

WELDING *Journal*



JANUARY 2021



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Industry Perspectives

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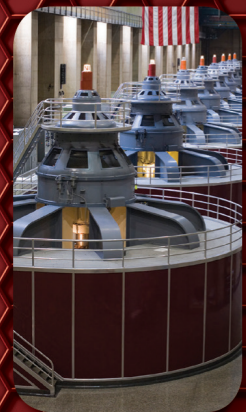
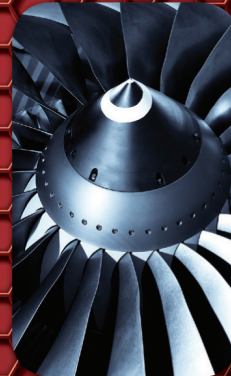
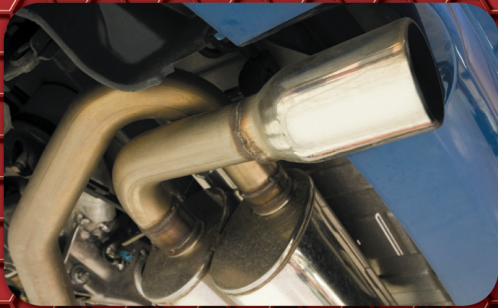
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Lifetime Achievement Award



American Welding Society®

Friends and Colleagues:

In 2018, The American Welding Society established the honor of the **Certified Welding Inspector Lifetime Achievement Award (CWI-LAA)**. The award is intended to recognize individual members for a career of distinguished service, outstanding accomplishments, exceptional leadership, and innovative contributions in the area of welding inspection and welding inspection technology. Individuals receiving the award may be currently working as a CWI, or have worked as one in the past. The selection committee is seeking nomination packages for qualified individuals who have demonstrated specific accomplishments in one or more of the following areas:

- Advancements in the field of welding inspection.
- Mentorship of individuals entering the field of welding inspection.
- Effective application of existing and new inspection technology.

This could be evidenced by one or more of the following:

1. Development of novel concepts or tools related to welding inspection.
2. Participation in activities directly related to the recruitment, training, education and/or mentorship of individuals entering the field of welding inspection.
3. Leadership in AWS or private industry, particularly as it impacts advancement of the welding inspection profession.
4. Consultancy in technical matters or welding industry business matters, including expert witness activities related to welding inspection.
5. Publication of books, papers, articles or other significant works related to welding inspection.
6. Meaningful participation in AWS committees, Sections or other AWS voluntary contributions related to welding inspection.

For more specifics on the nomination requirements, please contact Malisa Mercado at mmercado@aws.org at AWS headquarters in Miami, or simply follow the instructions on the AWS CWI Lifetime Achievement Award nomination form located at: aws.org/cwilaa.

Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is **July 1, 2021**. The CWI Lifetime Achievement Award Committee looks forward to receiving numerous nominations for 2022 consideration.

Sincerely,

Kerry Shatell

Chair, CWI Lifetime Achievement Award Committee

IMPORTANT Announcement!



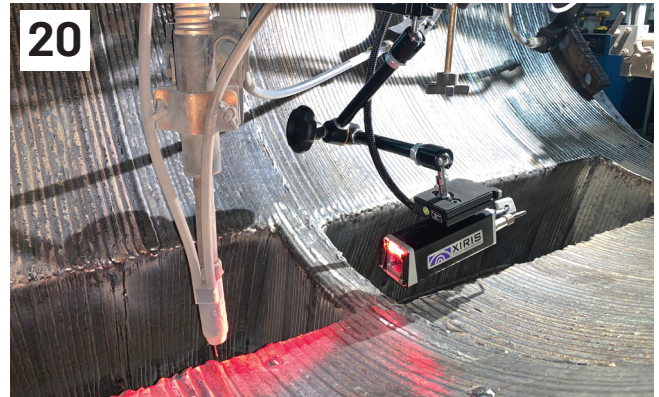
Nominate Your Colleague for the American Welding Society CWI Lifetime Achievement — Award —

July 1, 2021 Submission Deadline



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On the cover: SST portable cold spray technology. (Courtesy of CenterLine (Windsor) Limited. Photo by: Gene Schilling.)

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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.

Welding Journal (ISSN 0043-2296 Print) (ISSN 2689-0445 Online) is published monthly by the American Welding Society for \$120.00 per year in the United States and possessions, \$160 per year in foreign countries: \$750 per single issue for domestic AWS members and \$10.00 per single issue for non-members and \$14.00 per single issue for international. Not available for resale in either print or electronic form. American Welding Society is located at 8669 NW 36 St., # 130, Miami, FL 33166-6672; telephone (305) 443-9353. Periodicals postage paid in Miami, Fla. and additional mailing offices. **POSTMASTER:** Send address changes to *Welding Journal*, 8669 NW 36 St., # 130, Miami, FL 33166-6672. **Canada Post:** Publications Mail Agreement #40612608 Canada Returns to be sent to Bleuchip International, P.O. Box 25542, London, ON N6C 6B2, Canada.

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Hot off the Press, Serving Up the *Welding Journal*



Kristin Campbell
Managing Editor



Annette Alonso
Publisher/Editor

“It’s an honor to continue connecting with our readership every single month. Sharing someone’s story is also a unique privilege.”

Greetings and happy new year, American Welding Society (AWS) members! We wanted to take this opportunity to share behind-the-scenes details of what it’s like to produce the *Welding Journal* and let you know what’s in store for your magazine in 2021.

Combined, the two of us have more than 30 years of experience working at AWS. During that time, we’ve learned welding is much more than arcs and sparks — it’s given individuals an incredible sense of purpose by using their hands to create something good, which has transformed their lives and led to rewarding careers and so much more.

The *Welding Journal* has been published continually since 1922. It’s an honor to continue connecting with our readership every single month. Sharing someone’s story is also a unique privilege. Though it isn’t easy and we’re always challenged in different ways, the responsibility of serving you — when the magazine hits your email inbox and/or home mailbox — keeps us going.

It’s truly a team effort to get each issue finished from start to end, cover to cover. With that said, we’d like to recognize our colleagues for always going above and beyond; you might already be familiar with some of them. On the editing side, that’s Cindy Weihl, Katie Pacheco, Alexandra Quiñones, and Roline Pascal; our design and production team, Carlos Guzman, Zaida Chavez, and Brenda Flores; advertising duo Sandra Jorgensen and Lea Owen; and Sonia Aleman, our subscriptions representative.

We’re looking forward to bringing you new issues this year and to winning more awards from the Florida Magazine Association and Association Media & Publishing. Here’s our calendar, with the highlighted topics for each month:

- **January** — Industry Perspectives, Thermal Spray, Engine-Driven Welding Machines
- **February** — Gases and Consumables, Aluminum Welding

- **March** — Plastic Welding, Arc Welding, The American Welder: Welding’s Influencers
Editorial closing/ad insertion: January 11

- **April** — Education, Inspection
Editorial closing/ad insertion: February 10

- **May** — Pipe and Tube, Sanitary Applications
Editorial closing/ad insertion: March 10

- **June** — Automotive, Power Sources, The American Welder: Job Tips
Editorial closing/ad insertion: April 12

- **July** — Safety and Health, Naval Applications, FABTECH Product Preview
Editorial closing/ad insertion: May 10

- **August** — FABTECH Show Issue
Editorial closing/ad insertion: June 10

- **September** — Brazing and Soldering, The American Welder: Oxyacetylene Welding
Editorial closing/ad insertion: July 12

- **October** — Metallurgy, Cutting
Editorial closing/ad insertion: August 10

- **November** — Automation, The American Welder: Military/Veteran Focus
Editorial closing/ad insertion: September 10

- **December** — Additive Manufacturing, Pressure Vessels, FABTECH Recap
Editorial closing/ad insertion: October 11

To access the AWS 2021 Media Kit — plus learn about our other publications, including *Welding Journal en Español*, *Inspection Trends*, *Welding Marketplace*, and *SPRAYTIME®* — visit aws.org/publications.

In addition, we’ll be launching a re-designed *Welding Journal* this year. It will feature an updated, modern look with new design, fonts, and styles. Stay tuned for these exciting enhancements to come.

Before saying farewell, we very much want you to stay in touch with us and provide your feedback. For example, how did you like past issues? What would you like to see in future issues? Is there an article you’d like to submit? Please engage with us at aalonso@aws.org and kcampbell@aws.org.

We wish you a prosperous year. 

ESAB and YASKAWA Sign Collaborative Agreement; Xpanse Event Also Held Virtually



The arc equipment area is highlighted during ESAB's recent Xpanse digital experience.

The ESAB Group Inc., Annapolis Junction, Md., and robot and robot system company YASKAWA have signed a partnership to develop and market a line of pre-engineered robotic welding systems called XCellerator. These systems will be engineered and built by Yaskawa, then marketed by ESAB through its global sales channels.

Yaskawa brings more than 30 years of experience producing robots, robotic controllers, and robot cells to this effort. ESAB also brings its expertise in welding processes, filler metals, equipment, and automation together with its proprietary WeldCloud weld operations management infrastructure.

Pre-engineered cells like XCellerator are the fastest, simplest path toward automation. They improve productivity per worker by three to five times and offer a compelling return on investment. The cells also appeal to small and medium-sized manufacturers and fabricators that value easy installation, set-up, and operation, enabling them to take a step toward automating their welding operations.

In addition, ESAB hosted Xpanse, a virtual welding and cutting experience, from November 18 to 20 when FABTECH would've occurred.

"Product experts, educational information, discussion panels, instructional series, ESAB University, daily sweepstakes, special show pricing on select products, and 'buy now' capabilities — if we could include it as part of ESAB Xpanse, we did," said Steven Molenda, director of global marketing communications and marketing strategies, ESAB.

Once logged into esabxpanse.com, guests were welcomed into the 3D world. Entering the event under an enclosed hallway, the sound of metal being welded along with dynamic music could be heard. Inside, posters reflected the industry segments served as well as the company's history. Seventeen stations contained 70 different products.

At ESAB University, several videos from an educators panel discussion to pipe welding in tight spaces were launched. Visit the company's YouTube channel to see them.

Additional spaces were for the following divisions: filler metals; personal protection equipment; welding torches; wire feeders; gouging and exothermic; gas metal arc and multiprocess for heavy industrial; gas tungsten arc; shielded metal arc; multiprocess for light industrial; gas equipment;

manual plasma cutting; specialty gas; digital solutions; welding automation and robotics; Thermal Dynamics automation; cutting automation; and industry segments.

Advanced Manufacturing Certification Program Offered to Detroit Small Businesses Recovering from Pandemic

LIFT, the Detroit-based, Department of Defense-supported national manufacturing innovation institute, part of the Manufacturing USA network, has opened its Operation Next advanced manufacturing certification program to employees of Detroit-area small and medium-sized manufacturers to help them recover from the pandemic's impact.

The new Operation Next civilian program, funded through the Coronavirus Aid, Relief, and Economic Security Act and awarded to LIFT by the National Institute of Standards and Technology, will support the training of 250 workers — at no cost to the individual or their employer — in Detroit and Pittsburgh. The workers will participate in industry-standard training in computer numerical control machine operations, industrial technology maintenance, welding, and robotics.

Operation Next features a hybrid curriculum of online theory combined with performance-based activities and assessment, and its accelerated pace is ideal for reskilling or upskilling incumbent workers. In Detroit, employers will have the option of providing performance-based training at their own worksite or at LIFT's Learning Lab in Corktown. Completers will earn industry recognized credentials from the National Institute of Metalworking Skills and American Welding Society.

LIFT is also partnering with the Workforce Intelligence Network to bring manufacturers into the program. Visit winintelligence.org/initiatives/opnext/.

Monroe County Community College Receives National Science Foundation Grant

Monroe County Community College (MCCC) in Michigan has secured a \$105,027 grant from the National Science Foundation (NSF) for a three-year project titled "Collaborative Research: Improving the Educational Experiences, Outcomes and Career Pathways of Welding Technology Students."

The college was previously awarded a \$224,906 NSF grant in the spring of 2018 with the goal of increasing the region's supply of qualified welders with advanced levels of education who can further research, development, and innovation in the field.

MCCC is a sub grantee on this latest NSF grant; the University of Michigan (UM) is the fiduciary of the overall grant of \$799,982. In addition to UM, MCCC is partnering on the grant with sub grantees Wayne State University and Macomb Community College.

This project will help colleges to better understand what factors influence the experiences of welding students; what promotes their graduation and matriculation to welding career pathways; and how the expectations of students, instructors, and employers align with welding industry needs. It will build a research collaboration among faculty, administrators at UM, MCCC, Wayne State, and Macomb. 

AWS COUNSELOR NOMINATION



American Welding Society®

Friends and Colleagues:

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

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

For specifics on the nomination requirements, please contact Chelsea Steel at csteel@aws.org at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form located at www.aws.org/counselor. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is **June 1, 2021**. The Counselor Committee looks forward to receiving numerous Counselor nominations for 2022 consideration.

Sincerely,

David J. Nangle

Chair, Counselor Committee

IMPORTANT
Announcement



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

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

June 1, 2021
Submission Deadline

AWS Holds 101st Annual Meeting and Education Summit; WEMCO Celebrates Excellence in Welding Awards

In the spirit of moving forward, during the week when FABTECH would've happened, the American Welding Society (AWS), Miami, Fla., went online to host its 101st Annual Meeting as well as the Education 2020 Virtual Summit, where winners of the AWS Poster Session and WEMCO's Excellence in Welding Awards were honored.

• **101st Annual Meeting.** On November 16, AWS Executive Director and CEO Gary W. Konarska II welcomed guests at the annual meeting, which was held virtually for the first time. After rising for the National Anthem, he introduced Past President David Landon, Fellows Chair Sudarsanam Babu, Counselors Chair David J. Nangle, Foundation Chair William A. Rice, Vice President W. Richard Polanin, Past President Thomas J. Lienert, and President Robert W. Roth.

Roth officially called the meeting to order and presented the president's address. He reflected on how the year started with a full calendar, including a January trip to Israel to give the opening address for WJAM2020, the Welding, Joining, and Additive Manufacturing Symposium; a February visit to the New Mexico Section; then to the AWS Transition Ceremony and Winter Executive Committee meeting in Miami, Fla.; followed by a visit to Dallas and the North Texas Section in the first part of March.

"With a blink of an eye, 20% of 2020 was in the rear-view mirror . . . and then it stopped!" Roth said. "By the middle of March, you will remember, the pandemic was upon us."

Roth continued by explaining the change came quick and abrupt for AWS, too, as staff adjusted to remote work. On brighter fronts, he also mentioned that an important task was accomplished when Konarska was hired, and even with all the cancellations, the Society will add to its reserves this year. However, he stressed there's still much left to do.

"The pandemic accentuated the weakness in our IT infrastructure and our digital capability. The board has authorized a substantial multiyear investment in this area," Roth added. He further emphasized using technology to complete work, deliver content, and serve and support members.

"Like so many things, this is a journey. Quite a way to kick off the first year of our second century, but the journey continues. I am confident in our long-term success," he said.

A vote to amend the AWS Bylaws, as published in the October 2020 *Welding Journal*, was passed by membership. See this issue's Society News on page 41 for more details.

Additionally, in recognition of his outstanding and distinguished organizational leadership that has enhanced the image and impact of the welding industry, Richard Corbit was inducted as an AWS Counselor. Moreover, Susan Fiore, Michael Karagoulis, and Alexander Shapiro were inducted as AWS Fellows in recognition of their renowned work in the advancement of the science, technology, and application of welding.

Rice wrapped up the meeting with a report on the state



On November 16, AWS's 101st Annual Meeting took place online. Displayed is a screen shot from the start of the event.

of the AWS Foundation. He showed a chart highlighting 10,500 scholarship, fellowship, and grant awards totaling more than \$15 million since 1989.

“Since 2016, we have expanded our scholarship programs each year, launched two new grant programs, and increased our university research funding. This year, we expect to cross \$2 million in total awards, a 160% increase over 2015. In fact, in the past five years, we have awarded more scholarship, grant, and fellowship dollars than the previous 27 years combined. This year, we have impacted welding education and inspired the next generation of talent at a time when both are needed more than ever,” Rice said. (To learn more, see the 2019–2020 *Annual Report* starting on page 17 in the July 2020 *Welding Journal*.)

• **AWS Education 2020 Virtual Summit.** At this summit, held November 18–20, both the educational sessions and professional programs were live and interactive, packed with fresh research, insights, best practices, and more. Participants earned a maximum of 20 professional development hours during the three-day event, which attracted 489 registrants.

The educational meetings kicked off with **AWS Educational Overview of Welding Codes and Standards.** It was hosted by Paul Lynn Sturgill, Sturgill Welding & Code Consulting; presenters Bill Komlos, ARC Tech, and Rich Campbell, Bechtel Global Corp.; and AWS instructors. The 2-h courses highlighted the significant changes in recent revisions of AWS and American Society of Mechanical Engineers codes and standards.

The first day was also comprised of the **AWS/Weld-Ed Virtual Educators: Welding Procedure Specification Development and Educational Use** course, introduced by Rick Polanin, AWS vice president, professor at Illinois Central College, and co-principal investigator for Weld-Ed. Monica Pfarr, AWS Foundation executive director, opened the seminar by presenting information on the Foundation and student scholarships. The rest of the conference provided educators with the fundamental concepts of welding procedure specifications (WPSs) development, qualification, student use, and software solutions for WPS preparation.

“Welding training often focuses on teaching to improve a student’s ability to run a visually appealing weld bead . . . most practice time is spent on technique and eye-hand coordination,” said presenter Mark Baugh, professor at Weber State University. “To better prepare students for real-world careers in welding, we should provide instruction on the development and use of WPSs during student practice.”

The professional programs featured sessions on novel developments and research areas related to materials joining, including surfacing and additive manufacturing.

Included in the sessions was a plenary presentation titled **“101st Year of the American Welding Society: Changes in Welding & Outlook”** by Stephen S. Liu, Juan Carlos Madeni, and Zhenzhen Yu, Colorado School of Mines. Liu outlined landmarks in welding and joining technology beginning from 2000 to 2500 years ago BC when the Egyptians invented welded gold by pressure-forge welding. He touched on how technology evolution led to the development of enhanced power sources, fabricating and manufacturing have become increasingly complex because of construction of mega structures, miniaturization and automation of welding systems demand disciplines outside welding in a strict sense, and more.

Registered participants may view the entire education



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• The **AWS Poster Session**, an integral part of the AWS Professional Program, is where graphic displays of technical achievements are presented for close, first-hand examination. Posters present welding results/related material, as well as research results that call for the study of photomicrographs, tables, systems architecture, or other illustrative materials.

Winners for **High School Welding Program** were Ailsa Craigmile, first place; Evan Freeland, second place; Luke Wilson, third place; and Honorable Mentions Jarrett Sielke and N. Potanko.

Recipients for **Baccalaureate Engineering — Engineering Technology** were Ryan Lannutti, first place; Chris Dugan, second place; Timothy Babyak, third place; and Honorable Mentions Tushar Khemraj Telmasre, Shawn Burgan, and Nick Schlegel.

In **Graduate Engineering — Engineering Technology**, the awardees were Samuel Luther, first place; Ethan Sullivan, second place; Kaleb Gabbert, third place; and Honorable Mentions Jeremy McNicol and Dhruv Bhatt.

• Rounding out this recap are the **WEMCO, an Association of Welding Equipment Manufacturers and Industry Partner of AWS, Excellence in Welding Awards**. Recognizing individuals, schools, and businesses instrumental in raising the image of welding in their communities, the following are the 2020 recipients acknowledged during a 40-min video (now available at aws.org/wemco/imageofweldingawards).

Individual — Tom West. Among his accomplishments are more than 50 years of welding engineering experience in



The winners of WEMCO's Excellence in Welding Awards for 2020 were Tom West, Catherine Lindquist, Hobart Institute of Welding Technology, Multi-Craft Contractors, Arc3 Gases, Todd Clouser, and William Holmes.

the marine environment supporting repair and construction of U.S. Navy vessels and offshore oil field subsea work.

"Thank you. I hope my contributions have in some way advanced the state of the art in welding," West said.

Educator — Catherine Lindquist. In part, she said, "As a welding instructor, the real reward for the 33 years I spent at Lansing Community College, 31 years as an educator, was teaching new students starting a new career, those working to improve their skills, or those learning a new hobby. Through my ca-

reer as a welding educator, I know I have assisted in changing many lives as they have changed mine. I will be forever grateful."

Educational Facility — Hobart Institute of Welding Technology, Troy, Ohio. "On behalf of the Hobart Institute of Welding Technology staff, board of directors, students, alumni, and our community, thank you for the honor of this prestigious award. We are appreciative of every staff member, past and present, for their contributions over the course

A collage of images showing various thermal spray equipment and consumables. The main image shows a large orange thermal spray gun. Below it are several smaller images: a close-up of a spray gun nozzle, a collection of spray gun components, a spray gun in use, and a box of consumables.

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of our 90 years in welding education. Without their dedication to excellence, these awards would not be possible. The welding industry has our continued commitment to train the world's best welders for the next 90 years," said Scott A. Mazzulla, president and CEO.

Small Business — Multi-Craft Contractors (MCC), which began in 1972 in northwest Arkansas as a local contracting company, expanded and opened a plant in Springfield, Mo., in 2001, and now has operations in 15 states.

"MCC is passionate about the welding profession, and we are dedicated to work with the community and our educators to promote this great career. We are deeply blessed to have an education partner like Ozarks Technical Community College, which shares our passion for welding and encourages input and collaboration from the business community. I can't imagine where we would be without them by our side," said Gregory B. Herren, general manager, Springfield location.

Distributor — Arc3 Gases. The company is a multigeneration, and now multifamily owned and operated, business with 54 locations in Virginia, the Carolinas, and Georgia.

Regional Manager Paul Dillard said, "This award is a testament to our people and their dedication to customer service. Our associates have worked very hard to be helpful, promote welding in their communities, and serve the present and next generation of welders. With new technology and great people, coupled with the nationwide shortage of welders, the welding industry is abound with opportunity, and well worth promoting."

