphology, and porosity are very relevant factors in the tensile behavior of the welded joint of duplex stainless steel. It follows that simply restoring the phase fraction of the DSS does not guarantee restoration of the tensile properties of welded joints.

Conclusion

The high cooling rates characteristic of the laser welding process provided a mostly ferritic structure, as little austenite was reformed during the cooling process. In the condition with higher heat input (100 J/mm) and consequently, lower cooling rate, the largest fraction of reformed austenite was obtained (3.5%), while in the condition with the lowest heat input (50 J/mm), only 1.8% of the austenite volumetric fraction was obtained. These values are well below what is desirable, which is around 50%.

In both laser welding conditions, there was precipitation of chromium nitrides due to the fast cooling of the weld bead. Thus, diffusion of nitrogen is difficult and precipitates in the form of Cr_2N , inside the ferritic grain or within its boundaries.

The heat treatment after laser welding provided a readjustment of the volumetric fraction in the FZ at 1150°C for 10 min, obtaining a volume fraction of 44.2%, close to the as-received sample. Also, the presence of chromium nitrides via the OM was not noticed.

As-welded samples presented a hardness increase in the FZ in relation to the BM due to the precipitation of chromium nitrides. After heat treatment, the hardness values were very close in both the FZ and BM. The FZ hardness decrease is attributed to stress-relieving globularization of the intragranular austenite particles and dissolution of chromium nitrides.

The as-welded sample (AT100) presented the worst performance in the corrosion test compared to the postweld heat-treated sample (L4) because of the presence of Cr_2N . Heat treatment at 1150°C for 10 min considerably improved the corrosion properties of the welded joint. There was an efficiency increase of the passive film because of the dissolution of the chromium nitrides.

Phase balance by heat treatment tends to improve the tensile behavior of the welded joint. However, phase grain sizes, phase morphology, and porosity are very relevant factors that influence the tensile behavior of the welded joint of DSSL. The results show there is a great influence of the weld quality on the mechanical properties of the workpiece, besides the microstructure of the material. The presence of discontinuities, such as porosities in the weld, greatly impair the mechanical strength of the material.

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APARECIDA SILVA MAGALHÃES, CHARLES HENRIQUE XAVIER MORAIS MAGALHÃES, LEONARDO BARBOSA GODEFROID, and GERALDO LÚCIO DE FARIA (geraldolfaria@yahoo.com.br) are with the Department of Metallurgical and Materials Engineering, Federal University of Ouro Preto, Ouro Preto, MG, Brazil. MILTON SERGIO FERNANDES DE LIMA is with the Institute for Advanced Studies, São José dos Campos, Brazil. JULIANE CRUZ and RODNEI BERTAZZOLI are with the Department of Mechanical Engineering and Aeronautics, Technological Institute of Aeronautics, São José dos Campos, Brazil. BERTAZZOLI is also with the Brazilian Nanotechnology National Laboratory, Brazilian Center for Research in Energy and Materials, Campinas, Brazil.

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Characteristics of Arc and Metal Transfer in Pulsed Ultrasonic-Assisted GMAW

Compared to conventional GMAW, PU-GMAW of aluminum alloy is found to reduce droplet size and increase droplet frequency

BY C. CHEN, C. FAN, X. CAI, Z. LIU, S. LIN, AND C. YANG

ABSTRACT

Pulsed ultrasonic-assisted gas metal arc welding (PU-GMAW) is a newly developed welding method. Pulsed frequency is one of the most important parameters in the PU-GMAW process. In this paper, the influence of pulsed frequency on the GMAW of aluminum alloy was studied. The results showed that the conventional GMAW process was improved significantly by adding different pulsed frequencies. The pulsed arc length, which was the change of arc length with the change of pulsed frequency, was obtained when the pulsed frequency ranged from 1 to 10 Hz. The stable compression arc length was obtained when the pulsed frequency exceeded 20 Hz. The metal transfer frequency in PU-GMAW increased compared to conventional GMAW. The increase of burning arc space pressure in PU-GMAW was mainly the reason for the change of the arc length. The increase in electromagnetic force and acoustic radiation force was the fundamental reason for the increase in droplet frequency.