Media — Todd Clouser. "When I started with *Weld.com* back in 2011, there was very little activity from the industry

— continued on page 59

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Where There's a Welder, There's a Way

Barbie the Welder and Stephanie Hoffman get closer to completing the Lady Liberty sculpture despite challenges

Barbie the Welder has had a series of what she calls “art-enhancing moments” while crafting the welder Lady Liberty for the American Welding Society’s Arc 2 Art project. In a video on her Instagram account, *@barbiethewelder*, she explained that an art-enhancing moment is when a design doesn’t work and sends the artist back to the drawing board.

“These art-enhancing moments, they take a design you originally thought was amazing, and they actually make you work and think and change, and it ends up being way better than you ever imagined,” Barbie said in the video. “That moment was necessary so you as an artist and your art can be enhanced.”

In episode 5 of Arc 2 Art, Barbie shared the unexpected turn of events that led to a new and improved body for the sculpture. Episode 6 featured Barbie and Stephanie Hoffman as they troubleshooted the fabrication of the flag that will be draped across the welder Statue of Liberty. To watch the episodes and learn more about the Arc 2 Art project, visit aws.org/arc2art.

Hoffman and Barbie also discussed the sculpture on the *Arc Junkies* podcast with host Jason Becker. The entire podcast is available to listen at aws.org/podcasts.

Episode 5 — Perspective Matters

Barbie the Welder opened up episode 5 displaying the body of the Statue of Liberty, sans arms and head. At that point, she had used 285 ft of ¼-in. round bar, 44 lb of ER70S-6 wire, and 35 Tiger Paw™ angled flap discs to make the sculpture. In addition to a hefty amount of material, many hours went into revisions of the body and dress.

“When everything you do is one of a kind, there are no written instructions. There is no blueprint for this,” Barbie said.

The reworking began when a friend came to visit Barbie in her shop. He pointed out that the statue was leaning forward and the dress was on backwards. As a result, Barbie had to cut the statue in half, re-position and rotate the top half by 180 deg, and weld it back into place — Fig. 1. She also cut out a piece of the dress that was dipped in and reshaped it — Fig. 2.

“This is what happens in art a lot . . . It’s all about perspective,” Barbie mused. “I have been working closely with this sculpture for two months and two weeks now. Sometimes when you’re so close to something, you don’t always see something. But moving back and taking a look at it from a different angle, a different perspective, you get a different picture.”

In behind-the-scenes footage on her Instagram page, Barbie went into further details about the setbacks that arose with the proportions of the head and the raised arm of the statue. Despite the frustrations, she was able to tackle the challenges, correct the disproportionate parts, and finish her part of the project.

Episode 6 — Figuring Out the Flag

Episode 6 was a live video featuring Barbie and Hoffman together at Exit 74 Fabrication in New Jersey. The finished body of the statue, partially obscured to save details for the reveal, stood behind Barbie. She panned the camera over to another corner of the shop to show Hoffman’s base with copper panels and the aluminum welding helmet. With both of their respective components completed, the artists prepared to join their parts and build the American flag that hangs across the statue’s body — Fig. 3.

The pair went through trials and errors to figure out the best way to make the flag. Their first attempt involved cutting a 20-gauge steel sheet into pieces and forming it.

“Even with heat, it was not giving us the result we wanted, the look we wanted. We scrapped that idea and have been playing back around with the ¼-in. round bar,” said Barbie.

The two artists framed out the flag on the sculpture’s body, with Hoffman working from the right of the statue to the center and Barbie working from the left to the center.

“We’re now just creating the movement in the flag, and [Hoffman’s] got some amazing ideas on how to do the stars and stripes,” said Barbie. “I’m super stoked. I’m going to be learning so much while I’m here.”

Things may not have gone according to plan with the creation of the sculpture, but that has paved the way for creative solutions and a work of art nearing completion. [WI](#)

ALEXANDRA QUIÑONES (aquinones@aws.org) is associate editor of the Welding Journal.



Fig. 1 — A — The statue after the top half was cut off and rotated 180 deg; B — welding the upper and lower half of the statue back together.



Fig. 2 — Welds from reshaping the statue's dress.



Fig. 3 — Barbie the Welder (left) and Stephanie Hoffman stand in front of the Statue of Liberty sculpture with the frame of the flag covering the body.

Q: My boss recently put me in charge of resistance welding at our plant and the process is new to me. What do I need to know to avoid problems?

A: Although resistance welding has been widely used in manufacturing for decades, the process is not well understood outside of the automotive industry.

Unlike arc welding, which produces a bead that can be checked visually, successful resistance welding hinges on understanding the process, setting up the machine properly, and controlling all the variables.

Here are a few tips to get you started.

Choose the Right Welding Machine

Resistance welding machines come in many different sizes and varieties, and it's important to choose the right one for the job. Although a rocker arm spot welding machine (Fig. 1) is the least expensive and most versatile type in use today, a vertical action press-type spot welding machine (Fig. 2) is recommended when weld appearance needs to be optimized. Also, press-type welding machines are best suited for projection welding applica-

tions that include nuts and studs.

When welding a large part that is not easily manipulated by the operator, consider using a portable spot welding gun hanging from an overhead spring balancer.

kVA Rating

Comparing welding machines solely by their kVA rating confuses the task of machine selection because kVA can be inflated if the U.S. industry standard of 50% duty cycle is not used. Because kVA is a thermal rating, a welding machine with a lower duty cycle rating results in a higher kVA number on the data plate.

As an example, a machine rated 100 kVA at 50% duty cycle may also be rated 141 kVA at 25% duty cycle and 224 kVA at 10% duty cycle. This inflated rating is common for many imported resistance welding machines.

Secondary welding amps actually do the work, and a spot welding machine's throat depth is a critical variable in machine selection. As an example, a 100-kVA single-phase alternating current (AC) welding machine with a 12-in. throat will produce significantly more amps than the same machine with a 36-in. throat measurement. This is due to losses in the secondary loop.

Other throat depth considerations for rocker arm spot welding machines include the mechanical design of the force delivery system because, with everything else being equal, 12-in. arms will produce much more weld force than 36-in. arms.

Alternating Current/Direct Current

Although single-phase AC resistance welding machines were the industry standard for many years and are still in widespread use, welding machines with three-phase medium-frequency direct current (MFDC) power supplies are now taking over the higher end of the market, especially when welding advanced high-strength steel (AHSS) or aluminum.

In addition to the advantage of direct current (DC) output, which is superior to AC, three-phase medium-frequency machines present a balanced electrical load and draw less primary amperage when compared to a similar single-phase spot welding machine.

Purchase Setup Tools

The three main variables of resistance welding are secondary amps, weld time (current flow duration), and forging force. This is sometimes referred to as HTP (heat, time, pres-



Fig. 1 — If you're looking for the right resistance welding machine for your facility, the rocker arm spot welding machine is less expensive and more versatile.



Fig. 2 — The vertical action press-type spot welding machine is recommended when weld appearance needs to be optimized.

sure). These variables can be adjusted on the machine, and charts are available for mild steel and other alloys that will give you the initial settings (see the Resistance Welding Manufacturing Alliance [RWMA] manual referenced near the end of this column).

If your plant does not already own a gauge for measuring the force between the tips and a secondary amperage meter for measuring the output of a resistance welding machine, now is the time to buy these important setup tools.

Taking time to experiment with various welding machine and control settings will pay dividends in weld quality — Fig. 3. A tensile pull machine is the best way to test welds, but destructive testing by peeling the weld apart can also confirm strength.

Organize a Detailed R&D

Several combinations of resistance welding variables will work for mild steel. However, for best weld strength and appearance, a relatively high amperage setting and a short weld time will produce a good weld without excessive marking and expulsion.

If your plant is welding aluminum or the AHSS alloys now common in the automotive industry, choosing the proper settings for all three variables is more critical because the window for success is much smaller than mild steel.

Taking the time to do a thorough R&D experiment to determine the optimum “weld lobe” settings will pay off in consistently high weld strength.

Use the Force

Since weld heat is generated by the electrical resistance of the material being welded, and this electrical resistance is dependent on the force between the welding electrodes, setting the proper forging force is critical. Just like Goldilocks’s porridge, a weld joint that’s “just right” will result from using a force setting that produces weld heat that’s not too hot and not too cold.

Too much force will reduce resistance and result in a cold weld, whereas low weld force can cause expulsion. The correct force for a particular metal

thickness and alloy can be found on the chart.

An air cylinder that’s too small will run out of available force, and a cylinder that’s too large will not produce the weld followup required to properly forge the joint.

Some new machines now have electric servos to provide a wide and easily adjustable range of weld force.

Check to make sure your parts fit together intimately because the welding machine should not be used as a forming tool. If there’s a gap between the parts, “spring back” will rob the process of needed weld force.

Well-Dressed Tips

Choosing the proper copper electrode type, geometry, and alloy is critical.

Somewhat like tires on a car, “where the rubber meets the road,” resistance welding electrodes, commonly called tips, are the only connection between the welding machine and the part being welded.

And, regardless of whether the welding machine is a basic rocker arm or a press-type machine, welding current and force must pass through the electrodes to form a strong weld nugget at the interface of the material being welded.

Be Cool

Water cooling is critical to long tip life and it’s important to make sure that water tubes are properly installed. These tubes are designed to circulate water all the way into the end of the tip’s internal water-cooling cavity.

To ensure proper water-cooling flow and temperature, consider connecting your welding machine to a recirculating water chiller. To avoid condensation, set the water temperature above the prevailing dew point.

Picture This

Think of the electrode’s weld face as a “printing press” that leaves a picture of the tip’s weld face each time a weld is made. Since tips mushroom over time, it is imperative to maintain the

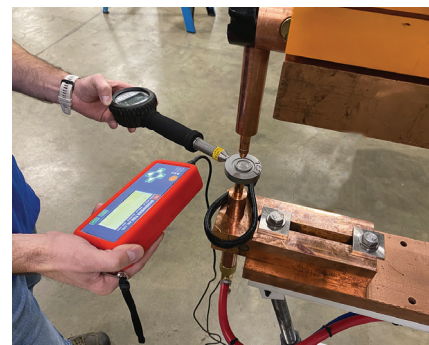


Fig. 3 — Investing in a weld force gauge and weld amp meter will pay dividends.

original tip-end configuration through a consistent program of dressing, either on the machine or offline. Dressing or replacing the tips before it’s absolutely necessary will pay dividends.

Education

As you’ve probably realized by now, there’s much more to the resistance welding process than meets the eye. Fortunately, there are single- and multi-day training classes available through the American Welding Society (AWS); the RWMA, a Standing Committee of the AWS; and private outlets. These classes cover much more than we have outlined here.

Even if you don’t attend a class, buy the RWMA *Resistance Welding Manual, Revised 4th Ed.*, which is available from the AWS Bookstore (pubs.aws.org/p/323/rwma-resistance-welding-manual-revised-4th-ed).

Become a Pro

Once properly trained, you might want to consider studying for and taking the 100-question multiple choice exam to become an AWS Certified Resistance Welding Technician (CRWT).

Similar to the AWS certification program for arc welding technicians, the CRWT training and certification program will enhance your professional standing in the industry.

You can find information at aws.org/certification/page/certified-resistance-welding-technician. **WI**

Q: What distinguishes a stainless steel from a nickel-based alloy?

A: There is a vast continuum of commercially useful iron-chromium-nickel-molybdenum austenitic stainless steels and nickel-based alloys. Any distinction is arbitrary. The mechanical properties, corrosion resistance, and chemical compositions overlap extensively.

The American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* (BPVC) assigns P-Numbers to base metals according to chemical composition for purposes of welding procedure and performance qualification. In this code, P-Numbers 1–15F are used to group various steels, and P-Numbers 41–49 are utilized to group various nickel-based alloys. The alloys within any given

P-Number group have similar welding characteristics, so that qualification of one base metal within a given P-Number group qualifies for all other base metals in that P-Number group.

ASME provides a guide for assigning P-Numbers. Table 1 is extracted from that document to illustrate the blurry overlap between austenitic stainless steels and nickel-based alloys. P-Number 8, Group 4 and P-Number 45 are particularly similar.

The American Welding Society (AWS) and ASME take a somewhat different approach to grouping welding filler metals than ASME took to grouping base metals. In this approach, any Fe-Cr-Ni-Mo filler metal in which the iron content exceeds that of any other element, when all elements except iron are taken at the minimum of the specification range for the alloy, is considered a stainless steel filler met-

al. Stainless steel filler metals are assigned A-Numbers by ASME for procedure and performance qualification. The A-Numbers of interest to this discussion are shown in Table 2. Note that there are no A-Numbers assigned to nickel-based alloy filler metals by AWS or ASME.

Table 3 shows three alloys that are commonly referred to in industry as stainless steels but are not all considered stainless steels by the ASME BPVC. These three steels are all used where very high corrosion resistance is essential. All three are generally recommended to be welded with NiCrMo-3- or NiCrMo-10-type nickel-based alloy filler metals to combat molybdenum segregation in the weld metal. There are no matching filler metal classifications produced for the AL-6XN or 254SMO base metals. However, there is a matching filler metal, Type 385,

Table 1 — ASME P-Numbers for Select Stainless Steels and Nickel-Based Alloys

P-Number	Group Number	Composition, % Single Value Is a Maximum	Tensile Strength	Yield Strength	Generic Description
8	1	16–19 Cr, 8–18 Ni, Ti, Nb, N	65–90 ksi (450–620 MPa)	25–50 ksi (170–345 MPa)	Austenitic stainless steel
8	2	21–25 Cr, 11–20 Ni	62–87 ksi (425–600 MPa)	28–45 ksi (195–310 MPa)	Austenitic stainless steel
8	3	17–22 Cr, 4–13 Ni, 4–12 Mn, 2 Mo, Nb, V, N	75–105 ksi (515–725 MPa)	30–60 ksi (260–415 MPa)	Austenitic stainless steel
8	4	17–20 Cr, 14–18 Ni, 4.5–6.0 Mo, Cu, N	75–115 ksi (515–795 MPa)	30–60 ksi (205–415 MPa)	Austenitic stainless steel
43	—	47–72 Ni, 15–29 Cr, 8–16 Mo, 5–18 Fe, 14 W, 13 Co, 3.5 Nb, Cu	70–120 ksi (485–825 MPa)	25–60 ksi (170–415 MPa)	Ni-Cr-Fe alloys
45	—	21–49 Ni, 15–46 Fe, 20–33 Cr, 1.5–7 Mo, 18 Co, 3 W, 2.3–3 Cu, Nb, Al, Ti, N	62–112 ksi (425–720 MPa)	25–55 ksi (170–380 MPa)	Ni-Fe-Cr alloys

Table 2 — AWS and ASME A-Numbers for Stainless Steel Filler Metals

A-Number	Types of Weld Deposit	Composition, Single Value Is a Maximum					
		C %	Cr %	Mo %	Ni %	Mn %	Si %
8	Chromium-nickel	0.15	14.5–30.0	4.00	7.50–15.00	2.50	1.0
9	Chromium-nickel	0.30	19.0–30.0	6.00	15.0–37.0	2.50	1.0

Table 3 — Three Alloys Commonly Considered Stainless Steels that Blur the Distinction between Stainless Steels and Nickel-Based Alloys

P-Number	Common Name	Unified Numbering System (UNS)	Composition, Single Value Is a Maximum										
			C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu	Fe
45	904L	N08904	0.020	2.00	0.045	0.035	1.00	19.0–23.0	23.0–28.0	4.0–5.0	0.10	1.0–2.0	49
45	AL-6XN	N08367	0.030	2.00	0.040	0.030	1.00	20.0–22.0	23.5–25.5	6.0–7.6	0.18–0.25	0.75	47
8	254SMO	S31254	0.020	1.00	0.030	0.010	0.80	19.5–20.5	17.5–18.5	6.0–6.5	0.18–0.22	0.50–1.00	54

produced for the 904L base metal. This filler metal is found in the stainless steel filler metal classification standards while the 904L base metal is considered by ASME to be a nickel-based alloy. This leaves us with a stainless steel filler metal (Type 385) matching a nickel-based alloy base metal (904L). Does this seem logical?

AL-6XN and 254SMO have virtually identical applications, and the welding considerations and recommended filler metals (NiCrMo-3 and NiCrMo-10 types) are identical. But AL-6XN is considered a nickel-based alloy (A-Number 45) by the ASME BPVC, while 254SMO is considered a stainless steel

(A-Number 8, Group Number 4) by that code. It does not seem logical, at least to me, that — because the A-Numbers are different — these two base metals require separate procedure and performance qualifications according to the ASME BPVC. On the other hand, 904L and AL-6XN, both P-Number 45, are less alike than 254SMO and AL-6XN but can both be included in a single procedure or performance qualification.

This is not said to indicate that the ASME BPVC is deficient, although it may be somewhat illogical in these examples. This is stated mainly to illustrate that there is no clear distinction

between stainless steels (at least the austenitic ones) and the nickel-based alloys. **WJ**

DAMIAN J. KOTECKI is president of Damian Kotecki Welding Consultants Inc. He is a past treasurer of the IIW and a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals, D1K Subcommittee on Stainless Steel, 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.



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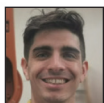


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— continued on page 60

Correction

In the *Welding Journal* November 2020 feature article, "Leveraging New Technology Can Add to Your Bottom Line" by Ricky Ludeman and Justin Morse, the Fig. 1 caption should read as follows: "Exhibit from 'Reinventing construction through a productivity revolution,' February 2017, McKinsey Global Institute, mckinsey.com. Copyright (c) 2020 McKinsey & Co. All rights reserved. Reprinted by permission."

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Industry Perspectives

Looking at the past year, along with what's likely for this one and beyond

As 2021 begins, we thought it would be interesting to pursue input on how companies have endured the pandemic, as well as upcoming expectations, and much more. Fortunately, that inquiry was well received. The following individuals graciously answered our questions.

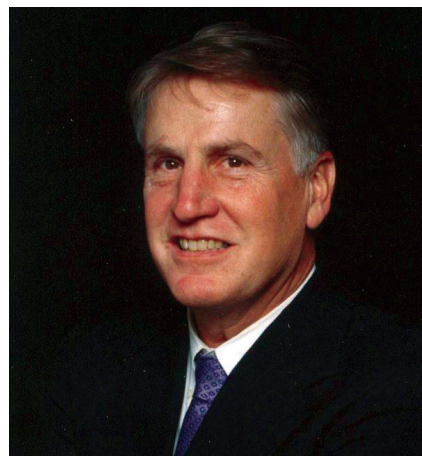
BY KRISTIN CAMPBELL, CINDY WEIHL,
ALEXANDRA QUIÑONES, AND ROLINE PASCAL



Justin Arbogast, sales, The Gasflux® Co., Elyria, Ohio, a custom manufacturer of flux dispensers, brazing alloys, and brazing fluxes.



Christopher Berg, president and CEO, Metabo®, West Chester, Pa., an industrial manufacturer of professional-grade portable electric power tools and abrasives for industrial, construction, and welding applications. It is a medium-sized company that focuses on the main target groups of metal craftsmen and industry along with building trade and renovation.



Wally Brant, CEO, Indiana Oxygen Co., Indianapolis, Ind., an independent, family-owned gas and welding supply distributor serving the state of Indiana and its surrounding markets.



Jake C. Brown, vice president — Americas, Hypertherm Inc., Hanover, N.H., a U.S.-based manufacturer of industrial cutting systems and software.



Daniel Hayden, president, Hayden Corp., West Springfield, Mass., an ISO 9002-2008 registered provider of thermal spray coatings and other wear and corrosion control surfaces. The company provides comprehensive pre- and post-surfacing services, including preparatory machining, laser cladding, finish grinding, and metallurgical coating quality analysis.



Asad Kamal, vice president — strategy, marketing and product management, ESAB Welding & Cutting Products, Annapolis Junction, Md., a producer of manual welding and cutting equipment, welding consumables, welding automation, and mechanized cutting systems.



David Knoll, vice president/general manager, Hobart Brothers LLC, Troy, Ohio, a manufacturer of filler metals, including tubular wires (flux cored and metal cored), solid wires, and covered electrodes under the brand name Hobart®.



Anshu Mehrotra, group president, global industrial platform, Illinois Tool Works (ITW) Welding, Appleton, Wis., a manufacturer of equipment and specialty consumables made with leading technology for a variety of industrial applications. It serves an array of end markets where weld quality is a critical factor.



Cameron Serles, president, Xiris® Automation Inc., Burlington, Ontario, Canada, a manufacturer of weld inspection and monitoring products.

1. How has your company endured throughout 2020?

Arbogast, The Gasflux Co.: We are a small company of nine, which has helped during these times. We have remained diligent on checking everyone's temperatures and keeping distance. We have also utilized online tools to connect with customers instead of the typical on-site visits.

Berg, Metabo: Given the circumstances, we've endured well this year, and I would attribute this to acting quickly and decisively in response to the pandemic. Our immediate priority was protecting the health and safety of our employees. We focused on implementing the government-recommended guidelines, along with additional company measures. Our next priority was to protect our business despite a very strong start to the year. We developed a range of potential crisis demand scenarios, selected the most likely, then quickly implemented measures to adapt our business. Beyond planning, communication to employees, suppliers, and distribution partners was a critical ingredient of our endurance. Rather than wait for perfect information, we just simply started talking to all these stakeholders, listening, and providing whatever infor-

mation we had at that time. One final, and perhaps the most important, observation is that we endured because of our employees. Without their passion and courage this year, we'd be in a much different place today.

Brant, Indiana Oxygen: It took Indiana Oxygen until the end of July to catch up with the year to date (YTD) sales revenue of 2019. As of October 31, 2020, we were +4.1% ahead of 2019 YTD same-store sales. Many of our employees — such as sales, administration, accounts receivable and payables, accounting, and purchasing — are working from home. Yet, all personnel did their jobs; we got product on the shelves and receivables collected.

Brown, Hypertherm: Following a strong 2019, 2020 looked promising. This outlook shifted quickly and unexpectedly at the end of the first quarter, as COVID-19 caused disruptions and created fear and uncertainty. Thankfully, Hypertherm's pre-established emergency planning procedures positioned our company to react quickly and effectively to protect associate (employee) health and well-being and

maintain business operations.

Our adaptation accelerated throughout a tough second quarter. With travel restrictions and industry events cancelled, we supported customers virtually. This was new for us. It drove innovation and generated efficiencies that will remain in place as we move into the future.

With improving business results, we remain optimistic and expect to emerge stronger as we enter 2021.

Hayden, Hayden Corp.: Business has been off, as we might have expected. Several sectors have reduced their activity, but, more directly, our customers and vendors and ourselves have suffered delays due to team members being sidelined by COVID-19. As the scale of the pandemic became apparent in March of this year, we were aware that business volume would suffer, but we are grateful that we did not have to cease production or reduce our staff in response to economic conditions.

Kamal, ESAB: First, I'd like to recognize the essential workers in the welding, cutting, and gas control industries

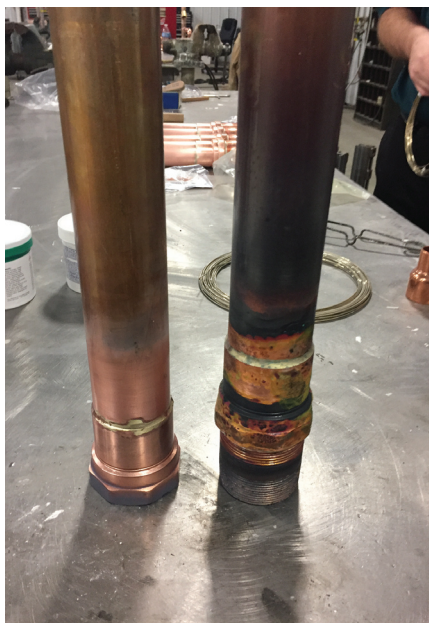


Fig. 1 — Copper brazed with and without the Gasflux process.

for their continued dedication to protecting the health and safety of their colleagues while serving customers and patients around the world. With the fabrication industries mostly rebounding in the third quarter of the

year, ESAB has endured the challenges of 2020 well. We have outperformed many other businesses because ESAB is a truly global company focused on innovation, with a broad and diverse product portfolio.

Knoll, Hobart Brothers LLC: From the very beginning, the ITW Welding companies and Hobart had two primary objectives, and we have lived these through the pandemic: 1) Care for the health and well-being of our employees and provide them with support; and 2) Continue to serve our customers with excellence to the best of our ability.

Thanks to our team's incredible commitment to safety and determination to perform for our customers, Hobart has weathered a very tumultuous year and continues to deliver products and technical support to customers as the pandemic and recovery continue.

Mehrotra, ITW Welding: We took a very intentional approach to ensure that the safety and security of our employees and our customers was the first priority. We spent a lot of time recalibrating our business, as well as re-

organizing our manufacturing facilities and offices to make sure we had proper protocols in place. That continues to be a focus for us to make sure we're protecting our employees and customers and their businesses.

From a business standpoint, many businesses among our customer base shut down during the second quarter, and we rapidly assessed that we were an essential business because we support customers in infrastructure, healthcare, power generation, and other critical industries. While the business of many of our customers was initially substantially reduced because of the COVID-19 impact, our commitment to our customers and focus on our business model has helped us remain strong and recover as their businesses have recovered. We are on a good path of continuing to improve year over year.

Serles, Xiris Automation: It has been a tough year. We entered the pandemic with an excellent backlog due to some very strong sales in January and February, but sales have grown weaker with every passing month.

2. What was the biggest challenge you faced in 2020, and how will it influence your operations in the future?

Arbogast, The Gasflux Co. (Fig. 1): Typically for a demonstration, we would ship equipment to the customer and meet them at their facility to run the trials. This has come to a halt with the travel restrictions and coronavirus protocols limiting outside visitors. I

also do braze training for companies, which again is difficult to do without being physically with the customer. Email and phone calls have been our main source of contact with customers during these times.

our crisis management readiness has dramatically improved. The real-world stress test we've been living is teaching us a lot, and we're applying these insights to make our business better and even more resilient.



Fig. 2 — Indiana Oxygen's palletized filling plant in Indianapolis.

Berg, Metabo: The biggest challenge we've faced this year has been the pandemic and the real, abrupt impact on our business. Overnight, the demand for our products came to a halt as our customers and suppliers were implementing their own measures to protect themselves. Even though the business is rebounding and there are signs of recovery, we have made some fundamental changes to our operations. For example, our selling process, traditionally in person and hands-on, shifted almost exclusively to remote/virtual meetings. This has created challenges for our team as they evolve and adapt to this new reality to stay "top of mind" for our customers. Another positive outcome of this year is that

Brant, Indiana Oxygen (Fig. 2): Keeping all 150 employees fully employed with a minimum of 40 h per week. Plus, we were challenged with keeping in touch with customers and converting them from face-to-face visits to Zoom virtual meetings.

Brown, Hypertherm: We invested serious thought and time to determine which jobs require face-to-face interactions and which can be completed virtually. The great challenge is finding the right balance to ensure customers are supported, collaboration and innovation flourishes, and business operations are reliable under any condition.

Hayden, Hayden Corp.: When busi-

ness became very slow, we decided to follow the lead of some of our customers and temporarily reduce operations by remaining closed one additional day per week. This was a difficult decision and was challenging to present to our team. Though I hope such a drastic step will not be necessary again, the fact that we were able to adopt the change and continue to operate effectively demonstrated an unexpected resilience in our team. Should we face difficulties again in the future, I have much greater confidence in our abilities to weather the storm as an organization thanks to the dedication of our team.

Kamal, ESAB: Welding is inherently a hands-on, in-person business, as is the production of our products. Ensuring the safety of our personnel was the first challenge. That said, our teams have adapted to the virtual work environment in a number of ways to maintain our continuous improvement momentum. Our in-person activities have temporarily declined, but the number of virtual activities has exploded. For example, in lieu of FABTECH, the ESAB Xpanse virtual event provided visitors with all of the information, education, and connections they've come to expect from the ESAB trade show booth.

Knoll, Hobart Brothers LLC: It would be very difficult to narrow this to one area. The pandemic brought with it a rapidly changing set of issues and health/business dynamics. Our organization adapted to this with a new level of agility in decision-making, procedure implementation, production, and inventory management through intermittent demand. At all times, we were proactively doing everything possible to protect our team and serve our customers.

Mehrotra, ITW Welding: The toughest situation was the uncertainty associated with the evolving impact of



Fig. 3 — Metabo, a manufacturer of portable electric power tools and abrasives, has made fundamental changes to its operations due to the COVID-19 pandemic.

COVID-19, not just on our employees but on our customer base and on the supply chain. Our biggest challenge was ensuring that we protected our employees and our customers, and the supply chain, so that we remained able to support the critical needs of our customers going forward. Having strong protocols and processes in place that we leaned back on as a part of our business model is what has kept us really well grounded to ensure we continue to support customers. Going forward, we understand that where our customers choose to buy and how they get informed about our products as they go through the path to purchase has changed and will continue to evolve. Complementing our strong existing go-to-market strategy with digital enablement is going to be a critical part of ensuring that we provide relevant information to our customers where they choose to buy.

Also, this year accentuated some of the existing key pain points in the welding industry. Labor issues and the

lack of welders are a consistent challenge, and the current environment further exposed the need for productivity-driven solutions that address this challenge. This challenge is also being highlighted in terms of acceleration of automation. As companies in some segments don't have enough people to work on critical processes or deliver high-quality welds as part of their manufacturing process, automation is becoming more pervasive. As I think about some of these macro elements that influence the welding industry, I'm very excited about what the future holds in terms of Miller, Hobart, and ITW Welding being key members and leaders of this industry.

Serles, Xiris Automation: The biggest challenge for us is trying to get our products in front of prospective customers, as often customers need to see our camera systems and test them before they buy. With restrictions on travel, we cannot visit customers, interact with them at trade shows, etc.

3. What expectations does your company have for 2021?

Arbogast, The Gasflux Co.: Travel restrictions will loosen up once a vaccine is approved and distributed throughout the country. The brazing industry has remained resilient during these times, and with the increasing demand for heating, ventilation, and air conditioning products by customers, de-

mand for our products by manufacturers will also increase. There are still several large manufacturers we hope will look at improving their brazing process by utilizing our equipment and products.

Berg, Metabo (Fig. 3): While there is

still considerable uncertainty in the economy and our industry, we remain cautiously optimistic about 2021. Economists predict the U.S. economy will return to positive, single-digit real gross domestic product growth next year, and we're also anticipating a strong rebound in sales. While this is



Fig. 4 — New Hampshire-based Hypertherm is still operating three-shifts a day in thanks to new safety protocols and procedures. Shown above is a photo taken pre-pandemic.

highly dependent on how quickly and effectively the health crisis is managed, I am convinced that people are very anxious to get back to work. Inventory levels in our sales channels are at historic lows, all while the demand for industrial and commercial work continues to rise. As confidence increases, so too will business and we'll be ready at Metabo.

Brant, Indiana Oxygen: A tsunami of business once the pandemic is over, which could clog the supply chain. I worry about having product ready and available to purchase.

Brown, Hypertherm (Fig. 4): We anticipate on-going challenges due to COVID-19 impacts in the first half of the year, followed by improving conditions in the second half.

Hayden, Hayden Corp. (Fig. 5): It may be snarky to say that things certainly aren't likely to get any worse than they did in 2020 . . . but, hey. As the world has become more accustomed to coping with the virus, as the reality of a vaccine becomes more and more probable, and as we all learn new ways to connect and conduct business, I think it is reasonable to expect our economy to shift back into patterns that are more familiar, or are at least easier to plan for. I expect we will return to an increasingly more normal workday, more familiar conversations with customers and suppliers, and a more recognizable balance sheet.

Kamal, ESAB: We have modestly positive expectations. Although the winter resurgence of COVID-19 around the globe will likely slow the

rate of recovery in the first half of the year, states and countries are being very careful to protect their industrial production base. By the second half of the year, the deployment of vaccines will be well underway, increasing people's confidence and helping businesses rebound.

We have focused on relatively faster growing parts of the economy and we have benefited from this. New product introductions, such as with the Rogue series of gas tungsten arc welding/shielded metal arc welding inverters, will continue to help us fortify our position. On the industrial side, we have a host of new developments that we look forward to in 2021. This includes pre-engineered robotic welding systems called Xcellerator, a range of new cutting automation equipment led by the Hydrocut™ HDX large gantry waterjet cutting system, and the continued growth of the ESAB Digital Solutions suite of applications.

Knoll, Hobart Brothers LLC: Like many, we do not know exactly what the pandemic holds for 2021, but we expect to see continued elements of recovery with the understanding that they will likely vary for different end markets and regions. The global oil and gas market has been hit severely, as evidenced by delayed and/or canceled projects around the world. With crude oil trading between \$40 and \$45 per barrel, recovery is not looking bullish in the near term. Other heavy industry markets, like railcar, heavy equipment, structural fabrication, etc., are showing mixed signs of life from zero recovery to modest improvement.

Mehrotra, ITW Welding: Our business foundations and our strategies are very consistent and strong, and our alignment with our end customers continues to remain strong. As the economy and our customer base continues to improve, we expect to have a very strong 2021 in support of solving our customers' problems.

Serles, Xiris Automation: Our main expectation is that the pandemic will end. We hope that will take place by the third quarter of 2021. Our feeling is that once the pandemic subsides, there will be a huge bounce back in demand for all aspects of infrastructure spending and that the fourth quarter of 2021 should be strong, leading into an even stronger 2022.



Fig. 5 — Tim Bernard works at a computer numerical control grinder.

4. In your opinion, what makes our industry so special?

Arbogast, The Gasflux Co.: Brazing is a skill that can be used to find a job almost anywhere in the United States. Although not widely known, it is a critical process in many different industries. From your air conditioning unit at your home to a chair you might be sitting on at a restaurant, brazing is an integral part of many manufacturing processes in our country. The results from using Gasflux are day and night for the brazing process, so it is pretty cool to see someone who has been brazing for many years see the results for the first time.

Berg, Metabo: Simply put, industry heritage and the character, integrity, and resilience of the people within it.

Brant, Indiana Oxygen: With such a diverse clientele, revenues are generally steady. That is, when one customer segment is down, another is probably up.

Brown, Hypertherm: I'm new to Hypertherm, starting just before the pandemic hit. I'm impressed and amazed by the people in the gas and welding industry and their willingness to support each other. This industry truly feels like a large family to me. It's a family able to adapt, overcome challenges, and continue to thrive.

Hayden, Hayden Corp.: Our category of manufacturing serves needs that are reliable and consistent; the products that we help to create aren't susceptible to short-lived trends or style. The upshot is that our customers, employees, vendors, and even, I believe, our competitors feel a sense of pride and dedication to our work; that what we do creates part of the durable fabric of our shared community. We continue to take pride in the fact that our work is "essential," and we suit up and show up despite the challenges to keep manufacturing moving. This may sound aspirational, I suppose, but the fact that our competitors have supported us and we have supported them when needs arose gives me a sense of shared purpose that other industries may not experience.

Kamal, ESAB (Fig. 6): Strength of character. Hands down, our people make the industry special. They know what needs to get done, and they find

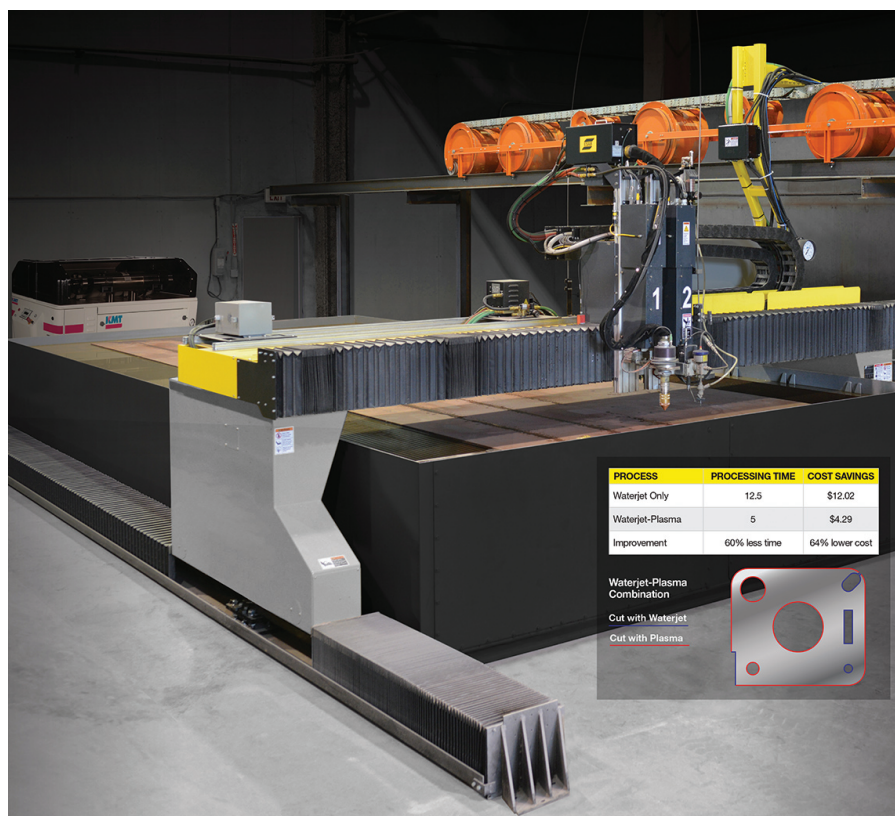


Fig. 6 — The ESAB Hydrocut HDX large gantry cutting system combines the precision of waterjet technology with the speed of plasma cutting to lower part cost and cycle time by up to 60% or more.

ways to make it happen despite all obstacles.

Knoll, Hobart Brothers LLC: We are a highly technical industry that designs and manufactures technologically advanced equipment and consumables for a host of industries fabricating incredible products out of steel and other alloys. Our industry is composed of a unique accumulation of people from very diverse backgrounds. Many of us have devoted our entire careers to this industry. Having grown up in a family-owned welding supply company, I know people today who I met at welding events 40 years ago.

Mehrotra, ITW Welding: As someone who joined the welding industry from the outside about three years ago, the epiphany I've had is that welding is pervasive in everything all of us touch and experience throughout our day, whether staying in a hotel or driving to work or using the electricity supplied to our homes. Every industry has aspects of welding embedded intrinsi-

cally into the delivery of their products and services to end customers in all walks of life. The pervasiveness of the welding industry and our nearness to the end customer is very special, and it really portends very strong business fundamentals for this industry going forward. In terms of the long-term sustenance of this industry and the position of Miller and ITW Welding in it, I'm very confident in what the future holds.

Serles, Xiris Automation: I feel the industry is full of interesting opportunities and people solving interesting technical challenges that are multidisciplinary. It is also global, so the problems that are being addressed in one continent are also being faced in another. And lastly, it is changing. With a welding skills shortage looming in most parts of more developed economies, automation is being looked at as a necessary next step. This is particularly interesting as new technologies will be entering the industry, such as our welding cameras.

5. What would you like to see happen in our industry over the next few years?



Fig. 7 — The new Hobart Customer Applications Lab features Hobart filler metals, along with the latest equipment from Miller Electric Mfg. LLC, Bernard, and Tregaskiss, for on-site demonstrations.

Arbogast, The Gasflux Co.: I hope that more manufacturing jobs keep coming to the United States instead of being shipped overseas. Well-paying jobs that don't require a college degree and highly skilled training are going to be critical in pulling a lot of people out of this bad situation. Hopefully the tradeshow will also be able to open back up to display the new technology that is out there.

Berg, Metabo: I would like to see more efforts to attract, train, and employ the next generation of skilled welding and utility workers. As with many other trades, there is a dangerous shortage of skilled professionals in our industry. This trend, regrettably, coincides with a deterioration of our infrastructure and increased global competition. We need more skilled welders and fabricators to rebuild and reinforce our country and our economy. Over my career, I've witnessed the definition of "building" change from something you do with your mind and hands to something you do with your

computer. There's plenty of room for both.

Brant, Indiana Oxygen: Stabilize the ownership of independent distributors and promotion of succession planning.

Brown, Hypertherm: I am hopeful that we see a continued improvement in American manufacturing jobs being filled by the next generation. We have a lot to offer in the future, but this will only be possible with the next generation being inspired to sustain our progress.

Hayden, Hayden Corp.: I'd hope that, in the near future, our work can become more collaborative. The pursuit of higher quality and lower cost has pressed manufacturing into divided camps of buyers and sellers. The architecture of the marketplace is built around the buyers' inflexible specification and a field of sellers whose quality management systems all ensure that they will meet the specification to the letter for the lowest possible price. If

American manufacturing is to truly maximize its potential, there should be some room for the exchange of ideas between the designers of new equipment and the craftsmen who know best how to make it. That exchange adds value, improves efficiency, and builds a shared sense of ownership in the quality of the finished product.

Kamal, ESAB: If there can be a bright spot to 2020, it is that people outside of our industry learned how manufacturing is an essential business that offers good-paying, stable jobs. We'd like to see interest in pursuing welding careers continue.

Knoll, Hobart Brothers LLC (Fig. 7): Hobart was founded in 1917 and has experienced incredible transitions in the products we make and how we make them. Our people have always been a crucial component in advancing and changing technology through that 100-plus years, and I expect that to continue. Hobart has countless examples of working to accomplish things that apply to industry challenges and organizational objectives and create wins. Good people make good things happen, and we expect that to continue at Hobart along with Miller Electric Mfg. LLC, Bernard and Tregaskiss, and our other global welding brands.

Mehrotra, ITW Welding (Fig. 8): I would like to see the continued natural evolution of technology becoming more embedded, not just in the products and solutions but also in the enablement of information and value exchange between elements of the value chain. Digital enablement can be an avenue of information provided by manufacturers and distribution partners to the end customer, but we also need to move that technology into easing transaction and engagement, gaining deeper insight into the customer pain points, and addressing those pain points in a timely manner. The acceleration of technology as an enabler for doing this will help our industry move forward faster.

Serles, Xiris Automation: Addressing the global skills challenge through the adoption of automation has to be at the top of the list.

6. Looking toward the future, what challenges do you think our industry will face? How should they be handled?

Arbogast, The Gasflux Co.: Automation, although a good thing, is going to put a lot of people out of work. I think there are going to be a lot more robotics being used by manufacturers, taking out any human variation and error. It will be interesting to see what the balance of automation vs. human labor will be.

Berg, Metabo: Beyond a retiring workforce and insufficient levels of new tradesmen and women poised to take over their Metabo grinders, our industry is facing challenges like many other industries. Increasing global competition and cost pressures force us to find ways to do our jobs cheaper, better, and faster; rapid advances in materials and manufacturing technology force us to evolve and adapt how we design, build, and install. On a positive note, if you asked the same question 25, 50, even 100 years ago, you would have heard similar answers. Change is, truly, the only constant, and I am confident that our industry will overcome our current challenges just as we did in the past. How? By making people a priority — attract the best and brightest, educate and train them to be the best at their trade, and work together as an industry to give them a future.

Brant, Indiana Oxygen: Obviously, the welder shortage. I think one solution could be a partnership between vocational education schools and manufacturing companies, where the manufacturer would assist in educational/books/material/supplies costs and guarantee a certain number of jobs with that manufacturing company upon graduation in exchange for a commitment from the students for a certain number of years.

Brown, Hypertherm: We continue to face a skilled labor shortage, and that gap will keep growing. Smart investments in education and automation are necessary now to ensure our industry remains capable of meeting future demands.

Hayden, Hayden Corp.: Consolidation and environmental impact are two key concerns. Both have excellent

opportunities, but both could easily lead to the well-intentioned destruction of domestic manufacturing. As a subcontractor, we have seen consolidation create a shift from design and manufacturing under one roof to specification and procurement. Procurement is easier to manage because it offloads responsibility to vendors, but it also tends to make every vendor appear the same to a buyer. From that perspective, a skilled U.S. manufacturer is equivalent to an overseas supplier, and the vendor with the lower price is likely to win every time. Consolidation can offer tremendous benefits by eliminating duplication and streamlining methods, making a group of U.S. shops more efficient and profitable than when they were going it alone, but the minute those methods are considered to be portable, a faceless parent company can also choose to shift manufacturing away from the communities that depend on them. Likewise, the pursuit of greater operating efficiency and lower environmental impact can have a tremendous beneficial impact on the cities and towns that host our manufacturers, but if well-meaning regulations make doing business impractical or impossible, we may legislate ourselves out of

existence. All of this sounds scary and hypothetical, but it has played out in real time here in the northeast where economic conditions have shuttered a string of precision manufacturers, and 100-year-old companies like ours seem to no longer exist.

Kamal, ESAB: We need to continue to embrace automation, digital solutions, and innovative technologies that increase productivity per employee to counteract the chronic shortage of skilled labor. Further, we'd like to change the mindset that technology takes away jobs. The truth is completely opposite. Technology creates jobs and makes those jobs more attractive to the next generation.