KEYWORDS

- Pulsed Frequency • Arc Length • Metal Transfer
- Pulsed Ultrasonic-Assisted Gas Metal Arc Welding (PU-GMAW)

Introduction

Gas metal arc welding (GMAW) is widely used in automobile manufacturing, rail transit, and aerospace fields due to its high efficiency and low cost (Refs. 1, 2). However, there are many insufficiencies during the conventional GMAW process, such as more welding spatter and lower arc energy. Many hybrid welding methods have been presented to improve the GMAW process, including adding a magnetic field, a pulsing laser, and an ultrasonic field (Refs. 3–5).

By adding an external magnetic field, the arc behavior, droplet transfer, and weld pool flow were improved (Refs. 6–8), but the magnetic field was easily disturbed by the welding environment. Jia et al. (Ref. 4) reported enhanced metal transfer of aluminum alloy in GMAW with a pulsed

laser. Although the introduction of laser improves droplet transfer, the cost of equipment increases significantly.

The ultrasonic-assisted GMAW process is a new development of the hybrid welding method, and it has shown improvement of the welding process and welded joint (Ref. 5). Fan et al. (Refs. 5, 9) studied the effects of continuous ultrasound on the droplet transfer behaviors in GMAW. The authors found that continuous ultrasonic-assisted GMAW (CU-GMAW) can compress the arc and increase the droplet frequency. The welding process stability was also enhanced. Additionally, the effects of ultrasound parameters on arc behavior during the GMAW process were reported by Xie et al. (Refs. 10, 11). The geometrical parameters of acoustic radiator were also optimized by analysis of the sound field distribution. However, CU-GMAW has the disadvantage of low ultrasound utilization.

Pulsed ultrasonic-assisted GMAW (PU-GMAW) was shown to enhance ultrasound utilization. Chen et al. (Ref. 12) confirmed the feasibility of pulsed ultrasound for controlling the GMAW process. The effects of pulsed ultrasound on short-circuiting transfer has been discussed in detail (Refs. 13, 14). The short-circuiting transfer process improved under the action of the pulsed ultrasound, which included an increase in droplet frequency.

The GMAW process is commonly employed in the welding of aluminum (Refs. 15–18). A commonly used transfer mode is globular transfer. However, there has been little research on the effect of ultrasonic-assisted pulsing parameters on metal transfer behavior during GMAW.

In this work, the influence of pulsed frequency on the characteristics of arc shape and globular transfer were analyzed during the PU-GMAW of aluminum alloy. The arc shape and droplet dimension were obtained with images from a high-speed camera.

Experimental Materials and Methods

Materials

2A14 aluminum alloy plate with a thickness of 5 mm was used as the base metal. ER2319 welding wire in a diameter of