Knoll, Hobart Brothers LLC: The pandemic will likely change the way we interact with people and customers for years to come. All of us have become accustomed to and/or reliant on virtual mediums for communication. At Hobart and across ITW Welding, we have a large percentage of people working from home or in some hybrid of working at home and office. This will likely be a part of our culture for the foreseeable future and beyond. Our customers and distributors are or



Fig. 8 — A welder performs gas metal arc welding in a manufacturing setting. This year accentuated some of the existing challenges in the welding industry, including labor issues, and the current environment further exposed the need for productivity-driven equipment solutions.

will likely do the same.

Demonstrating value-based solutions, solving technical challenges, and creating new processes and technologies in less-than-accessible customer locations has already started changing the way we engage and serve. Creative and effective use of virtual environments is already a part of our new normal.

Mehrotra, ITW Welding: The future of industrial distribution as a core part of the value chain is something that we really need to keep an eye on. I think industrial distribution needs to adapt. As the level of information and the transparency of information increases between members of the value chain, including manufacturers, distri-

bution partners, and customers, there is a greater availability of information exchange happening directly between manufacturers and end customers. And that's where industrial distribution needs to recognize where it can add incremental value in the value chain other than being a provider of goods and services. For them to continue to accelerate their relevance and value in the whole chain, they need to be able to adapt as well.

Manufacturers also must become much more targeted and focused in developing solutions that address identified pain points of customer market segments (an outside-in perspective as opposed to inside-out). In the past, manufacturers may have leveraged

technology to develop products and then find the application or applicability of it. Our focus of customer-backed innovation — of really understanding them, securing deep insight into the key challenges of customer segments, and using those insights to develop products and solutions — is a strength. Continued focus on this would make the value chain that much more additive to the end customers.

Serles, Xiris Automation (Fig. 9): As previously mentioned, it is the skills shortage that will drive the industry in my mind. The industry will have to change to address this by incorporating more automation, systemization, and process standardization.

7. What other words of wisdom would you like to share?

Arbogast, The Gasflux Co.: Keep striving to be the best out there. Brazing processes have been kind of put on the backburner and have not really been improved at a lot of companies. We are always open to helping customers try to find cost-saving alternatives and improvements to their brazing process.

Berg, Metabo: While I certainly don't consider myself to be a "wise, old man," I can offer what I've learned over the course of my career. First, we need to continually challenge the status quo. A crisis will force you to as-

sess what you're doing and how you're doing it, but make this a priority even when there isn't one in front of you. Make it a habit. Be comfortable being uncomfortable. Finally, make your culture and your people your priority. They are your most valuable assets.

Brant, Indiana Oxygen: I beg our government to keep the recent corporate tax cuts, which have allowed our company to invest in people and capital assets and improvements. I would also hope the shortage of qualified commercial driver's license (CDL) drivers could be addressed. Similar to my

comments on the partnership between welding students and manufacturers, I would like to see partnerships between corporations and local high schools to sponsor courses for high school seniors that would result in CDLs to the students upon completion. (We have proposed this to our local high school, but besides some initial interest, we have seen no traction.)

Brown, Hypertherm: People do business with people, and our relationships remain the glue holding us together. We've all made virtual tools work, but I'm really looking forward to the day when I can see people in person again. That's the fun and most fulfilling part of my job.

Mehrotra, ITW Welding: I'm very excited about what the future of the welding industry holds, not just for manufacturers but for all the segments of customers we serve.

Serles, Xiris Automation (Fig. 9): This industry is always changing. We all need to keep an open mind to new ideas and new possible solutions to develop the technology, which will make it more accessible and move it forward. [WJ](#)

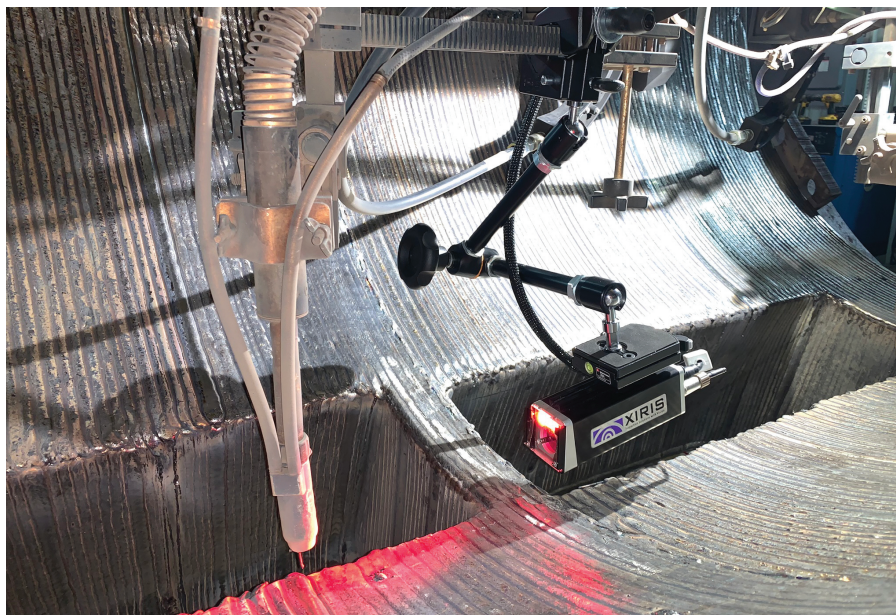


Fig. 9 — The Xiris XVC-1000e weld camera in action during a cladding application.

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- ◆ 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, 2021**. The Fellows Committee looks forward to receiving numerous Fellow nominations for 2022 consideration.

Sincerely,

Dr. Sudarsanam Babu
Chair, AWS Fellows Committee

IMPORTANT Announcement



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

**Elect them now
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of the Society.**

August 1, 2021
Submission Deadline

Historical Aircraft Soars with Cold Spray Technology

This process allows the restoration of vintage engines

BY JULIO VILLAFUERTE

More than 70 years after first entering service, hundreds of vintage Chipmunk airplanes remain airworthy around the world, mainly as trainer aircraft. Repair and maintenance of many of their components remain a challenge due to lack of components as well as process temperature sensitivity. Fortunately, there is cold spray, a solid-state metal consolidation process that can be used to dimensionally restore components made of materials that are highly sensitive to elevated process temperatures.

In this article, a leaky engine casing of a Chipmunk vintage aircraft was successfully restored, for the first time, using cold spray technology. This study shows a step-by-step restoration procedure, which was then certified as a new repair procedure by Transport

Canada (TC), the Canadian organization responsible for safe air transportation policies and programs.

A History of the Chipmunk

The Chipmunk, named after a small Canadian chipmunk squirrel, is a post-war, vintage aircraft originally developed and manufactured in 1946 by De Havilland Aircraft of Canada Ltd. (De Havilland Canada), now part of Bombardier. The De Havilland Canada DHC-1 Chipmunk is a tandem, two-seat, single-engined primary trainer aircraft. During the late 1940s and 1950s, this aircraft was procured in large numbers by military air services, such as the Royal Canadian Air Force,

Royal Air Force, and several other nations' air forces, where it was used as their standard primary trainer aircraft.

Many of the Chipmunks that had been formerly in the military were eventually sold to civilians, either to private owners or to companies, where they were typically used for a variety of purposes, often involving their excellent flying characteristics and capability for aerobatic maneuvers.

However, spare components for these historical aircrafts are either scarce or price prohibitive, and repair technologies are not always available for maintenance of a variety of their components.

Restoration Challenges

Mechanical wear and tear had put a toll on the integrity of the engine casing of a Chipmunk DHC-1 aircraft. During overhaul of the Gipsy DH Major 10MK1-3A engine, following the Canadian Historical Aircraft Association's TC-approved *Maintenance Manual*, unacceptable cracking of a flange area and bolt holes of the lower crankcase and upper cover were discovered by the liquid penetrant nondestructive examination (NDE) method (Ref. 1) — Fig. 1. These cracks put the mechanical integrity of the engine at risk by allowing engine oil to leak out. One of the flaws included a through-thickness crack at the root of the flange, which caused detachment of the flange and thus eradication of one fastening post to the lower crankcase.



A Chipmunk aircraft repaired by cold spray. (Photo courtesy of the Canadian Historical Aircraft Association.)

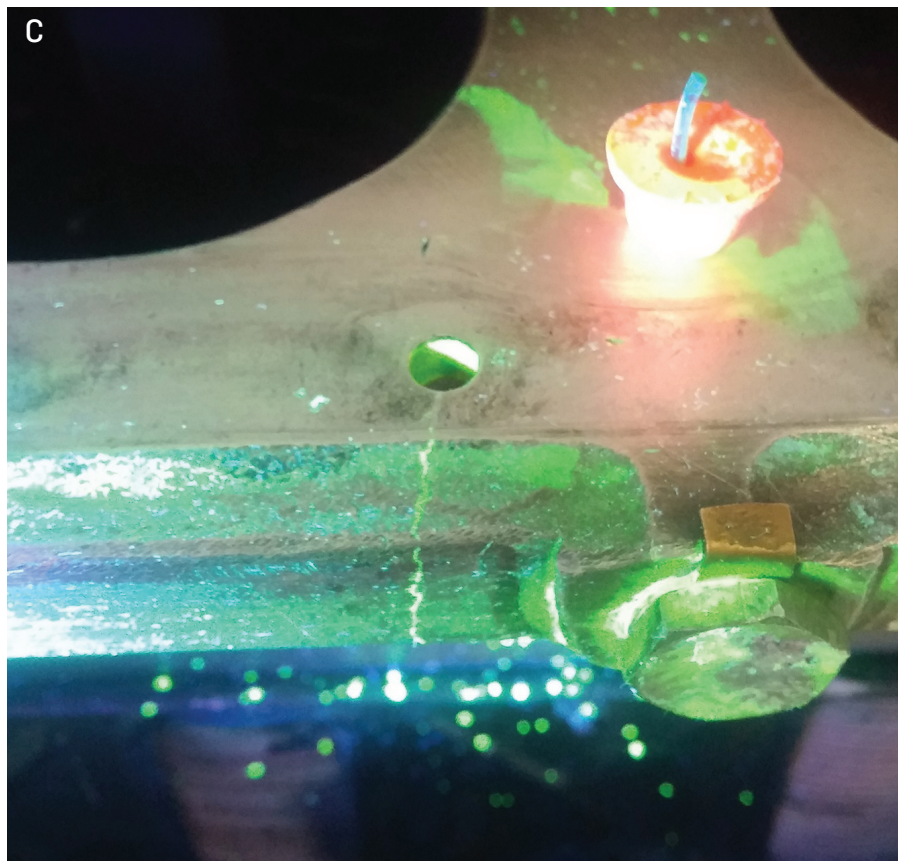
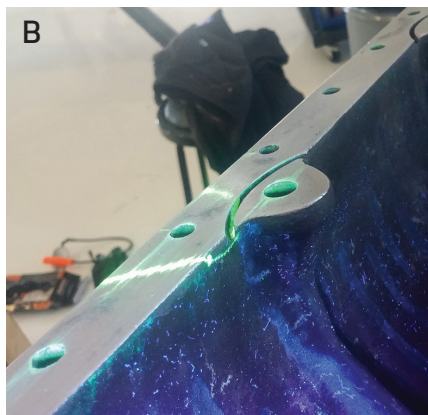


Fig. 1 — A — Gipsy DH Major 10MK1-3A engine overhaul; B — liquid penetrant NDE of the cover; C — liquid penetrant NDE of the lower crankcase.

The materials of the top cover and lower crankcase were magnesium and aluminum cast alloys, respectively, which would not tolerate elevated-temperature repair processes, such as welding.

Cold Spray Technology

Cold spray is a solid-state metal consolidation process that uses a high-speed gas jet to propel metal and other powder particles against a substrate where particles plastically deform and consolidate upon impact. The term cold spray refers to the relatively low temperature involved in the process, which is typically much lower than the melting point of the spray material and substrate. In the Supersonic Spray Technologies (SST™) cold spray equipment, air can be used as a propellant gas and temperatures will be low enough not to thermally disturb the substrate material. After low-temperature dimensional restoration of the area, the new consolidated material can be effectively machined back to tolerance using standard machining techniques. SST cold spray

offers the ability of all-metal consolidation for dimensional restoration in both manual and robotic applications — Fig. 2.

The Repairs Take Off

Both the top cover and the lower crankcase were assessed for restoration by cold spray. Due to the already weakened condition of the material, it was recommended that both the cracked flange at the cover and the cracked region on the lower crankcase be completely removed.

The missing features were rebuilt using the SST cold spray process, following the recommendations of MIL-STD-3021(2), *Department of Defense Manufacturing Process Standard: Materials Deposition, Cold Spray*, for nonstructural repair (Ref. 2). A specific repair procedure was developed in conjunction with TC, which included simulation trials of the free-form rebuild to ensure the viability of the repair — Fig. 3. The pre qualified spray material recommended for this repair was a mixture of 99.5% aluminum par-



Fig. 2 — Commercial SST Series P cold spray system.

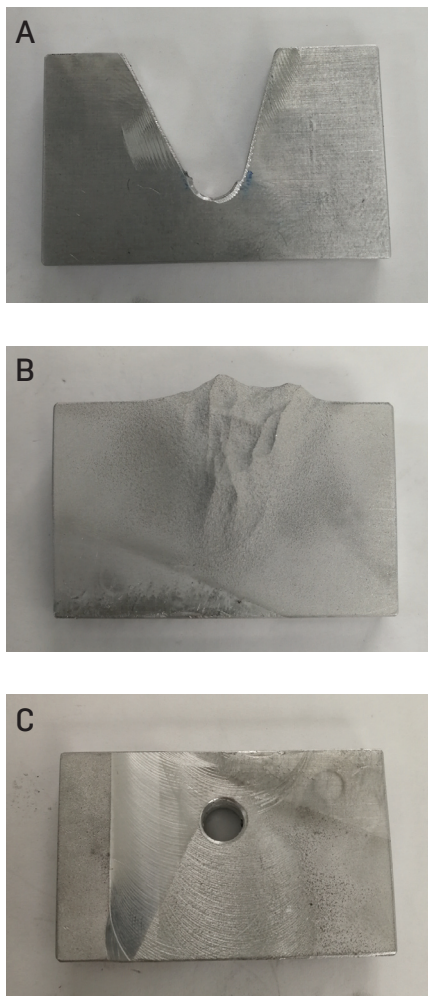


Fig. 3 — Simulation coupons. A — Before spraying; B — as sprayed; C — machined to tolerance.

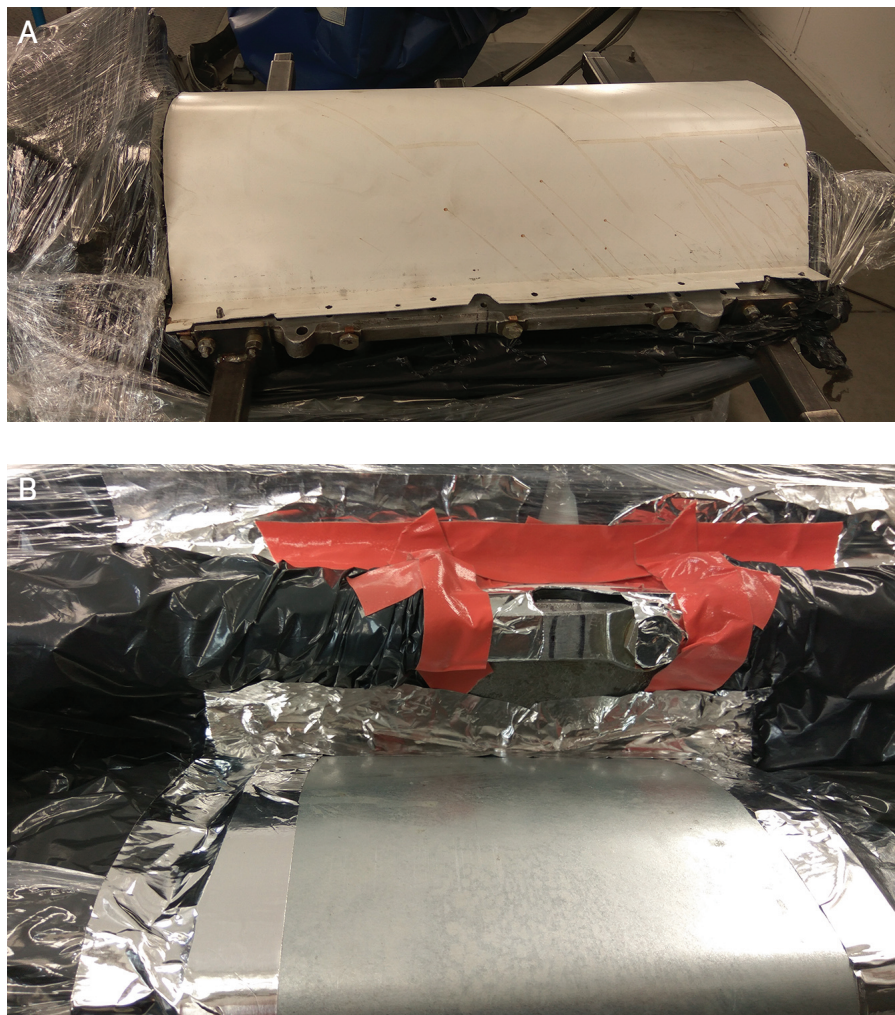


Fig. 4 — Readying the engine lower crankcase prior to the repair procedure. A — A custom-fabricated hard mask; B — a polymeric wrap mask around the work area.

ticles and 99.0% aluminum oxide particles. When sprayed using the parameters in Table 1, the material met the requirements of ASTM C633, *Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings*, yielding cohesive/adhesive strengths higher than 6000 lb/in.² with densities higher than 99.5% (Ref. 3).

During the actual repair, the lower crankcase needed to be carefully masked to protect engine components during spraying and post-machining as well as avoid any kind of engine tear

down or disassembly. Masking included dual hard mask and polymeric wrapping — Fig. 4.

The final repair procedure was approved under TC Standard 625, *Aircraft Equipment and Maintenance Standard — Canadian Aviation Regulations*, and documented. The new TC repair procedure “specifies the process by which a repair may be performed on the following engine cover flanges. The flanges are used to bolt the engine cover down on a De Hallivand DHC-1 aircraft equipped with a Gypsy Major piston engine.”

The procedure consists of removal of damaged areas, surface preparation with SST-G0002 alumina grit to roughen surfaces (Ref. 4), free-form spraying using the spray parameters depicted in Table 1, conventional machining to dimensional tolerances, dimensional check using coordinate measuring machines, and approval and release. The repair procedure for the top cover and lower crankcase are illustrated in Fig. 5. The engine was finally assembled and readied for delivery — Fig. 6.

Conclusion

Because adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are unique, making the process suitable for producing well-bonded, low-

Table 1 — Spray Parameters

Machine: SST Series P, manual gun, 2.0-mm orifice, UltiLife™ nozzle
Spray Powder: SST A0082 (aluminum – alumina)
Gas: Nitrogen
Surface Preparation: Sections completely removed, grit blasting with SST-G0002
Gas Temperature: 425°C
Gas Pressure: 180 lb/in. ² (12.5 bar)

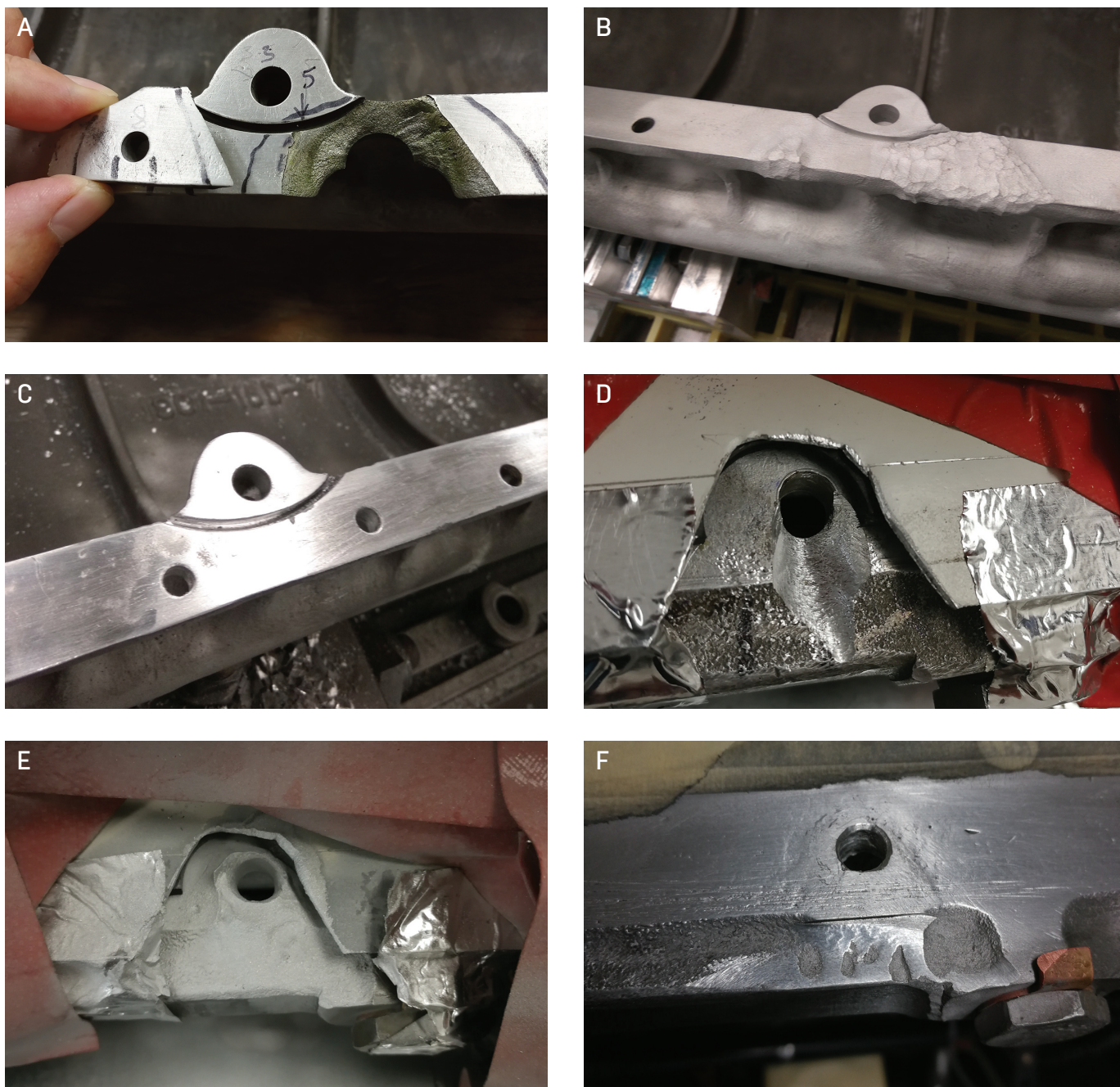


Fig. 5 — Gipsy DH Major 10MK1-3A engine top cover and lower crankcase flange repair by cold spray. A — Cover prior to spray; B — cover as sprayed; C — cover machined to tolerance; D — lower crankcase prior to spray; E — lower crankcase as sprayed; F — lower crankcase machined to tolerance.