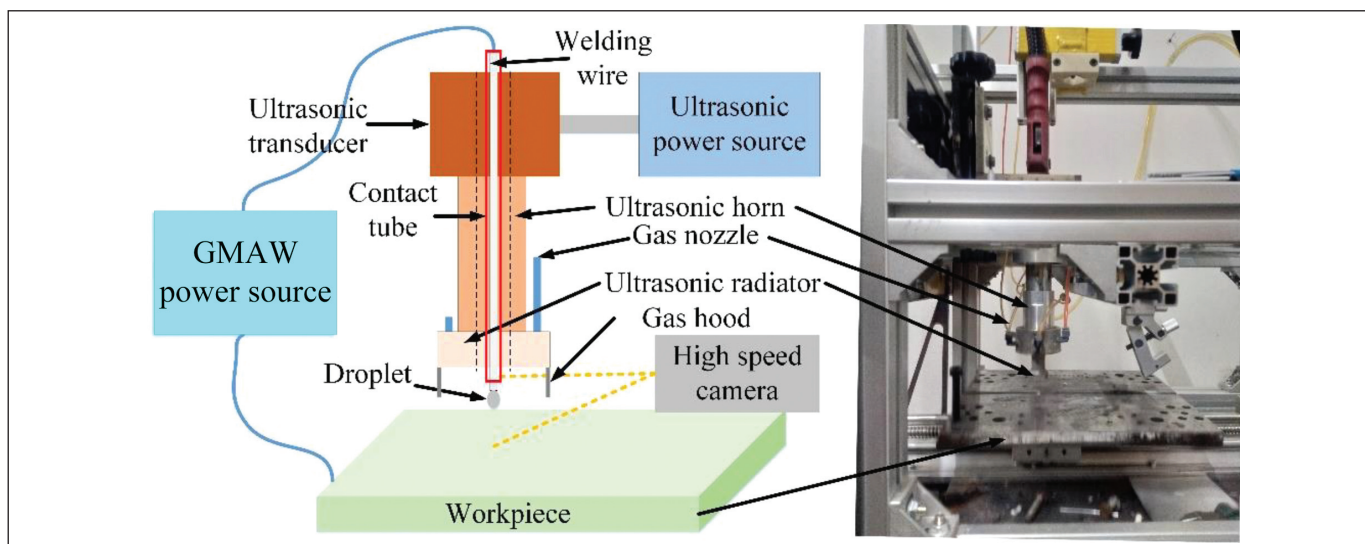


Fig. 1 — Schematic diagram of the PU-GMAW process.

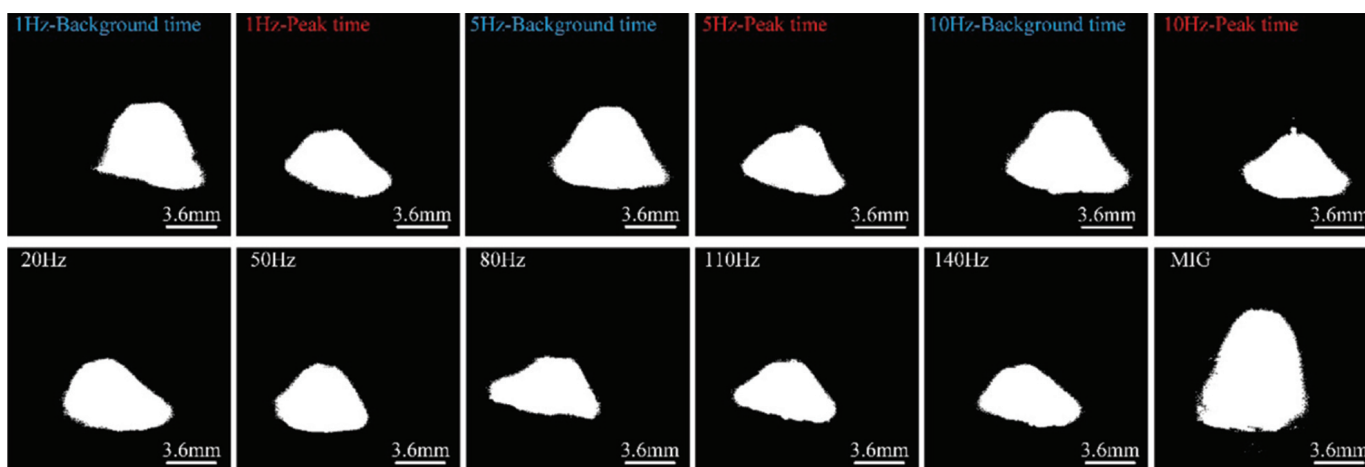


Fig. 2 — Images of arc shape in different welding processes.

Table 1 — The Chemical Compositions of 2A14 Alloy and ER2319 (wt-%)

Elements	Cu	Mg	Si	Zr	Mn	Fe	V	Ti	Zn	Al
2A14	4.48	1.68	1.24	0.81	0.59	0.43	0.29	0.15	—	Bal.
ER2319	4.33	0.91	0.62	0.29	0.70	—	0.33	0.55	0.26	Bal.

1.2 mm was employed. The chemical compositions of the base metal and the welding wire are given in Table 1.

Methods

Figure 1 shows the equipment of pulsed ultrasound-assisted GMAW. The working principle of the PU-GMAW process has been given in literature (Ref. 14). The ultrasonic power source can produce the maximum power of 2000 W. The ultrasonic wave frequency was 20 kHz. The welding power source was Fusion Pro™ 450 GMAW, which was produced by the Kenbey Co. of Finland. The welding parameters are given in Table 2.

During welding, 99.99% argon was employed as the shielding gas. The contact tip-to-workpiece distance was 12 mm. Previous research (Ref. 19) indicated the compression degree of the arc shape could be altered by changing the transmitting height. When the transmitting height of 16 mm was employed, the arc length was compressed. When the transmitting height of 20 mm was employed, the arc length could be further compressed compared with that of the transmitting height of 16 mm.

In this work, the shorter arc length was useful to observe the effect of pulsed frequency on the arc shape, and the longer arc length was useful to analyze the effect of pulsed frequency on the metal transfer. Therefore, the transmitting height of 20

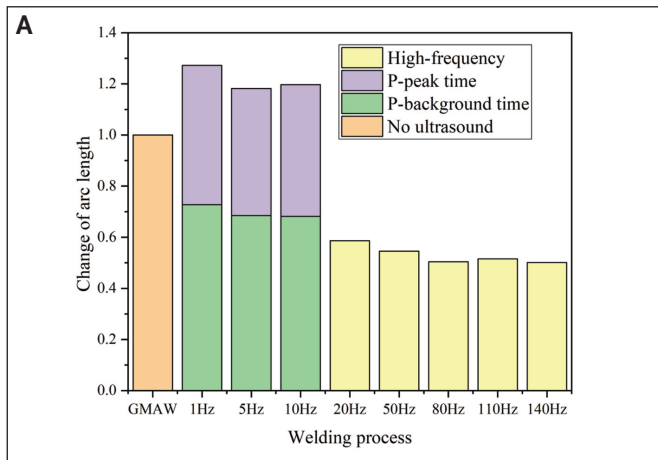


Fig. 3 — Change of arc length.

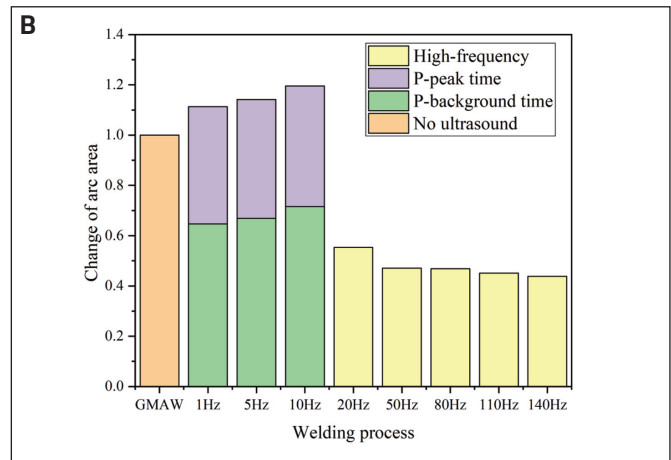


Fig. 4 — Change of arc area.