Fig. 6 — Gipsy DH Major 10MK1-3A engine assembled and readied for delivery.

porosity, oxide-free deposits. These attributes make cold spray fit for depositing a range of temperature-sensitive materials. [WJ](#)

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2. MIL-STD-3021 (w/Change-2), *Department of Defense Manufacturing Process Standard: Materials, Deposition, Cold Spray*. March 2015.

3. CenterLine. *Technical Data Sheet*. January 2020. supersonicspray.com/uploads/documents/SST-TDS-A0082-PR-2_0-0120.pdf

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Engine-Drive Remote Solutions Give Welders More Control

Adjusting parameters with a remote can optimize efficiency, performance, and cost savings in field welding

BY JAKE ZWAYER

When welding and repairs are done in the field, there are plenty of challenges that can add time and costs to the project. On a jobsite, operators may be working far away from their trucks. If they want to turn their machine on or off, or when parameter changes are inevitably needed, they are ultimately required to return to the power source. To avoid that hassle, operators often leave their machine running constantly and are tempted to weld with the parameters already set — even when those param-

eters aren't ideal for the job at hand. These scenarios present opportunities to improve quality and efficiency on the jobsite while also reducing operating costs.

As operations continually look for ways to save time and money and improve safety, there is growing demand for having complete independence from the welding machine/generator with total control of the machine wherever the operator is working from. New and evolving engine-drive technologies with comprehensive re-

mote solutions give operators access to this much-needed level of control.

Accuracy on the Spot

Working far away from the welding machine/generator can make it difficult and time consuming for operators to make the necessary adjustments to parameters or the arc when they're welding on a jobsite. As a result, they might use less than ideal parameters, which can impact weld quality. The



Fig. 1 — Wireless Interface Control for the Trailblazer® and Big Blue® places full control of the welding machine/generator in the palm of the operator's hand, so he or she can remotely adjust amperage and voltage, customize welding programs, turn the machine on and off, select processes, and fine-tune the welding arc.



Fig. 2 — Remote start/stop on the Bobcat™ 260 and 225 lets operators easily turn the welding machine/generator on and off without having to walk back to the unit.

ability to easily adjust processes or parameters with a remote eliminates this issue and gives operators both convenience and the ability to dial in a perfectly tuned arc.

Available remote solutions for a welding machine/generator in the field range from simple to more advanced. The complete control provided by some remote solutions, such as Wireless Interface Control from Miller, allows operators to adjust amperage and voltage, customize welding programs, change processes, and fine-tune arc control — Fig. 1. This provides more responsiveness to better handle changing joint conditions.

Placing this type of full control of the machine in the operator's hand improves productivity, weld quality, and safety for welding on the jobsite.

Turning the Machine On and Off

Extended idle time between usage is another issue that stems from working far from the welding machine/generator. A typical machine is used either for welding or auxiliary power about 30% of the time it's running. That means, for up to 70% of the time, the

welding machine/generator is left idle to burn fuel, generate noise, and rack up engine hours with no benefit to the operator.

When it's a time-consuming hassle to walk back to the machine to turn it on or off, operators may instead just leave it running all day. This may seem convenient, but it can significantly drive up fuel costs while adding to jobsite noise levels. In addition, the longer a machine runs, the more often it will need preventive maintenance, resulting in additional costs and downtime that could have been avoided.

When remote technologies let operators easily turn the machine on and off with the push of a button, it reduces unnecessary engine hours to help optimize machine life — Fig. 2. This can save up to \$1500 a year in fuel and maintenance costs and extend the time between maintenance. Running the machine only when it's needed also helps reduce jobsite noise levels, improving operator comfort and improving his or her ability to communicate throughout the day.

Safety Benefits

In addition to the productivity and cost-saving benefits of using re-

mote solutions for welding machines/generators, these technologies can also deliver value for jobsite safety, which is a top-of-mind issue for many organizations.

When operators have control of their welding machine/generator at the point of use, it eliminates the need to walk back to the machine. This reduces the chance of encountering a slip, trip, or fall hazard.

Remote Solutions Offer Complete Control

Welding on the jobsite can introduce challenges that cost time and money. When operators have complete control independent from the front panel of their welding machine/generator, it improves productivity, safety, and quality.

Engine drives with remote solutions can deliver these benefits for operations looking to optimize efficiency, performance, and cost savings in field welding. **WJ**

JAKE ZWAYER (jake.zwayer@millerwelds.com) is product manager, engine drives, Miller Electric Mfg. LLC, Appleton, Wis.

Choosing the Right Engine-Driven Welding Machine

To save time and money, keep these five considerations in mind before buying or renting a welding machine

No matter the task at hand, it's always important to have the right tool for the job. The same principle applies to engine-driven welding machines. However, with so much equipment available on the market, the process of choosing the proper engine-driven welding machine for your application can be overwhelming. Without the appropriate knowledge, it's easy to choose the incorrect machine for a given

application. It could be undersized and unable to meet the needs of the job, or it could be too large, which means you probably overspent. These judgment errors — which require time, effort, and money to correct — are made every day when buying or renting engine-driven welding equipment.

You can avoid these pitfalls when buying or renting your next engine-driven welding machine by keeping the

following five considerations in mind:

1. Fuel type,
2. Welding output/duty cycle,
3. Auxiliary power output,
4. Engine manufacturer, and
5. Additional functionality



With so many engine-driven welding machine options on the market, it's important to know which machine is best suited for your application. Pictured is the Dual Maverick™ 200/200X from The Lincoln Electric Co., Cleveland, Ohio.

Fuel Type

The first thing to consider is fuel type. The three primary fuel options are gasoline, diesel, and liquefied petroleum gas (LPG).

Gasoline

Gasoline-powered engine-driven welding machines are generally smaller in size and have more limited output capabilities. The typical gas welding unit will produce 300 A, or less, of welding output. These are generally available at a lower upfront cost than a diesel machine, but they use more fuel and are prohibited on some jobsites due to the low flashpoint of gasoline. Furthermore, gas engines with higher revolutions per minute require service more frequently.

Diesel

Diesel welding machines are typically in the 300-A class and above. They have a higher upfront cost than gas engines, but they are jobsite workhorses with more welding and auxiliary output than their gas counterparts. Diesel engines also have up to 35% more fuel efficiency and a typically longer life than gas engines. Additionally, some jobsites require diesel engines for safety reasons.

LPG

LPG engines are similar to gasoline engines but they burn clean fuel, making them more suitable for use in poorly ventilated environments. The LPG engine-driven welding machine is also an ideal choice for environments where gasoline and diesel emissions are not acceptable.

Welding Output/ Duty Cycle

After determining the best fuel option, it's important to choose a welding machine/generator that is appropriately sized for your application. The most important thing to determine is how much output is needed to run your welding process. Too often, customers ask for a 400-A welding machine without knowing what that means or what they actually need. Consider the following information

when determining your needed output.

Shielded Metal Arc Welding (SMAW)

When performing SMAW with electrodes up to $\frac{1}{2}$ in., a 200-A unit is usually sufficient. However, larger electrodes require a higher amperage, and a higher amperage will require a larger machine.

Gas Tungsten Arc Welding (GTAW)

Like SMAW, GTAW is a constant-current process. Most GTAW applications do not require more than 200 to 300 A.

Flux-Cored Wire

When welding outdoors, wind tends to blow shielding gas away from the weld, so a flux-cored wire is needed to shield the weld pool. The wires used in this process require a constant-voltage power source that is typically 300 A or larger. It's important to consult the welding procedure specification to find out how much current you'll need prior to choosing a welding machine.

Arc Gouging

Arc gouging is a process that melts metal and blows it away, removing it from the base material. This process requires a great deal of energy and puts stress on smaller machines. If you plan to arc gouge, a larger machine is recommended to remove material faster. For $\frac{1}{4}$ -in. carbon, the recommended output is 300 A, while the recommendation for $\frac{3}{8}$ -in. carbon is 450 A.

Single or Dual Output

While most machines include one set of output studs, some offer two – like the Dual Maverick™ 200/200X from The Lincoln Electric Co. (see lead photo). A machine with multiple sets of output studs can be beneficial on crowded jobsites. One less machine means more fuel savings, reduced emissions, and less noise.

Once you understand your process, consider the welding output, duty cycle, and horsepower of a machine to ensure it's appropriate for your application.

Table 1 — Breakdown of Amperage Class and IEC Duty Cycle Rating

Amperage Class	IEC Duty Cycle Rating
200	200 A/28 V/100%
300	300 A/32 V/100%
400	400 A/36 V/100%
500	500 A/40 V/100%
600	600 A/44 V/100%

The first thing to understand is the real output of the machine. This is determined by the duty cycle. The industrial standard for welding machine duty cycles is the International Electrotechnical Commission (IEC) rating. The IEC rating uses a formula to calculate the amount of time you can run a welding machine at a specific amperage and voltage. A breakdown of amperage class and IEC duty cycle rating is shown in Table 1.

Common Pitfall #1: Comparing Welding Machines Based on Model Names

Some manufacturers sidestep the IEC formula and give a name to their equipment based on an unrealistic amperage. This can steer customers into making misguided decisions, which can negatively affect their job performance. When shopping for a welding machine, what really matters is the true welding output and horsepower. Make sure to look beyond the product name and compare the specifications of competing machines that can be found in the product literature or owner's manuals.

It's best to compare the IEC rating of each machine. Sometimes the current ratings of two machines will match but the voltage or duty cycles will differ. Higher voltages, duty cycles, and horsepower mean more output.

Lincoln Electric eliminates this confusion by naming its machines according to the IEC amperage class and horsepower. This gives customers a clearer sense of what they're getting. For example, the company's Vantage® engine-driven welding machine includes a nameplate that lists the duty cycle of the machine.

Auxiliary Power Output

It's important to consider your aux-

iliary power needs. Engine-driven welding machines generate auxiliary (alternating current [AC]) power that can be used to run lights, pumps, power tools, and other devices. As with welding output, it is important to review machine specifications closely to ensure a true comparison. The two ratings often used for auxiliary power are

peak power and continuous power.

Common Pitfall #2: Not Comparing Auxiliary Power Correctly

Peak, continuous, three phase, single phase — with so many different types and ways to rate the auxiliary

(AC) output of your machine, it can get confusing. Here are a few things to remember to help you get the amount of power you need.

Peak Power vs. Continuous Power

The peak power will always be high-

Table 2 — Auxiliary and Weld Output with Different Amps and Watts

Weld Amps	1 Phase			3 Phase			Both 1 and 3 Phase	
	Watts	Amps		Watts	Amps		Watts	Amps
0	12,000	50	Or	20,000	50	Or	—	50
100	12,000	50		17,800	43		—	50
200	12,000	50		14,000	34		—	50
250	12,000	50		12,000	29		12,000	—
300	10,000	42		10,000	24		10,000	—
400	5600	23		5600	13		5600	—
Up to 600	0	0		0	0		0	0



Fig. 1 — Understanding the needs of your jobsite is important when making a decision about purchasing an engine-driven welding machine. Pictured is the Hudson Yards construction site in New York City, N.Y.

er than the continuous power but can only be sustained for a short time (about 30 s or less). Peak power is needed for certain applications, such as starting pumps or other inductive loads, which can require a large in-rush current to get running. After that initial surge, it settles into the lower continuous power rating. Continuous power is the power available at a 100% duty cycle.

Always be sure you are comparing peak ratings to peak ratings and continuous ratings to continuous ratings.

Single Phase vs. Three Phase

Single- and three-phase auxiliary power are fundamentally different due to the design of the AC circuit. As a result, these two types of output cannot be directly compared. More importantly, jobsite tools may require one over the other. For example, most hand-held tools are single phase, while many pumps, welding machines, and plasma cutting machines require three-phase power. The available three-phase power will be higher than the available single-phase power.

Once again, be certain to compare available three phase with three phase and single phase with single phase.

Simultaneous Welding and Auxiliary Power

Just like the weld output ratings, the auxiliary power ratings are the maximum output the machine can give you. These machines are designed to provide both auxiliary and weld output at the same time, but there is some give and take. Table 2 offers an example of this by highlighting both auxiliary and weld output with various amps and watts.

As you can see, when you increase the weld output, the available auxiliary power decreases and vice versa. It is important to understand the needs of your jobsite and application before you buy or rent — Fig. 1.

Additionally, depending on the machine's available auxiliary output, it is possible to run a second operator by plugging in an inverter-style welding machine to provide two arcs simultaneously. For example, the diesel-

driven Vantage® 549X unit can power the Flextec® 350X PowerConnect inverter welding machine.

Engine Manufacturer

There are multiple engines available in the same amperage class. This is another important consideration in the buying process. Engine service networks can vary by location. For maintenance reasons, you'll want to consider an engine manufacturer that has a presence in your area. You can also streamline your maintenance operations by having the same engine manufacturer work on your fleet of equipment, such as welding machines, lifts, tow motors, and more.

Additional Functionality

While all machines offer welding and auxiliary output, some machines provide additional functionality to maximize versatility on the jobsite. Lincoln Electric offers engine-driven welding machines with integrated air compressors, hydraulic pumps, and battery jump-start terminals. This can save space on your truck or jobsite by combining multiple functions into one piece of equipment. Another benefit is not having to run cranes or tools off of your truck engine, thus saving fuel as well as reducing wear and tear on the truck engine. It is especially useful in areas where vehicle engine idling is restricted.

Conclusion

With so many engine-driven welding machines available on the market, it's easy to get overwhelmed. Remember to keep the process simple by focusing on the five primary considerations outlined in this article: fuel type, welding output/duty cycle, auxiliary power output, engine manufacturer, and additional functionality. Do not be confused by product names that can sometimes be intentionally misleading. All the information you need can be found on the product specification sheet or owner's manual. Just look over the documentation and buy what you need. **W**



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Note: The 2021 schedule for all certifications are posted online at awo.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
Pittsburgh, PA	Feb. 7–12	Feb. 13
Los Angeles, CA	Feb. 7–12	Feb. 13
Seattle, WA	Feb. 14–19	Feb. 20
Orlando, FL	Feb. 14–19	Feb. 20
Indianapolis, IN	Feb. 21–26	Feb. 27
San Diego, CA	Feb. 21–26	Feb. 27
Cleveland, OH	Feb. 28–March 5	March 6
Atlanta, GA	Feb. 28–March 5	March 6
Waco, TX	Feb. 28–March 5	March 6
Miami, FL	March 7–12	March 13
Salt Lake City, UT	March 7–12	March 13
Houston, TX	March 7–12	March 13
Chicago, IL	March 14–20	March 21
Phoenix, AZ	March 14–20	March 21
Boston, MA	March 21–26	March 27
Portland, OR	March 21–26	March 27
Dallas, TX	April 11–16	April 17
Minneapolis, MN	April 11–16	April 17
Norfolk, VA	April 11–16	April 17
Las Vegas, NV	April 18–23	April 24
St. Louis, MO	April 18–23	April 24
Cleveland, OH	April 25–30	May 1
Bakersfield, CA	April 25–30	May 1
Baton Rouge, LA	May 2–7	May 8
Sacramento, CA	May 2–7	May 8
Detroit, MI	May 2–7	May 8
Denver, CO	May 16–21	May 22
Nashville, TN	May 16–21	May 22
Pittsburgh, PA	June 6–11	June 12
Birmingham, AL	June 6–11	June 12
Benicia, CA	June 13–18	June 19
Spokane, WA	June 13–18	June 19
Hartford, CT	June 13–18	June 19
Farmingdale, NJ	June 20–25	June 26
Beaumont, TX	June 20–25	June 26

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
Sacramento, CA	March 10–12	March 13
Las Vegas, NV	May 19–21	May 22
Minneapolis, MN	July 28–30	July 31
Cleveland, OH	Sept. 29–Oct. 1	Oct. 2
Miami, FL	Dec. 15–17	Dec. 18

9-Year Recertification Seminar for CWI/SCWI

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

Location	Seminar Dates
Houston, TX	Feb. 7–12
San Diego, CA	Feb. 14–19
St. Louis, MO	March 7–12
Seattle, WA	March 21–26
Dallas, TX	April 18–23

Certified Welding Educator (CWE)

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

Certified Welding Sales Representative (CWSR)

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

Certified Resistance Welding Technician (CRWT)

A comprehensive two-day seminar to arm attendees with the knowledge needed to take the exam with confidence. More information at aws.org/certification/page/certified-resistance-welding-technician.

Certified Welding Supervisor (CWS)

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

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
Dallas, TX	April 26–30	May 1
Las Vegas, NV	June 7–11	June 12

Certified Robotic Arc Welding (CRAW)

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

IMPORTANT: This schedule is subject to change without notice. Please verify your event dates with the Certification Dept. to confirm your course status before making travel plans. Applications are to be received at least **six weeks** prior to the seminar/exam or exam. Applications received after that time will be assessed a \$395 Fast Track fee. Please verify application deadline dates by visiting our website at aws.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.

National and District Officers to Serve through 2021



Fig. 1 — Pictured is the 2020/2021 Board of Directors. Not shown are Dist. 7 Director Roger Hilty and Dist. 10 Director Tom Kostreba, who were specially elected to serve on the Board after this photo was taken.

During the November 16, 2020 American Welding Society (AWS) Annual Business Meeting of Members, an amendment to the AWS Bylaws (Article IX. Nomination and Election of National Officers and Directors, Section 8. Date to Assume Office) passed that extends the 2020 Board of Directors' terms of service for 12 months, ending on December 31, 2021. The 2021 Board of Directors are as follows — Fig. 1.

Officers

Robert W. Roth, president
W. Richard Polanin, vice president
Dennis K. Eck, vice president
Michael A. Krupnicki, vice president
Carey Chen, treasurer

Directors-at-Large

Anthony Anderson
Debra Doench
Richard L. Holdren
Sayee Raghunathan
Kerry Shatell
Walter J. Sperko

District Directors

Dist. 1 — Doug Desrochers
Dist. 2 — Harland W. Thompson

Dist. 3 — Sean Moran
Dist. 4 — Lynn Showalter
Dist. 5 — Howard Record
Dist. 6 — Ronald Stahura
Dist. 7 — Roger Hilty — Fig. 2
Dist. 8 — James Thompson
Dist. 9 — Michael Skiles
Dist. 10 — Tom Kostreba — Fig. 3
Dist. 11 — Phillip I. Temple
Dist. 12 — Dale H. Lange
Dist. 13 — Ron Ashelford
Dist. 14 — Tony Brosio
Dist. 15 — Michael Hanson

Dist. 16 — Karl R. Fogleman
Dist. 17 — J. Jones
Dist. 18 — Thomas S. Holt
Dist. 19 — Shawn McDaniel
Dist. 20 — Denis E. Clark
Dist. 21 — Sam Lindsey
Dist. 22 — Robert Purvis

Past President Directors

Dale Flood
Thomas J. Lienert 



Fig. 2 — Roger Hilty, who was elected to serve as AWS Dist. 7 director, is co-owner of Hilty Sign and Fabrication Co.



Fig. 3 — Tom Kostreba, who was elected to serve as AWS Dist. 10 director, is a welding instructor at Erie High School.

TECH TOPICS

Opportunities to Contribute to AWS Technical Committees

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

S. Borrero, sborrero@aws.org, ext. 334. **Definitions and symbols**, A2 Committee (E). **Titanium and zirconium filler metals**, A5K Subcommittee. **Piping and tubing**, D10 Committee (C, E, U). **Welding practices and procedures for austenitic steels**, D10C Subcommittee. **Aluminum piping**, D10H Subcommittee. **Chromium molybdenum steel piping**, D10I Subcommittee. **Welding of titanium piping**, D10K Subcommittee. **Purging and root pass welding**, D10S Subcommittee. **Low-carbon steel pipe**, D10T Subcommittee. **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). **Titanium structural welding**, D1N Subcommittee (C, E, G, P, U).

J. Molin, jmolin@aws.org, ext. 304. **Structural welding**, D1 Committee (E). **Sheet metal welding**, D9 Committee (C, G, P).

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 equip-**

ment, 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, stevhe@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**, 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 Committee (C, E, G, P, U). **Railroad welding**, D15 Committee (C, E, G, U). **Robotic and automatic welding**, D16 Committee (C, E).

AWS A3.0M/A3.0:2020 Interpretation

Subject: Manual vs. mechanized process definitions

Code Edition: A3.0M/A3.0:2020, *Standard Welding Terms and Definitions*

Provisions: Definitions for manual and mechanized processes

AWS Log: A3.0-20-I01

Inquiry 1: Is a welding process where the torch is mechanically mounted but is manipulated by hand during welding considered mechanized?

Interpretation 1: Yes. If the torch or gun is mechanically held and any type of adjustment is made by a person (hand pressure, screw adjustment, joystick controller, etc.), it is mechanized. If the adjustment is made by a device (probe-type seam tracker, laser, photo system, etc.), and not a person, it is automatic or robotic.

Inquiry 2: Is a welding process where the torch is mechanically mounted but manipulated by micrometer spindles

on the torch holder during welding considered mechanized?

Interpretation 2: Yes. See Interpretation 1.