Table 2 — The Parameters of Welding

Welding voltage	Welding speed	Shielding gas flow	Wire feeding speed
20 V	7 mm/s	20 L/min	4.5 m/min

mm was used to study the effect of pulsed frequency on the arc shape. The transmitting height of 16 mm was used to study the effect of pulsed frequency on the metal transfer. The pulsing frequency was changed from 1 to 140 Hz. Images of the metal transfer were captured by a high-speed camera with a frame of 2000 fps. The exposure time was 30 ms during the capture of the arc shape. During the capture of the droplet transfer, the exposure time was 1.99 ms.

Results and Discussions

Arc Characteristics

Figure 2 shows arc shape images during different processes. Compared with conventional GMAW, the arc length during PU-GMAW was reduced. This result was also found in CU-GMAW (Ref. 9). Compared to GMAW, the arc energy in PU-GMAW increased due to the arc shape compression, which enhanced welding efficiency (e.g., increased weld penetration). The arc length was stabilized and compressed during CU-GMAW. However, during PU-GMAW, the arc length of the pulsed background time was greater than that of the pulsed peak time when the pulsed frequency was changed from 1 to 10 Hz. A pulsed arc length could be obtained by PU-GMAW with a lower pulsed frequency. When the pulsed frequency was increased to 20 Hz, the stabilized compression arc length was obtained.

The GMAW arc length was defined as a normalized arc length. The influence of pulsed frequencies on the arc length is shown in Fig. 3, which was obtained by Equation 1. The P-peak time expresses the arc length during the pulsed peak time. The P-background time expresses the arc length during the pulsed background time. Compared with GMAW, the arc length during the P-background time was decreased to around 0.7. The arc length during the pulsed peak time

was decreased to around 0.55. The arc length of the P-background time was greater than that of the P-peak time. The normalized arc lengths during PU-GMAW were approximately 0.5, which were similar to the arc length during P-peak time when the pulsed frequency was increased to 20 Hz. At a higher pulsed frequency (~20 Hz), the arc lengths were the same as that of the P-peak time. As shown in Fig. 4, the influence of pulsed frequencies on the arc area was obtained by Equation 2. It could be said that with the change of process parameters, the length and area of the arc had the same change tendency.

$$P_L = \frac{L_0 - L_U}{L_0} \quad (1)$$

where P_L is the change rate of the arc length, L_0 is the arc length during GMAW, and L_U is the arc length during PU-GMAW.

$$P_A = \frac{A_0 - A_U}{A_0} \quad (2)$$

where P_A is the change rate of the arc, A_0 is the arc area during GMAW, and A_U is the arc area during PU-GMAW.

Droplet Transfer Characteristics

This section mainly studies the characteristics of droplet transfer during the stable compression of arc length. Images of droplet transfer with the different processes are given in Table 3. The droplet transfer mode was the typical globular transfer. The metal transfer frequency and droplet size was always used to describe the droplet transfer behavior (Refs. 20, 21), as shown in Table 3.

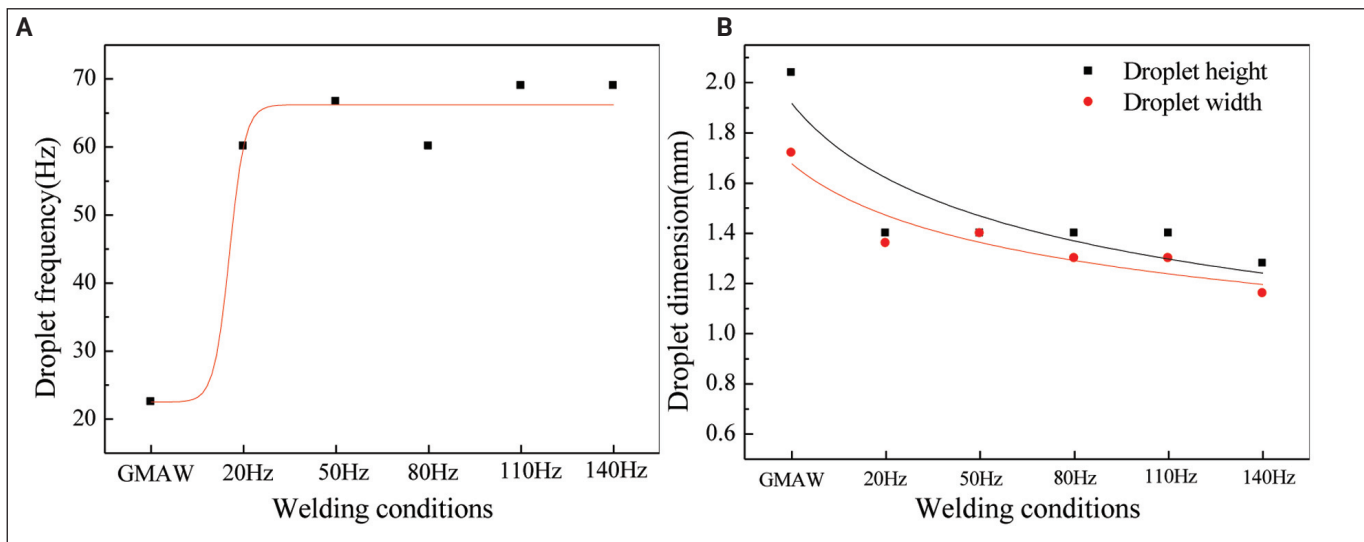


Fig. 5 — Droplet frequency and droplet dimension during the different processes: A — Droplet frequency; B — droplet dimension.

Figure 5 shows the high-speed imagery of the effect of ultrasonic and pulsed ultrasonic-assisted droplet behavior. The droplet frequency is illustrated in Fig. 5A. The droplet transfer frequency of 22.5 Hz was obtained using conventional GMAW. Figure 5A indicates the droplet frequency remained relatively constant above a 20-Hz pulsed frequency. Under the action of a higher pulsed frequency, the droplet frequency during PU-GMAW was increased by about two times compared to conventional GMAW. Similar results were found during CU-GMAW, and it is believed the acoustic radiation force increased the droplet frequency (Ref. 9). Figure 5B shows the height and width of the droplet. The droplet dimensions during PU-GMAW were less than that of GMAW. There was a slight decreasing trend in the droplet dimensions as the pulse frequency increased. During PU-GMAW, the droplet frequency and the droplet dimensions had a similar variation tendency with the change of pulsed frequency.

Discussions

Mechanisms of Arc Compression

A standing wave sound field was formed between the ultrasound radiator and base metal face. The standing wave sound field was employed in the arc-burning space, which increased the space pressure and improved the arc shape. Previous research indicated the arc would be compressed under the action of the standing wave sound field (Ref. 11). It is well known that sound intensity is proportional to sound pressure. The standing wave sound field intensity (I) can be described by Equation 3.

$$I = c^2 \times f^2 \times A^2 \quad (3)$$

where c is the acoustic speed, f is the ultrasonic frequency, and A is the amplitude of the ultrasound.

In this work, the pulsed ultrasonic power was a square wave output, where there was a peak ultrasonic output and a background ultrasonic output, as shown in Fig. 6A. The ul-

Table 3 — Images of Droplet Transfer with the Different Welding Processes

	0ms	0.5ms	3ms	5.5ms	44ms	44.5ms
GMAW						
20 Hz						
50 Hz						
80 Hz						
110 Hz						
140 Hz						

trasonic transducer's output had a 50% duty cycle. The ultrasound amplitude was increased with the increase of ultrasonic power. Therefore, during PU-GMAW, the standing wave sound field intensity had a periodic change due to the change of ultrasonic power. During the lower pulsed frequency, the arc length oscillated and contained the peak time arc length and the background time arc length, as shown in Fig. 2. However, the obtained compression arc shape required a certain amount of time during PU-GMAW so the pulsed waveform of the arc length could be different from that of the pulsed ultrasonic power.