AWS C3.6M/C3.6:2016-AMD1 Interpretation

Subject: Uninterpretable discontinuities

Code Edition: AWS C3.6M/C3.6:

2016-AMD1, *Specification for Furnace Brazing*

Code Provision: Subclause 6.6

AWS Log: C3.6AMD1-16-I01

Inquiry 1: The quality assurance provisions (Section 6), external discontinuities (Subclause 6.6.1), and pinholes and voids (Subclause 6.6.1.1) sections state, "Pinholes, voids, or filler metal skips are allowed provided they shall not exceed the limits specified below. Discontinuities of less than 0.38 mm [0.015 in.] are uninterpretable and are not considered as defects." 6.6.1.1 continues by describing the visual inspection criteria in detail and the acceptable flaw sizes. My question is in regard to the application of "uninterpretable discontinuities" in subsequent subsections. Does the definition of uninterpretable discontinuities (pinholes, voids, and filler metal skips) less than 0.38 mm (0.015 in.) apply to 6.6.1.1 only or all of the subsequent sections of 6.6?

Interpretation: Discontinuities with a major dimension of less than 0.38 mm (0.015 in.), which are uninterpretable, are not considered defects.

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.

January 26. Technical Activities Committee. Miami, Fla. Contact: P. Portela, pportela@aws.org, ext. 311.

February 2, 3. D15 Committee and Subcommittees on Railroad Welding. Miami, Fla. Contact: J. Rosario, ext. 308, jrosario@aws.org.

Revised Standard Approved by ANSI

D17.3/D17.3M:2021, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*. Approval Date: 10/2/2020.

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.

A5.13/A5.13M:20XX, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*. Revised Standard. \$36.00. ANSI public review expires 1/4/2021. Contact: R. Gupta, ext. 301, gupta@aws.org.

D14.9/D14.9M:20XX, *Specification for the Welding of Hydraulic Cylinders*. Revised Standard. \$42.00. ANSI public review expired 12/21/2020. Contact: K. Bulger, kbulger@aws.org, ext. 306.

Z49.1:20XX, *Safety in Welding, Cutting, and Allied Processes*. Revised Standard. \$38.00. ANSI public review expired 12/21/2020. Contact: S. Hedrick, steveh@aws.org, ext. 305.

AWS Foundation Annual Staff Campaign

The 2020–2021 AWS Foundation Staff Campaign raised \$14,500, an 8.7% increase from last year, for AWS scholarships.

MEMBERSHIP ACTIVITIES

AWS Member Counts December 1, 2020

<i>Sustaining</i>	569
<i>Supporting</i>	346
<i>Educational</i>	838
<i>Affiliate</i>	637
<i>Welding Distributor</i>	61
Total Corporate	2451
<i>Individual</i>	55,713
<i>Student + Transitional</i>	10,262
Total Members	65,975

New AWS Supporters

Sustaining Company Member

Air Products

7201 Hamilton Blvd.
Allentown, PA 18195

IQS Inspection LLC

1718 Engineers Rd., Ste. A
Belle Chasse, LA 70037

IQS Inspection is a woman-owned business that enables clients to apply the appropriate inspection and nondestructive examination methods to mit-

igate risk. The company qualifies and certifies in accordance with the policies and bylaws of the American Welding Society, American Society for Non-destructive Testing, American Petroleum Institute, NACE International, and STI. The company also provides field and laboratory services such as welding inspection, welding procedure development, and procedure qualification record development.

Mechanix Wear

28525 Witherspoon Pkwy.
Valencia, CA 91355

Affiliate Corporate Members

AC Inc.

P.O. Box 17069
1085 Jordan Rd.
Huntsville, AL 35810

Affton Fabricating and Welding Co. Inc.

1635 Sauget Business Blvd.
Sauget, IL 62206

Brown Diving LLC

811 Fairway Dr., #14C
Alexander City, AL 35010

CommScope

11312 S. Pipeline Rd.
Euless, TX 76040

Electro Mechanical Solutions

1555 Gunn Hwy.
Odessa, FL 33556

H.D. Fowler Co.

6017 29 Dr. NE
Marysville, WA 98271

Oak Ridge National Laboratory

P.O. Box 2008
Bldg. 4500N, MS-6208
Oak Ridge, TN 37831

Peak Construction Group Inc.

660 Liberty Way
Unit C
North Liberty, IA 52317

Puritan Manufacturing Inc.

1302 Grace St.
Omaha, NE 68110

Quality Machine of Iowa

1040 4 Ave.
Audubon, IA 50025

Red River LLC

P.O. Box 2548
Gillette, WY 82717

Samsung

482 Jeongjo-ro, Seryu-dong
Gwonseon-gu, Suwon
Gy 2 floor, Suwon-si
Gyeonggi-do 16656 South Korea

Steel Now Group LLC

1401 Riverplace Blvd.
Apt. 1703
Jacksonville, FL 32207

Versa Integrity

10831 Train Ct.
Houston, TX 77041

Weld-Fab Mfg. Corp.

180 James St.
Slinger, WI 53086

Educational Institute Members

Cutting Edge Staffing

1400 N. 6 St.
Milwaukee, WI 53212

Jim Ned High School — Consolidated Independent School District

441 Graham St.
Tuscola, TX 79562

Kent Career Technical Center

1800 Leffingwell Ave. NE
Grand Rapids, MI 49525

Maine Maritime Academy

1 Pleasant St.
Castine, ME 04420

Muhlenberg Job Corp. Center

3875 State Route 181 N.
Greenville, KY 42345

Ridgevue High School — Vallivue School District 139

18800 Madison Rd.
Nampa, ID 83687

Russellville Career and Technical Education Center

1865 Waterloo Rd.
Russellville, AL 35653

Square Training Center FZE

Service Block Al Jazirah Al Hamra
Rakez Business Zone Fl.
Ras Al Khaimah
United Arab Emirates 41061

Texas Southmost College

301 Mexico Blvd.
Brownsville, TX 78520

University of Alaska Fairbanks Community and Technical College

604 Barnette St.
Fairbanks, AK 99701

U.S. Grant Career Center — Joint Vocational School District

718 W. Plane St.
Bethel, OH 45106

WeldStar Academy

1522 Preston Rd.
Pasadena, TX 77503

2020 Membership Challenge

Listed here are the members who participated in the 2020 Membership Challenge — point standings as of November 17. 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 49 of this *Welding Journal* or call the AWS Membership Dept. at (800) 443-9353, ext. 480.

J. W. Fregia, Houston — 95
J. W. Morris, Mobile — 75
A. P. Duris, Northwest Ohio — 51
A. D. Dillon, Detroit — 38
S. A. Milner, San Francisco — 36
B. J. Cain, Los Angeles/Inland Empire — 34
J. P. Theberge, Boston — 31
A. D. Stute, Madison-Beloit — 30
J. C. Durbin, Tri-River — 30
V. O. Harthun, Northern Plains — 30
D. L. Galiher, Detroit — 29
T. A. Uff, Lehigh Valley — 29
D. P. Thompson, Southwest Virginia — 29
R. Young, Iowa — 24
T. Edwards, Tulsa — 20
H. J. Merrill II, Louisville — 20
D. S. Beecher, San Diego — 20
R. K. McClure, Los Angeles/Inland Empire — 18
J. Napier, Cleveland — 17
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
C. Consentino, Pittsburgh — 13
R. Riggs, Tulsa — 13
T. A. Harris, Johnstown-Altoona — 13
S. Silverstein, Milwaukee — 12
M. D. Stein, Detroit — 11

AWS Education & Training Committee Seeks New Members

The AWS Education & Training Committee is welcoming new members from secondary education, higher education, and industry. The commit-

tee continues to work toward the betterment of welding education by reviewing present state and developing criteria to improve training standards

nationwide.

If you are interested in becoming a member, contact Alicia Garcia at agarcia@aws.org for more information.

AWS Recognizes Member Anniversaries

Every year, the American Welding Society (AWS) honors members who have achieved a membership milestone. The milestones are 50 years (Gold Member), 35 years (Life Member), and 25 years (Silver Member).

Unable to host the traditional luncheon in 2020 due to the COVID-19 pandemic, AWS transitioned this experience to an online format. The 2020 Membership Milestone achievers, for the first time, were recognized on the AWS website and during the AWS Education 2020 Virtual Summit held November 18–20. They have also received their awards by mail.

This year, a total of 611 members achieved AWS membership milestones. There were 69 Gold Members, 149 Life Members, and 393 Silver Members.

To see the complete list of members who achieved AWS membership milestones this year, download the *AWS Membership Milestone Achievers 2020* booklet at aws.org/memberrecognition.

AWS's 2020 Gold Members

The following are the 69 members who achieved 50 years of AWS membership (Gold Member) this year: John F. Daamen, Brian T. Connolly, Gary I. Senff, Kenneth W. Maidment, Alexis I. Kaznoff, Daniel Desserich, Eugene A. Silva, Harold A. Sadler, Isaiah Randolph, Kenneth A. Young, Larry D. Holt, Robert P. Neumann, U. G. Williamson, Stanley W. Anderson, Don J. Henderson, Jacques Major, Lambert G. Lamberson, Wayne R. Gahwiller, William S. Thom, Michael L. Rankin, Charles E. Blackful, Lloyd Anderson, Ronald P. Stocker, Paul F. Fantelli, Del A. Moerke, James C. Yeh, James E. Hollowell, John T. Myers, Richard A. Marciniak, William L. Engelhard, Henry J. Leaty, Dave S. Golani, David E. Johnson, Gregory R. Swank, R. Shiva Shankar, Stan Johnson, Calvin V. Norton, John H. Griffin, Leslie E. Robertson, Carmine J. Puniello, Darrell L. McLaughlin, Dennis R. Amos, Herman Tucker, William B. Butler, Brian H. Keelean, Dennis Wilson, Fredrick L. McCall, G. B. Cline, John Colgan, Joseph F. Campbell, Joseph Mammarelli, Richard A. Lafave, Roger L. Schnabel, Frank D. Deets, Glenn N. Fischer, Myron L. Hoitomt, Robert J. Teuscher, William A. Owczarski, Arthur B. Waskey, Bob R. Allen, Clifford H. Anderson, Richard Farniok, Robert E. Owen, Stephen S. Endrizzi, David L. Forrest, H. Z. Lin, Mahendra V. Desai, Robert E. Poland, and Ross C. Butzow.

Distinguished Welder Award Nominations

The Distinguished Welder Award recognizes an individual whose welding skills and experience would earn him or her the recognition of being an AWS Distinguished Welder.

A complete nomination packet

should include information addressing the candidate's definition and application criteria as outlined in the AWS Distinguished Welder Award Nomination Form found at aws.org/about/page/outstanding-achievement-awards. The

focus of the nomination packet should include specifics of the individual's skills.

Send nominations by the May 1 deadline to Malisa Mercado at mmercado@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. Tamara Topley is profiled on the next 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



Tamara Topley

“Tamara doesn’t read well.” These seemingly innocent words uttered by a second-grade teacher changed the course of Tamara Topley’s academic life. Mis-labeled as having a learning disability, Topley found herself funneled into a special education track, where she was underestimated and underchallenged.

“It was subtly reinforced that I just wasn’t smart and had little potential,” she recalled. “As a result, I never pushed myself academically and had gone through most of my life in a safe zone with little personal growth.”

Years later, Topley unearthed a truth that empowered her to imagine a different future.

“I recently discovered that my internal daydreams and inability to focus were actually symptoms of undiagnosed attention deficit disorder, not an intellectual disability as I had been made to believe,” she explained. “That self knowledge has freed me from a self-imposed mental cage limiting my potential.”

Before staking her claim on a welding career, Topley worked as an apprentice glazer. The physically taxing job enabled her to foster new skills and experiences.

“It introduced me to skills such as how to work in cooperation with other disciplines on a jobsite to achieve a common goal and how to work in -5 to 100 deg weather, all while wearing OSHA-approved protective gear,” she said.

Topley then became a furniture assembler at a high-volume store. Looking back, she takes pride in being unmatched by her male co-workers.

“To date, I am the only female to

have survived in my position,” she said. “I smile with silent pride knowing I could still outperform 20-year-old boys, even at my age.”

However, over time, Topley found her job as a furniture assembler to be mundane and uninspiring.

“This led me to daydream designs of my own, most of which relied on metal as the substrate,” she recollected. “I toyed with the thought of going to school for welding, but I never found the right moment to start. Hypnotized by daily routine, I blinked, only to realize that more than a decade had passed, and I was still in the same comfortable but unfulfilled place.”

After dedicating 16 years to the furniture business, Topley was ready for a change. In 2017, she enrolled in an oxyacetylene class at a local metal arts studio, where she discovered a passion for the craft.

“Welding had been on my radar for years as a way to add a new dimension to my wood-based furniture designs, but this class was the first time I had any formal instruction on the subject,” she explained. “I was smitten! Welding touched something inside of me that was both zen and intoxicating at the same time. I loved the feeling of taking two rigid, obstinate pieces of ferrous metal and artfully persuading them to join as one harmonious piece, using only a flame and a skillful hand.”

The class left an indelible mark on Topley. In 2019, she took a leave of absence from her job and enrolled in the welding and metal fabrication program at Minneapolis Community and Technical College, Minneapolis, Minnesota.

“The oxyacetylene class turned out to be the cold splash of water that I needed to instigate positive change in my life,” she said. “With the support of my now-wife, I took the plunge. I quit my job and committed to welding as the dream career I always knew I could have.”

A week after she returned to school, Topley welcomed twins — a boy and a girl. They help her take the challenges of being a student in stride.

“The shock of becoming a mother and being responsible for two other human lives helped dampen the shock of being inside an educational institution for the first time in 20 years,” she

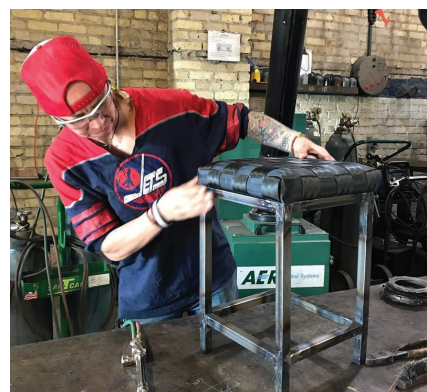
said. “Motherhood is humbling and helps me put life in perspective. I’ve come home from school swimming in frustration from not being able to conquer a specific weld. Previously, this may have sullied my mood for the whole night. Now I come home and see the gleeful energy of my spunky toddlers and know that life is too precious to sweat the small stuff.”

Despite the obstacles caused by the COVID-19 pandemic, Topley is scheduled to graduate in the spring of 2021.

“Finishing a technical degree amidst a global pandemic has been a new adventure,” she asserted. “I am a hands-on learner, so the reduced face-to-face contact and more condensed class schedules are making it more challenging to learn and practice the skills being taught, but I’m always up to the challenge.”

Topley enjoys combining her welding skills with her years of experience in the furniture industry. She especially likes breathing new life into discarded pieces. She dreams of opening her own business one day to design and create custom furniture that is both artistic and functional.

“I like to incorporate found objects and upcycled elements whenever possible. I recently created a set of metal bar stools upholstered with reclaimed seatbelts that featured three transmission gears welded together as the cross-brace. I love the way it feels to take a design from the sketch phase all the way through final product,” she affirmed. “The most fulfilling part is being able to share these designs with others.”



Tamara Topley examines a barstool she created using oxyacetylene welding.

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@phillyshipyard.com

District 4

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

District 5

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

ATLANTA

September 28

Location: Fortis College,
Smyrna, Ga.

Summary: Section Student Liaison
Chair Rachel Lee discussed the bene-

fits of becoming a student member from her perspective as a student at Lanier Technical College. She also spoke about joining social media platforms, explained the importance of applying for scholarships, and answered questions on how to complete applications correctly. Five student memberships were raffled, and four new student members signed up. The Section also raffled off a bag full of welding supplies.

October 15

Location: Lincoln Electric, Lithia Springs, Ga.

Presenters: Rachel Nolan and Ryan Shepard, technical sales representative, Lincoln Electric

Summary: Nolan and Shepard explained how the HyperFill™ welding solution works. They covered technical info and then went to the lab to demonstrate the process. Attendees were able to try welding groove beads. Certified Welding Inspectors earned professional development hours for attending.

District 6

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



ATLANTA — October meeting attendees gathered for a group photo.



ATLANTA — Welding students are seen with the Section's Student Liaison Chair Rachel Lee (far right from banner).

NORTHERN NEW YORK October 15

Location: Albany Pump Station, Albany, N.Y.

Summary: The Section hosted a dinner in honor of Dave Parker, an AWS member since 1967 who has been involved with the Section's leadership since 1971. Section members are grateful to Parker for his service and bid him safe travels on the next chapter of his life. He has been an integral part of the Section, and his dedication and enthusiasm will be missed now that he's moving away.



NASHVILLE — Section Chair Curtis Duncan (right) presented a speaker gift to Shane Meador.

District 7

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

District 8

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

NASHVILLE October 20

Location: Tennessee Central Railway Museum, Nashville, Tenn.

Presenter: Shane Meador, president, Nashville Steam Preservation Society
Summary: Meador took AWS members through the history of the 576 steam locomotive restoration. He discussed the challenges of finding the correct material and welding processes to complete repairs on the train. Thirteen members attended the outing.

District 9

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

AUBURN-OPELIKA October 22

Location: Wilmore Labs Conference Auburn, Ala.

Presenter: Josh Gray, sales representative, Elcometer USA

Summary: Gray demonstrated some of his equipment, including paperless quality-assurance software, specifically in use with material thickness gauges, and devices for surface roughness and profiling.

SOUTHEASTERN LOUISIANA (SELU) STUDENT CHAPTER October 19

Location: SELU, Hammond, La.

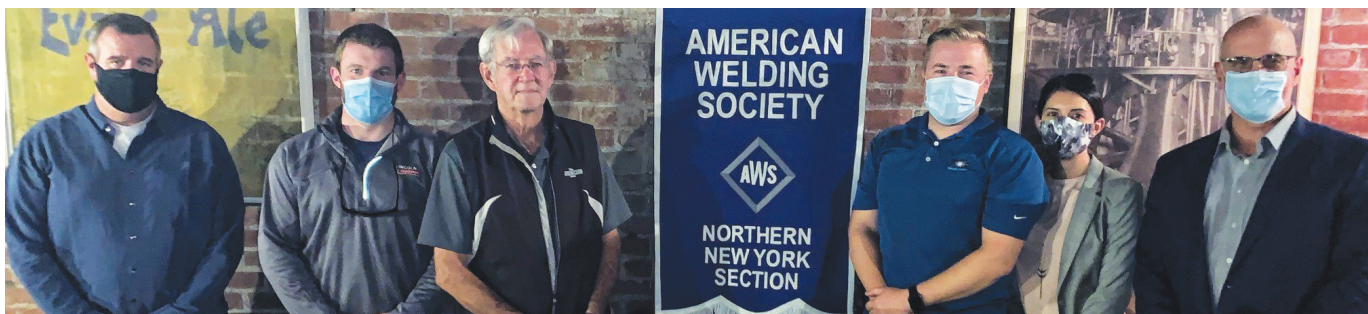
Presenter: Calvin Pepper

Summary: The Student Chapter had its first meeting of the semester on nondestructive and destructive examination. Students gained more knowledge on the testing processes from Pepper, as well as experienced it hands-on as they learned how to handle the testing machines and equipment.

November 2

Location: SELU, Hammond, La.

Summary: Faculty Advisor Anthony



NORTHERN NEW YORK — Members gathered to honor Dave Parker for his many years of service to the Section.



AUBURN-OPELIKA — Pictured are October meeting attendees.



American Welding Society®
MEMBERSHIP



SPARKING CONNECTIONS – 2020 AWS MEMBERSHIP CHALLENGE



■ *What it is:*

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

■ *How it works:*

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

■ *What you get:*

Grand Prize Winner: \$200 gift card

2nd Place: \$100 gift card

3rd Place: \$100 gift card

4th Place: \$100 gift card

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

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



American Welding Society®
MEMBERSHIP

8669 NW 36 ST. #130 | Miami, FL 33166-6672

T: 800.443.9353 | F: 305.443.5647 | aws.org

Application for Membership

PRIMARY CONTACT INFORMATION (Please Print)

☐ Mr. ☐ Ms. ☐ Mrs. ☐ Dr.

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

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

Company/School (if applicable): _____

Mailing Address: _____

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

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

Technical Interests (Circle All That Apply)

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

STUDENT MEMBERSHIP

☐ New

☐ Renewal, Member #:

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

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

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

(outside of US, Canada, and Mexico)

\$

INDIVIDUAL MEMBERSHIP

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☐ Renewal, Member #:

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

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

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

\$

Renewing Member

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☐ 2 Year - Print and Digital *Welding Journal* \$171

\$

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☐ 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

\$

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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 \$

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

Job Classification (Circle ONE Letter Only)

- | | | | | |
|---|-----------------------------|---------------------------|--|---------------------|
| 01 President, Owner, Partner, Officer | 04 Purchasing | 10 Architect Designer | 08 Supervisor, Foreman | 15 Educator |
| 02 Manager, Director, Superintendent (Or Assistant) | 05 Engineer — Welding | 12 Metallurgist | 14 Technician | 17 Librarian |
| 03 Sales | 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 |

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

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

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

Date: _____ AWS Staff: _____

Blakeney guided students through the process of oxyfuel cutting, giving a short demonstration and then allowing the students to use the torch and cut metal themselves.

November 16

Location: SELU, Hammond, La.

Presenter: John Perilloux, professional blacksmith and metal artist
Summary: Perilloux taught students the techniques of hammering, bending, and cutting hot metal to create any shape desired. The students had the opportunity to practice by forging iron nail hooks for themselves.

District 10

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(814) 881-0632
kostreba@hotmail.com

District 11

Phillip Temple, director
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nwcllc_ptemple@att.net

OWENS COMMUNITY COLLEGE STUDENT CHAPTER October 15

Presenters: Anthony Duris, student advisor chair; Candace Guy, student advisor co-chair; and Kevin Bauer, sales manager, DeLille Oxygen
Summary: The Chapter held a hybrid meeting with eight students, two advisors, and two representatives in attendance to follow social distancing guidelines put forth by the school. The Student Chapter got creative with this year's kick-off meeting. They streamed it to roughly 14 new AWS student members who could not attend in person due to restrictions. Two Jackson welding



SELU Student Chapter — Calvin Pepper explained destructive and nondestructive examination.



SELU Student Chapter — Professional blacksmith and metal artist John Perilloux demonstrated the art for members.



SELU Student Chapter — Anthony Blakeney guided the students on the process of oxyfuel cutting.