Figure 6A and B shows the relationship between the change of arc length and the pulsed ultrasonic power. The peak time arc length was obtained after the time of t_{p1} during the pulsing peak time of t_{p2} . The t_{p1} was the rise time of the pulse front. Af-

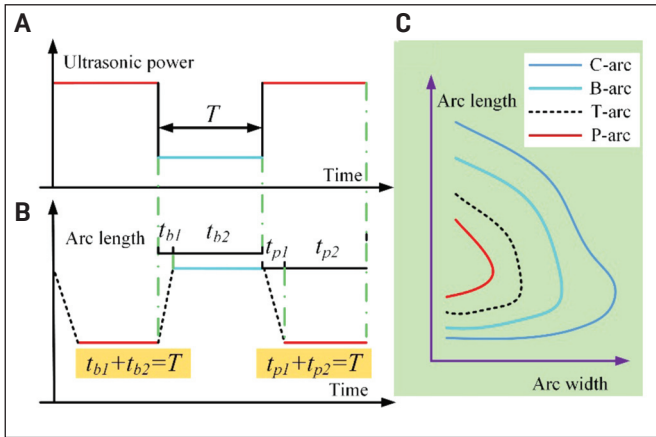


Fig. 6 — Relationship between the change of arc length and the pulsed ultrasonic power.

ter the time of t_{p2} , the arc length was changed from P-arc to B-arc length, which needed the time of t_{b1} during the pulsed background time. The t_{b1} was the falling time of the pulsed back edge. When the pulsing frequency was increased to a constant value (the pulsed width was small enough), the arc length could not respond quickly enough to the pulse change from background to peak amplitude. Therefore, a stable compression arc shape could be obtained, which could be the B-arc, T-arc, and P-arc, as shown in Fig. 6C. (Note: “C-arc” expresses the conventional arc shape, “B-arc” expresses the arc shape during the background time, “T-arc” expresses the arc shape in the time of t_{b1} or t_{p1} , and “P-arc” expresses the arc shape during the peak time.)

According to the Arc Characteristics section in this work, the stable compression arc shape was the same as the P-arc during the higher pulsed frequency. Therefore, it could be concluded that t_{p1} should be much less than t_{b1} , which means the P-arc was quickly obtained. During the pulsed peak to the pulsed background, the P-arc didn’t instantaneously change to B-arc due to thermal inertia, which kept a time (t) and then changed to B-arc gradually. During the higher pulsed frequency, the pulsed width could be less than the time of t , so the arc shape kept the P-arc.

Mechanisms of Acceleration Droplet Transfer

In conventional GMAW, the droplet transfer was affected by the surface tension, friction force, electromagnetic force, and gravity effect, as shown in Fig. 7. The surface tension had a hindrance effect on droplet transfer, which is given in Equation 4 (Ref. 22). The welding wire diameter and the surface tension coefficient were constant. The surface tension was constant. The electromagnetic force (P_r) is defined by Equation 5 (Ref. 22). Through observation of the arc shape, it could be found that the arc width (R) during PU-GMAW was reduced compared with that of GMAW. When r was zero, P_r was given as shown in Equation 6. Therefore, P_r during PU-GMAW increased compared to GMAW. The compression arc shape during PU-GMAW could promote droplet transfer.

$$F_s = 2\pi R_w \sigma \quad (4)$$

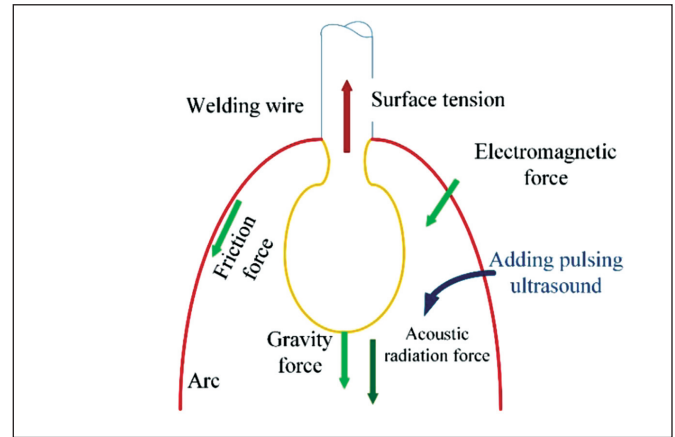


Fig. 7 — Schematic diagram of the droplet transfer during the different processes.