Owens Community College Student Chapter — New members socially distanced and wore facial coverings inside the school's welding facility.

helmets were raffled (one to a present attendee and one to a virtual attendee). They enjoyed a safety presentation by DeLille Oxygen. Attendees learned about the proper use of gases, gas storage, and the dangers of oxygen. The students were interested and engaged even in this new hybrid meeting model. Members are appreciative to Evelyn Andino, AWS program manager, Sections and Student; DeLille Oxygen; Student Advisor Chair Anthony Duris; and all the new student members.

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dale.lange@nwtc.edu

District 13

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



Owens Community College Student Chapter — Raffle winner Chris Allen poses with his new welding helmet.

CHICAGO October 21

Location: Mama Luigi's Restaurant Bridgeview, Ill.
Summary: The Section held a board meeting to discuss old and new business and to schedule future gatherings.

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Owens Community College Student Chapter — Virtual raffle winner Dakota Dubois is seen with his new welding helmet.

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shawnm@bigbend.edu

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Denis Clark, director
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denis.clark.51@gmail.com

COLORADO September 19

Location: Lakewood, Colo.
Summary: Joe Troppman, a retired boiler and pressure vessel quality-control inspector and volunteer proctor for Colorado AWS Certified Welding Inspector (CWI) exams for many years, was presented the District Meritorious Award for 2016–2017 at a lunch held in his honor. Also in attendance were Galen Altman, retiree from Murphy Co. Mechanical Contractors and Engineers Inc. and former CWI test supervisor for the Section; Bob Teuscher, AWS past president and current Section program director; and Section Chair Marj Oliver.

COLORADO October 8

Location: Sterling, Colo.
Summary: Presentations were started with Steve Unrein, a former local northeast area sales representative and Section executive board member, who introduced the meeting and thanked Jay Jackson, manager at Buckeye Welding Supply, for hosting the dinner and meeting. Bob Teuscher addressed the many scholarship opportunities at all levels that are available from AWS and spoke about how the process for applying is followed. Additionally, Jackie Nolan, Lincoln Electric technical sales representative for northern Colorado, introduced the



CHICAGO — Meeting participants included Costica Iftimie, Craig Tichelar, Anghelina Iftimie, Elisabeth Darnell, John Hesseltine, Section Chair Dave Viar, and Jim Greer.

company and discussed the many available career opportunities in welding and associated fields all over the world.

District 21

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(858) 740-1917
slindsey@sandiego.gov

District 22

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

CENTRAL VALLEY October 22

Location: College of the Sequoias,
Tulare, Calif.

Summary: Section Chair Randy Emery facilitated an advisory meeting between local industry professionals and College of the Sequoias faculty and ad-

ministration. Discussion was centered around the specific needs of the industry and ways of developing meaningful partnerships between industry and the school's welding program. This meeting provided valuable feedback from local welding inspectors and several welding companies, and will increase the quality of welding education in the Central Valley.

SAN FRANCISCO November 2

Summary: During the month of October, members were invited to submit their welding-related photos to the AWS San Francisco Section Halloween Photo Contest. The winners were announced during a virtual meeting in November. The winners were, first place, Ben Martin's "Wolf Guy," and second place, Bill Holt's "Welder in the City" photograph. Martin received a \$100 Visa gift card and Holt got a \$50 Visa gift card.



SAN FRANCISCO — Ben Martin's "Wolf Guy" is the winner of the Section's Halloween Photo Contest.



COLORADO — Award recipient Joe Troppman (second from left) is seen with (from left) Galen Altman, Marj Oliver, and Bob Teuscher.



CENTRAL VALLEY — Randy Emery (front, far right) and advisory committee meeting attendees.



COLORADO — Bob Teuscher speaks to October meeting attendees.

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American Welding Society

Motor-Driven and Engine-Driven Generators and Alternators

Generator power sources and alternators convert mechanical energy into electrical power suitable for arc welding. Rotating mechanical power can be obtained from an internal combustion engine or an electric motor. For welding, two basic types of rotating power sources are used: the generator and the alternator. Both have a rotating component, called a *rotor* or an *armature*, and a stationary component, called a *stator*. A system of excitation is needed for both types. In practice, a generator has a stationary field and moving conductors, while an alternator has a moving field and stationary conductors.

Generators

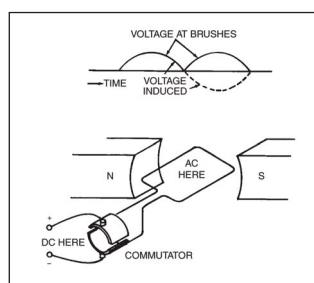


Fig. 1 — Schematic of a generator.

The direct current (DC) generator has a commutator-brush arrangement for changing alternating current (AC) to DC welding power — Fig. 1. Normally, the DC generator is a three-phase electrical device. Three-phase systems provide the smoothest welding power of any of the electro-mechanical welding power sources.

A DC generator consists of a rotor and stator. The rotor assembly is comprised of a through shaft; two end bearings to support the rotor and shaft load; an armature, which includes the laminated armature iron core and the current-carrying armature coils; and a commutator. It is in the armature or rotating coils that welding power is generated. The stator is the stationary portion of the generator within which the rotor assembly turns. It holds the magnetic field coils of the generator. The magnetic field coils conduct a small amount of DC to maintain the necessary continuous magnetic field required for power generation. The DC amperage is normally no more than 10 to 15 A and is very often less.

In electric power generation, there must be relative motion between a magnetic field and a current-carrying conductor. In the DC generator, the rotating armature is the current-carrying conductor. The stationary magnetic field coils are located in the stator. The armature turns within the stator and generates the welding current.

The armature conductors of a welding generator are relatively heavy because they carry the welding current. The commutator, located at one end of the armature, is a group of conducting bars arranged parallel to the rotating shaft to make switching contact with a set of stationary carbon brushes. These bars are connected to the armature conductors. The whole arrangement is constructed in proper synchronization with the magnetic field so that, as the armature rotates, the commutator performs the function of mechanical rectification.

Alternators

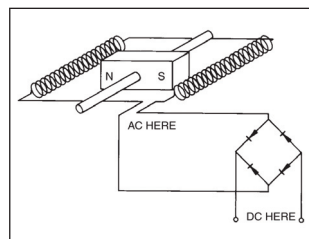


Fig. 2 — Schematic of an alternator.

An alternator power source is very similar to a generator, except that the magnetic field coils are generally wound on the rotor and the heavy welding current winding is wound into the stator — Fig. 2. These power sources are also referred to as revolving or rotating field power sources.

The AC voltage produced by the armature coils moving through the magnetic field of the stator is carried to copper commutator bars through electrical conductors from the armature coils. The conductors are soft soldered to the individual commutator bars. The latter may be considered as terminals, or collector bars, for the AC generated from the armature.

The commutator is a system of copper bars mounted on the rotor shaft. Each copper bar has a machined and polished top surface. Contact brushes ride on the top surface to pick up each half cycle of the generated AC. The purpose of the commutator is to carry both half cycles of the generated AC but on separate copper commutator bars. Each of the copper commutator bars is insulated from the other copper bars.

The carbon contact brushes pick up each half cycle of generated AC and direct it into a conductor as DC. It may be said that the brush commutator arrangement is a type of mechanical rectifier because it changes the generated AC to DC. Most of the brushes are an alloy of carbon, graphite, and small copper flakes. The DC characteristics are similar to those of single- and three-phase transformer-rectifier power sources.

The alternator construction places the heavy conductors in the stator, eliminating the need for carbon brushes and a commutator to carry high current. The output, however, is AC, which requires external rectification for DC application. Rectification is usually accomplished with a bridge using silicon diodes. An alternator usually has brushes and slip rings to provide the low DC to the field coils. Both single- and three-phase alternators are available to supply AC to the necessary rectifier system.

System of Excitation

An alternator or generator may be self-excited or separately excited depending on the field power source. Both may use a small auxiliary alternator or generator, with the rotor on the same shaft as the main rotor, to provide exciting power. In many engine-driven units, a portion of exciter field power is available to operate tools or lights needed for welding operation. In generators, this auxiliary power is usually 115-V DC. With an alternator power source, 120-V or 120/240-V AC is usually available. Voltage frequency depends on the engine speed. **WJ**

Wire Wizard® Makes Executive Leadership Appointments

Wire Wizard Welding Products, Jackson, Mich., a distributor of wire products for gas metal and submerged metal arc welding applications, has promoted Brian Cooper to executive vice president. He will oversee day-to-day operations, implement strategic goals, and build strong relationships with the

company's customers, partners, and suppliers. Cooper has been with the company since 2006 and previously served as vice president after holding other positions in sales. He is also the co-founder of The BenjaMen, a group-funding mission that raises money for underfunded critical programs in the local community. Additionally, Wire Wizard has hired Tom Walley as vice president of sales. He has more than



B. Cooper



T. Walley



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Scholarships available through the AWS Foundation

Since 1991, the AWS Foundation has awarded over \$11 million in scholarships, and 2021 is expected to be the best year yet with over \$1.5 million dollars in scholarships available for students pursuing education in welding and related fields.

The AWS Foundation offers various types of scholarships at the National, District, and Section level for four-year, two-year, and certificate programs.



APPLY at scholarship.aws.org
National, District and Section
Scholarship Application

deadline is **March 1, 2021.**

Some Sections post independent scholarship applications.
Please check your section webpage for all available local scholarships.

For more information on all scholarship programs, visit aws.org/scholarships.



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25 years of experience in sales and marketing in the manufacturing and industrial supply sectors. He previously worked for National Standard, where he held the position of vice president of sales and marketing, as well as Miller/Illinois Tool Works, Oshkosh Corp., and Bombardier. Walley will be responsible for directing global sales efforts, developing growth-driven sales strategies, and collaborating with the marketing team to increase market penetration in key territories.

Cincinnati Incorporated Welcomes President and CEO



T. L. Warning

Cincinnati Incorporated (CI), Harrison, Ohio, a U.S.-based, build-to-order machine tool manufacturer, has appointed Timothy L. Warning as president and CEO. He has also been elected to the board of directors. Prior to this role, Warning

spent 20 years at Occidental Chemical Corp. and 16 years at various Dover Corp. companies.

Newport News Shipbuilding Announces Vice President of In-Service Carrier Programs

Todd West has been named vice president of in-service aircraft carrier programs for Huntington Ingalls Industries' Newport News Shipbuilding division, Newport News, Va. He will lead the planning and execution of aircraft carrier refueling and complex overhauls as well as aircraft carrier



T. West

fleet support. He will also be responsible for the company's industrial subcontract at the Kenneth A. Kesselring Site, a research and development facility in West Milton, N.Y., that supports the U.S. Navy's nuclear propulsion program. West,

who serves as USS *George Washington* (CVN 73) program director, brings 35 years of shipyard experience and knowledge of program, construction, and overhaul experience to the position. He began his career as an engineer and has served in both engineering and construction leadership roles.

Harris Products Appoints Vice President of Strategy and Technology



K. Elliott

The Harris Products Group, Mason, Ohio, a Lincoln Electric company, has selected Kimberly Elliott as vice president of strategy and technology. In this role, she will expand the company's market presence through new products and ac-

quisitions. Previously, she served in several executive capacities with American Greetings Corp., including her most recent role where she led the company's Asian operations. Prior to that, she led an account team for a leading North American retailer, where she managed commercial activities and operations associated with more than \$800 million in sales. In addition, she has extensive experience in strategic management, manufacturing technology, and engineering. Elliott began her career as a senior metallurgical engineer with Alcoa, where she developed manufacturing processes and oversaw critical programs. Later, she managed the development and launch of new products manufactured in 13 international facilities. She also worked for several years with Booz & Co., where she helped clients develop growth strategies.

Force Control Chooses Southwest Regional Manager

Force Control Industries, Fairfield, Ohio, a manufacturer of oil shear technology, has added Dillon Altwegg as its regional manager in the Southwest region. In this newly created position, he will support representatives and distributors, original equipment manufacturers, and industrial customers in Arizona, California, Nevada, Utah, Colorado, and New Mexico, as well as Baja California and Sonora, Mexico, from his



D. Altwegg

home office in Flagstaff, Ariz. Altwegg comes from Kaeser Compressors, where he worked with customers across many industries, including food and beverage processing, chemical processing, wastewater, and general manufacturing.



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Castolin Eutectic Names CEO



P. Fetzer

Castolin Eutectic, a global provider of maintenance and repair solutions, has announced Patrick Fetzer as CEO. He will operate from the company headquarters in Kriftel, Germany. Fetzer has held executive positions within

the power industry through General Electric and Alstom. With more than 25 years' experience, he has operated in North and South America, all parts of Europe, the Middle East, India, China, and Asia Pacific.

HGG Hires Area Sales Manager for United States/Canada

HGG Profiling Equipment, Medina, Ohio, a subsidiary of HGG and supplier of cutting equipment solutions, has appointed Todd Wellens as the area sales



T. Wellens

manager for eastern and midwestern United States and Canada. He will provide support for customers in both sales and customer service. Wellens comes with an extensive background in manufacturing engineering and operations management as well as 27 years of experience in metal fabricating machine tool sales.

Obituary

Clayton Charles "Chic" Bartlett



C. C. Bartlett

Clayton Charles "Chic" Bartlett, a leader in the Canadian welding supply business, passed away on September 30, 2019. He was 88. Bartlett began his career in the welding supply business as a salesman for Lincoln Electric in Toronto, Canada. He went

on to help start a welding supply distributorship, where he spent a couple of years, before joining the then newly formed Hobart Brothers of Canada Ltd. as a sales representative. By 1979, he was promoted to vice president and general manager of the company, then later to president. He led the company's growth to become a leading supplier of filler metals and equipment in the Canadian market. He undertook many expansions, including growing product development, adding electrode capabilities, expanding the flux-cored wire, and adding solid wire manufacturing. He retired in 1997. Additionally, Bartlett participated in many volunteer organizations and committees, including the Canadian Standards Association/Canadian Welding Bureau, Canadian Welding Society, Welding Products Manufacturing Association of Canada, Canadian Pipeline Contractors Association, and more. He is preceded in death by his wife, Valerie "Jean," and is survived by his daughters, Lynne and Cathy, four grandchildren, and one great grandchild. **WJ**



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Community College
Kansas City, KS
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Applications open in **February 2021**.

Learn more at aws.org/workforcegrant



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— continued from page 11

on social media. Video content, in particular, was primarily used to sell product with little value added to the shop floor. We had the amazing privilege to be pioneers in helping companies build communities of loyal customers through education and engagement. It's exciting to see more companies adopting this strategy of appealing to the front-line men and women in their marketing efforts, as it brings up the industry as a whole. Thank you so much for this incredible honor. I look forward to continuing to push the limits of media creation for the welding/metalworking industry," he said.

Veteran — William Holmes. "I would like to thank my instructor at Baptist Hill High School for encouraging me to pursue a career in welding. Also, for companies such as General Electric and Stevens Towing for providing me work for many years to develop my craft. My recent years in this trade are the most memorable because Mathilde Dumond and I came together to provide welding training, job skills, and encouragement to local high school students in my community and surrounding areas," Holmes concluded. — *Kristin Campbell, managing editor, and Roline Pascal, education editor*

ITSA Enters Into Trans-Pacific Thermal Spray Partnership

The American Welding Society (AWS), Miami, Fla., on behalf of the International Thermal Spray Association (ITSA), has entered into a partnership with Swinburne University of Technology in Australia to further surface engineering science and technology within a global context. The agreement will allow both organizations to expand their international outreach and ensure a path for the promotion and advancement of fundamental knowledge and understanding of surface engineering. ITSA is a standing committee of AWS.

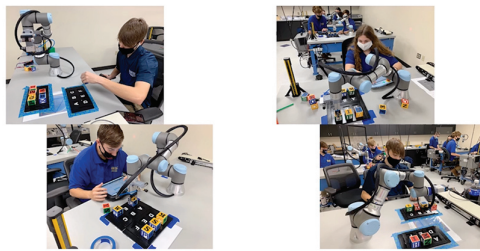
"This partnership between AWS and the Australian Research Council Training Centre for Surface Engineering for Advanced Materials (SEAM) is a great outcome," said SEAM Director and Professor Chris Berndt.

"Part of the AWS mission is to advance the science, technology, and application of allied joining processes, including thermal spraying," added Alfred Nieves, AWS membership operations manager and ITSA program manager. "The partnership between ITSA/AWS and Swinburne aligns with our mission and will encourage the next generation of engineers to advance both the technology and their career paths in surface engineering."

Cobot Expo 2.0 Highlights Automation Systems and Education Program

Universal Robots (UR), a manufacturer of industrial collaborative robot (cobot) arms headquartered in Odense, Denmark, hosted the virtual Cobot Expo 2.0 on November 16 and 17. It was a follow-up to the first run of the online expo in July.

The North American digital tradeshow showcased a variety of automation systems designed to help manufacturers



A slide from the Cobot Expo 2.0 shows students at RAMTEC Ohio partaking in the UR education program.

address the productivity challenges exacerbated by the COVID-19 pandemic. The expo was free to attend, and its interface featured an auditorium and two halls with floor plans organized by the most popular application segments. Guests had their choice of visiting ten UR booths and 21 partner booths, along with a roster of live demonstrations and keynote presentations. Each booth had content for download, such as brochures, how-to guides, application videos, and white papers. If guests had questions, more than 100 automation professionals were available for voice and text chat.

Some live demonstrations included installing UR+ caps, ActiNav flexible machine loading, and palletizing, while keynote presentations covered topics such as succeeding in your first cobot project, accelerating projects with UR+ application kits, and more.

The presentation Accelerating Tomorrow's Engineers was an event highlight, announcing UR's first collaborative robot certifications for education. It is projected that 2.4 million manufacturing jobs will be open between 2018 and 2028. The UR Program for Education aims to fill many of those positions by recruiting younger generations. It offers a curriculum track for students to pursue an advanced manufacturing/robotics Industry 4.0 career via trainings on robot fundamentals and expanded factory interconnectivity, as well as employment skills, project management fundamentals, practical application, and more.

"This hands-on learning initiative will be instrumental in addressing the skills gap and get state-of-the-art cobots into classrooms, offering students instant employability and manufacturers access to an upskilled workforce," said Joe Campbell, senior manager of applications development at UR.

Accredited by the International Accreditors for Continuing Education and Trainings, the program can be taught in high schools, dual-enrollment courses, and colleges. Upon completing the 32-h course, students are eligible to receive an industry-recognized UR certification. A teacher certification training is also offered and required for instructors to perform the UR curriculum and certify their students.

The core package includes a UR3e cobot, UR+ gripper, formalized curriculum and 23 user licenses, PolyScope software, and an academy peripheral hardware set. In addition, there is a core retro package for educational institutes that may already have a UR cobot.

"What we really want to do is accelerate tomorrow's engineers, today," said Campbell during a press briefing. "We want to make them aware of the technology, comfortable with the technology, and increase their interest in manufacturing." — *Alexandra Quiñones, associate editor*

PRODUCT & PRINT SPOTLIGHT

— continued from page 19



market. Additionally, because they utilize a laser excitation source, there is minimal to no regulatory licensing requirements. They also have a MIL-STD 810G drop-test certification and an IP-54 dust protection rating.

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Report Discusses the Impact of COVID-19 on the Thermal Spray Coatings Market

Thermal Spray Coatings — Global Market Trajectory & Analytics presents statistics on how the COVID-19 pandemic has impacted production and buy-side for the 2020–2027 thermal spray coatings market. The 296-page report estimates the global market was worth \$9.8 billion in 2020 and will increase to \$14.4 billion by 2027, growing at a compound annual growth rate (CAGR) of 5.5%. Ceramic, one of the segments analyzed in the report, is projected to record a 6.2% CAGR, reaching \$5.3 billion globally. In the United States, the report forecasts the thermal spraying coatings market to close at \$2.7 billion in 2020. In China, the market size is projected to be \$3 billion by 2027, a CAGR of 8.6%. The Japanese, German, and Canadian markets are expected to grow at a CAGR of 3, 3.5, and 5%, respectively.

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ranchers, truck drivers, heavy-machine operators, utility workers, and oil and gas workers. It comes in three versions: 6 in., 8 in., and pull-on. All models come standard with the full-grain Crazy Horse leather, welted construction, Bootbed™ memory foam removable footbed, and abrasion-resistant outsole. The 6- and 8-in. boots add a layer of weather protection with a Hydrotex® waterproof liner.

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Updated Standard Covers Testing and Labeling of Laser Protective Equipment

ANSI Z136.7-2020, *Testing and Labeling of Laser Protective Equipment*, replaces the 2008 edition and includes new content. The standard is intended for anyone selecting or testing laser protective materials. It provides recommendations for testing and labeling laser protective materials and protective equipment — such as eye protection, barriers, and windows — designed for use with lasers and laser systems that operate at wavelengths between 180 and 10^6 nm. Some of the updates included in this standard are as follows: a comparison of different filter types; factors to consider before selecting a filter; refined angular protection test procedures for reflective filters (i.e., dielectric stacks, holograms); and material damage thresholds and environmental considerations.

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Arc Characteristics and Welding Process of Magnetic Field Assisting Plasma-GMAW-P

Plasma-GMAW-P arc profile, temperature field, and welding process at the different external magnetic fields were investigated

BY J. YU, H. ZHANG, X. YANG, Y. TENG, Q. WANG, L. WEI, P. HE, AND W. ZHANG

ABSTRACT

Low-carbon steel Q235B was successfully joined by plasma-pulsed gas metal arc welding (plasma-GMAW-P) with an external magnetic field. The arc profile, temperature field, electrical signal, microstructure, and mechanical properties of this method were analyzed. The results indicated that the coupling degree of the two arcs increased with the strengthening of the magnetic field current. However, when the magnetic field current was greater than 1 A, the arc profile changed slightly with the increase of the magnetic field current. Fixed on the magnetic field current, the coupling degree first increased and then decreased with the increase of the plasma welding current, GMAW-P welding current, plasma gas flow rate, and nozzle height, respectively. The maximum temperature had no obvious influence on joint penetration at different magnetic field currents. However, the average temperature had an inverse effect on joint penetration at different magnetic field currents. The weld fusion zone joint tensile test results showed that the ratio of depth to width increased with the application of magnetic field currents. Moreover, tensile strength on the upper and lower part of the tensile samples were 521 and 488 MPa, respectively, which were 4.6% and 3.2% higher than those without the magnetic field. The microhardness of the weld joints was higher than that without the magnetic field.