where F_s is the surface tension, R_w is the diameter of the welding wire, and σ is the coefficient of the surface tension.

$$P_r = K \frac{I^2}{\pi R^4} (R^2 - r^2) \quad (5)$$

$$P_r = K \frac{I^2}{\pi R^2} \quad (6)$$

where I is the welding current, R is the arc radius, and r is any radius.

As shown in Fig. 5, the droplet dimension during PU-GMAW was less than that of GMAW. Accordingly, the gravity force of PU-GMAW was less than that of GMAW. The acoustic radiation force (F_a) acted on the droplet under the action of ultrasound, which could enhance the droplet transfer, as shown in Fig. 7. The F_a was expressed by the time-averaged potential (U_0), as follows (Ref. 23):

$$F_a = -\text{grad}U_0 \quad (7)$$

U_0 is defined as follows (Ref. 23):

$$U_0 = 2\pi R_s^3 \left[\frac{\bar{P}_{in}^2}{3\rho_0 c^2} f_1 - \frac{\rho_0 \bar{v}_{in}^2}{2} f_2 \right] \quad (8)$$

where R_s is the droplet dimension; $\bar{P}_{in}^2$ is the mean square deviation of the acoustic pressure; ρ_0 is the density of the shielding gas; c is the sound velocity in the shielding gas; $\bar{v}_{in}^2$ is the mean square deviation of the vibration speed; $f_1 = 1 - \rho c^2 / \rho_s c_s^2$, $f_2 = 2(\rho_s - \rho) / (2\rho_s + \rho)$, ρ_s is the ultrasonic radiator density; and c_s is the sound velocity in the ultrasonic radiator.

Normally, U_0 is increased with the increase of the acoustic pressure. The acoustic pressure is increased with the increase of the ultrasonic power. The acoustic radiation force is in direct proportion to the ultrasonic power. Therefore, the acoustic radiation force was pulsed during PU-GMAW. Under the action of the higher pulsed ultrasound, the

droplet frequency was increased — Fig. 5. It can be concluded that PU-GMAW increases the electromagnetic force and introduces a pulsed acoustic radiation force that reduces the droplet size and increases the droplet frequency.

Conclusions

1) A pulsed arc length can be obtained during PU-GMAW with a lower pulsed frequency. When the pulsed frequency was increased to 20 Hz, the stabilized compression arc length was obtained.

2) Under the action of higher pulsed frequency, the droplet frequency during PU-GMAW was increased by about two times compared to conventional GMAW. The droplet size during PU-GMAW also decreased.

3) The changed ultrasonic power, which led to the change in the sound field intensity, was the main cause for the formation of the pulsed arc length.

4) The increase in electromagnetic force and the introduction of the pulsed acoustic radiation force was the main reason for the increase in the droplet frequency during PU-GMAW.

Acknowledgment

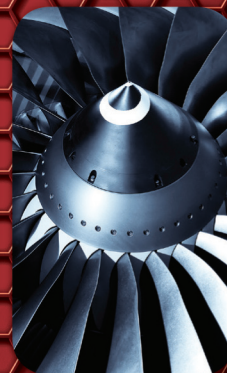
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CHAO CHEN, CHENGLEI FAN (fclwh@hit.edu.cn), XIAOYU CAI, ZENG LIU, SANBAO LIN, and CHUNLI YANG are with the State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, China.

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