KEYWORDS

- Plasma-GMAW-P • Arc Profile • Coupling Degree
- Magnetic Field Current • Tensile Strength

Introduction

Laser beam welding (LBW), electron beam welding (EBW), and plasma arc welding (PAW) are considered as high-power-intensity heat source welding methods due to

the function of the keyhole mode, which promotes deep penetration and enhances mechanical properties (Refs. 1–3). Due to the welding equipment costs, PAW is more widely applied in various industries to join different materials than LBW and EBW (Refs. 4–6). Gas metal arc welding (GMAW) has the features of high deposition and a wider process zone as well as lower power density, which allows extensive application in the industrial field (Refs. 7, 8). Hybrid arc welding methods have been regarded as effective in improving joint properties in the scope of welding (Ref. 9). A series of hybrid welding technology for the aforementioned methods is performed, such as plasma-GMAW (Ref. 10) and double-electrode GMAW (DE-GMAW) (Ref. 11). DE-GMAW achieves the welding process of double wires located in the same molten pool, which improves welding speed and productivity (Ref. 12). There is a 7.5-deg angle between two respective wire electrodes and the vertical, and the distance between the electrode tip spacing is 9 mm (Ref. 13). Therefore, two wires operate close in the torch and may render magnetic interaction. Pulsed GMAW (GMAW-P) could achieve a stable welding process by droplet transfer with one drop per pulse, and pulsed mode is applied to this method to minimize magnetic interaction, which is claimed as double-pulsed GMAW (DP-GMAW) (Ref. 14).

Hybrid arc profiles and their interactions have an important effect on the hybrid welding process and weld quality. Liu et al. studied the DP-GMAW arc profile variation process and found that the arc profile variation and droplet transfer in the thermal peak were higher than in the thermal base, but the variance of arc size in the thermal peak was opposite (Ref. 15). Schnick et al. analyzed arc interactions and their influence on the gas shield flow in the DP-GMAW process, which enhanced the understanding of the causes of periodic instabilities and joint imperfections (Ref. 13). Wu et al. investigated the double arc interaction and quantitative analysis of double arc offset of DP-GMAW and felt that electromagnetic field, arc pressure, and arc stiffness had important effects on arc offset behavior (Ref. 16).

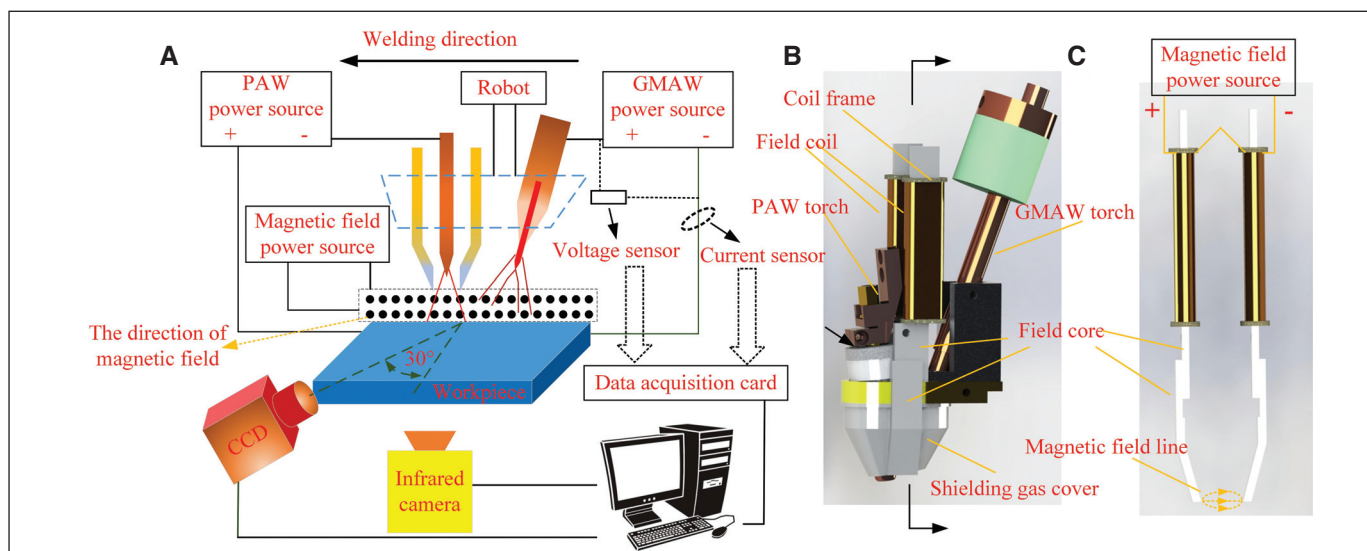


Fig. 1 — Experimental setup. A — Schematic diagram of plasma-GMAW-P hybrid welding system; B — hybrid welding torch; C — mode of the magnetic field.

However, few studies are implemented in the area of arc characteristics of plasma-GMAW. Plasma-GMAW was first studied by Essers et al. in 1972 and could be achieved in a single torch (Refs. 17–19). The plasma arc plays a role in the keyhole and preheating wire in the plasma-GMAW process. The gas metal arc is significant in gaining stable droplet transfer (Refs. 20, 21). Lower porosity, less welding spatter, and higher efficiency are observed in this method with the complementary advantages of PAW and GMAW (Ref. 22). Meanwhile, two different welding arc plasmas interact in the workpiece together, which improves welding heat and efficiency compared to a single welding arc plasma (Refs. 23, 24). According to the space position combination structure, the plasma-GMAW method is divided into the coaxial and paraxial plasma-GMAW. At present, the majority of researchers primarily concentrate on coaxial plasma-GMAW, but the structure of the single coaxial hybrid welding torch is complicated, and the plasma current is only focused on low (Ref. 25). Additionally, by comparison, the paraxial plasma-GMAW hybrid has a smaller constricting nozzle, gaining a more concentrated plasma arc (Ref. 26).

Therefore, it is significant and necessary to study and understand the paraxial plasma-GMAW hybrid arc profile and its

interaction. Paraxial plasma-pulsed GMAW (plasma-GMAW-P) under the control of the external magnetic field welding method is proposed in this article. Arc profile and the distribution of the temperature field in this method were analyzed by a charge-coupled device (CCD) camera, electrical signals, and an infrared thermal imager, separately. In addition, the plasma-GMAW-P process with different magnetic field currents on medium-thick plates was also carried out to demonstrate the advantage of the external magnetic field.

Experimental System and Procedure

Experimental System

The schematic diagram of the experimental welding systems is shown in Fig. 1A, including the PAW power source, GMAW-P power source, magnetic field power source, CCD camera, infrared thermal imaging, current and voltage sensors, data acquisition card, welding robot, and hybrid welding torch. As shown in Fig. 1B, a tandem was realized in the single torch with both the PAW torch and the GMAW torch at a certain angle with the axis of the plasma torch. Field

Table 1 — Detailed Welding Parameters

Parameter Set	I_w/A	I_m/A	$q/L \cdot \min^{-1}$	$v/mm \cdot s^{-1}$	H/mm	I/A
#1	120	160	3	5	6	0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5
#2	80, 100, 120, 140, 160	160	3	5	6	1.0
#3	120	80, 120, 160, 200, 240	3	5	6	1.0
#4	120	160	2, 3, 4, 5	5	6	1.0
#5	120	160	3	5	5, 6, 7, 8	1.0

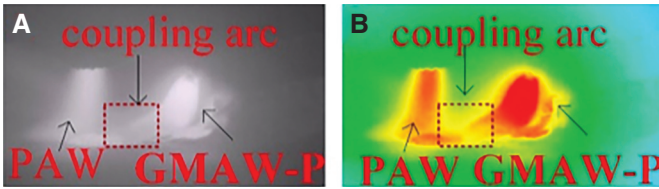


Fig. 2 — Arc profile of plasma-GMAW-P. A — Gray-scale image; B — pseudocolor image.

Table 2 — Detailed Pulsed Parameters

I_m/A	I_p/A	I_b/A	t_p/ms	t_b/ms	f/Hz
80	127	67	3	10.5	74
120	170	95	3.5	7	95
160	200	125	3	3.5	153
200	234	148	3	2	200
240	281	171	2.5	1.5	250

cores were located on both sides of the shielding gas cover and applied as a magnetic conductor by connecting to the field coil. There are 500-turn field coils at every coil frame. The application mode of the magnetic field and the direction of the magnetic field line are depicted in Fig. 1C. The magnetic field lines were generated by the magnetic field power source, then transmitted to the plasma and GMAW-P arc. The direction of the generated magnetic field was vertical to both arcs. Therefore, the plasma and GMAW-P arc were coupled under the function of the magnetic field. The hybrid welding torch and a CCD camera (the Xiris XVC-1000 weld camera, 55 frames/s acquisition rate) were fixed on the robotic manipulator, and the entire welding speed was adjusted by the welding robot directly. The plasma-GMAW-P arc profile in the whole welding process was captured with the CCD camera. The infrared thermal imaging camera (FLIR A315) was fixed directly below the welding workpiece to measure the back temperature of the specimens by surfacing welding, and every welding parameter was measured three times, then the average temperature was taken. The electrical signal acquisition system was composed of a Hall current sensor, a Hall voltage sensor, a National Instruments PCI-6251 data acquisition card, and a computer control system.

The transferred PAW arc was realized by the PAW power source under the direct current straight polarity condition (maximum current of 300 A). The GMAW-P arc was burning by the GMAW-P power source under the direct current reverse polarity condition (maximum current of 400 A). Therefore, the plasma and GMAW-P arc repelled each other in the actual welding process. The magnetic field was produced by the direct current magnetic field power source (maximum current of 30 A).

The medium-thick plates of lower-carbon steel Q235B were used and welded by plasma-GMAW-P utilizing a 3.2-mm tungsten electrode in a 3-mm orifice diameter. The specimen dimensions were 200 × 100 × 8 mm, and the specimens' sur-

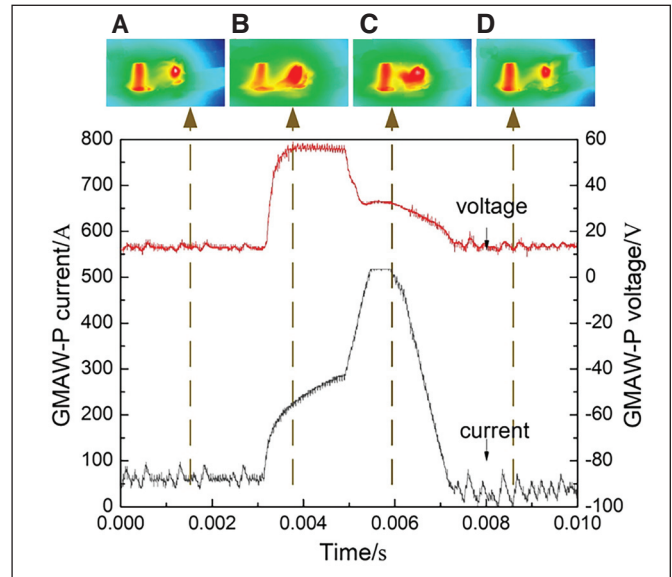


Fig. 3 — The successive images in the one-pulse period of plasma-GMAW-P. A, D — Pulse base phase; B, C — pulse peak phase.

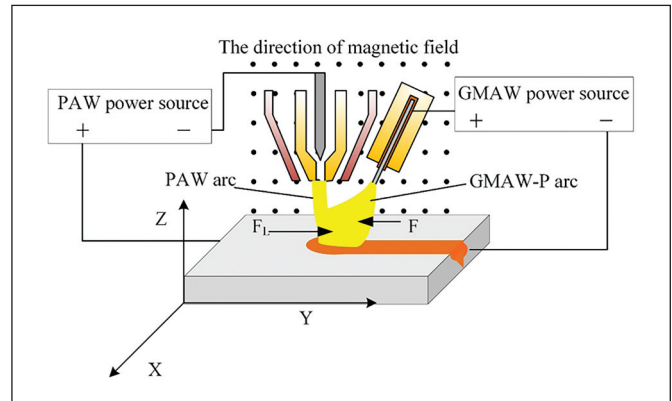


Fig. 4 — Schematic diagram of forces on the arc profile.

faces were brushed by a buffing machine and then cleaned with acetone and alcohol in turn. ER50-6 wire with a diameter of 1.2 mm was chosen as filler metal. Argon (80 vol-%) and carbon dioxide (20 vol-%) were used as shielding gas with a flow rate of 12 L/min. Pure argon (99.99%) was employed as plasma gas. The other detailed parameters are shown in Table 1. The distance from the end of PAW to the workpiece is the nozzle height. Plasma welding current, GMAW-P mean current, plasma gas flow, welding speed, nozzle height, and magnetic field current were represented by I_w , I_M , q , v , H , I , respectively. Moreover, Table 2 lists the detailed pulse parameters involving pulse current (I_p), base current (I_b), pulse time (t_p), base time (t_b), and pulse frequency (f).

Experimental Procedure

In the plasma-GMAW-P hybrid process, the plasma arc and GMAW-P arc were burning and stable, then the magnetic field power source was opened in the welding process. Subsequently, the CCD camera, infrared thermal imaging, and electrical

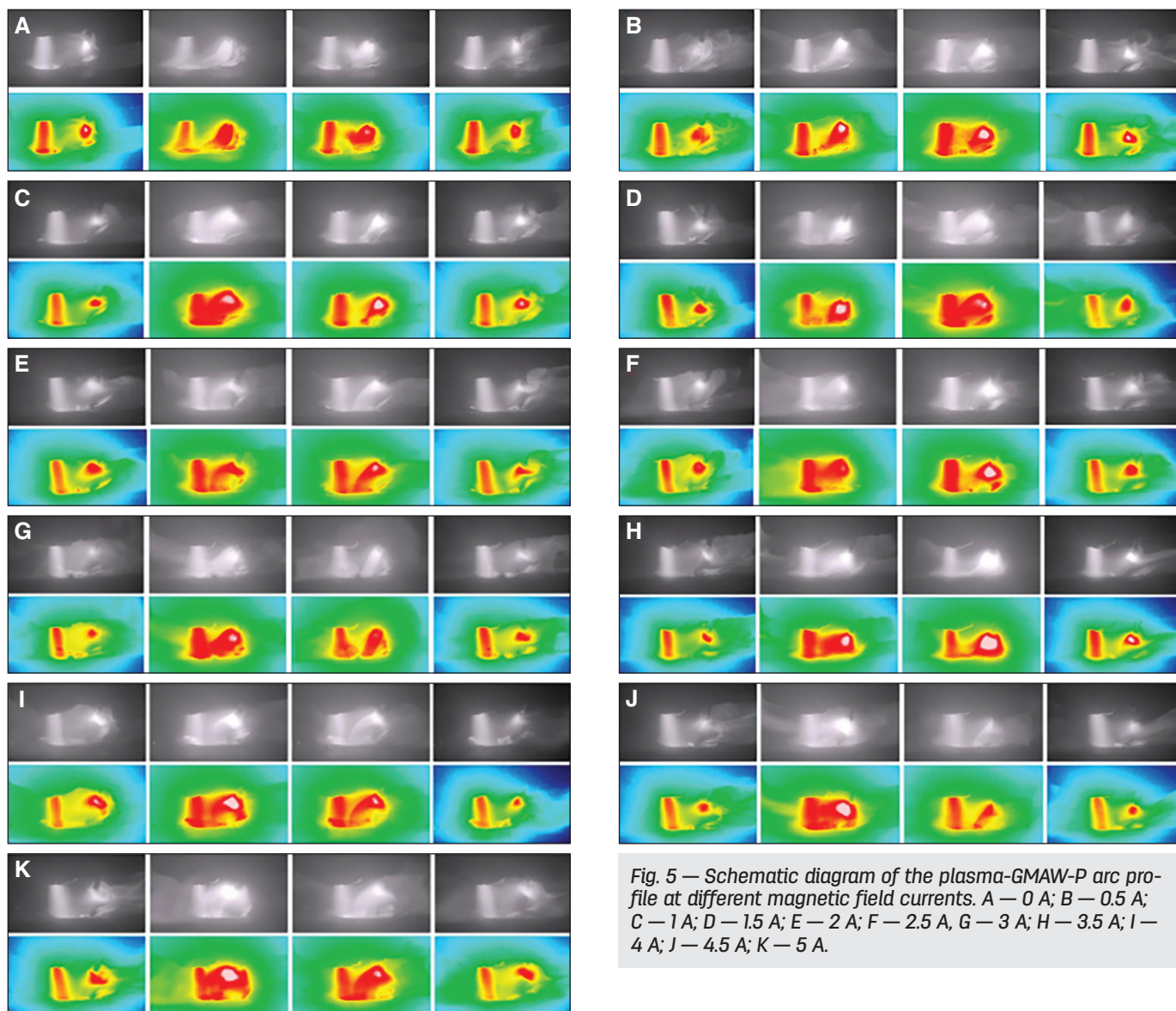


Fig. 5 — Schematic diagram of the plasma-GMAW-P arc profile at different magnetic field currents. A — 0 A; B — 0.5 A; C — 1 A; D — 1.5 A; E — 2 A; F — 2.5 A; G — 3 A; H — 3.5 A; I — 4 A; J — 4.5 A; K — 5 A.

signal acquisition system were also used. The PAW arc was located in front of the welding direction, which formed a keyhole in the workpiece. The GMAW-P arc was in the rear.

All the workpieces were polished to remove the surface oxidation film before welding and then cleaned by alcohol and acetone. All the metallographic specimens, tensile specimens, and bending specimens were cut out from the weld joints by wire cutting after welding. After the metallographic specimens were ground, polished, then etched, the metallographic test was conducted through the Olympus-DSX510 optical microscope. Welding reinforcement and back-side regions of the test specimens and bending specimens were removed by the milling machine. The tensile and bending tests were carried out by an electronic tensile testing machine (CSS-44400) with a travel speed of 1 mm/min. Apart from the tensile and bending tests, the microhardness of the welding joints was measured via a digital microhardness tester (ArtCAM-400SSI-C) with a load of 2.94 N and time of 10 s.

Results and Discussions

Pseudocolor processing in Xiris WeldStudio™ software (2.0.3, Xiris Automation, Burlington, Ontario, Canada) could convert the required gray-scale images from the CCD camera to pseudocolor images to analyze conveniently in Fig. 2. As shown in Fig. 2, the plasma arc was perpendicular to the welding workpiece and the GMAW-P arc was biased to the workpiece because the axes of the two arcs had certain angles. According to the arc profile, the plasma-GMAW-P arc shape could be divided into the following three regions: plasma arc, GMAW-P arc, and coupling arc. The successive images of the arc profile of plasma-GMAW-P without the magnetic field in the one-pulse period were depicted in Fig. 3, according to experimental parameter Set #1 in Table 1. The images of the plasma-GMAW-P arc profile in the pulse base phase of the GMAW-P current are shown in Fig. 3A and D. The images of the plasma-GMAW-P arc profile in the pulse peak phase of the GMAW-P current are sketched in Fig. 3B and C.

The main forces acting on the plasma-GMAW-P arc pro-

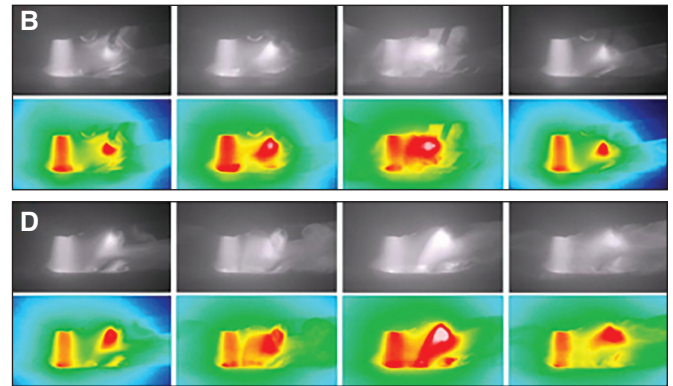
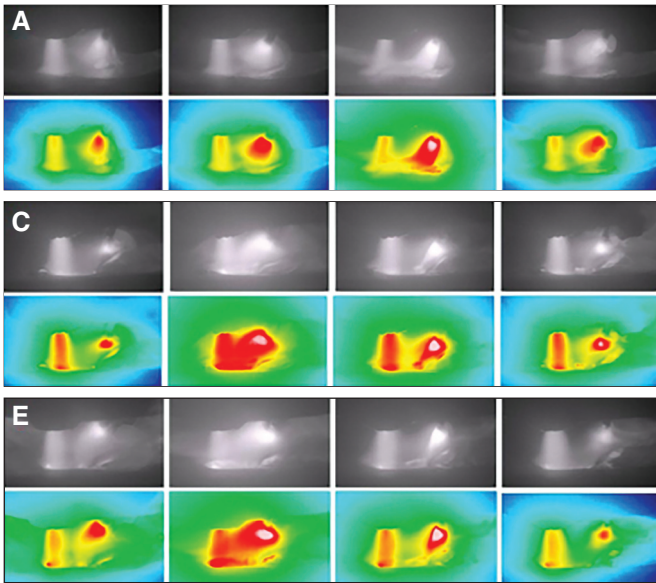


Fig. 6 — Schematic diagram of the plasma-GMAW-P arc profile at different plasma welding currents. A — 80 A; B — 100 A; C — 120 A; D — 140 A; E — 160 A.

file are Lorentz force, electromagnetic force, repulsive force, surface force, plasma flow force, etc. However, the Lorentz and repulsive force significantly influence the arc profile in the welding process in Fig. 4, which could be calculated by the following formulas, respectively.

(1) Lorentz force, F . Lorentz force is produced in the external magnetic field and can be calculated by Equation 1 as follows:

$$F = BIL \quad (1)$$

where B and I are magnetic field intensity and current, respectively.

(2) Repulsive force, F_L . Repulsive force can be calculated by Equation 2 as follows:

$$F_L = K \frac{I_1 I_2}{L} \quad (2)$$

where I_1 , I , and L represent the plasma current, GMAW-P current, and the distance between the plasma axis tungsten and wire, respectively. K is the coefficient ($K = \mu / 4\pi$; μ is dielectric permeability).

The Effect of Welding Parameters on the Plasma-GMAW-P Arc Profile

To explore the effect of external magnetic field intensity on the plasma-GMAW-P process, the successive images of the hybrid arc profile in the one-pulse period are shown in Fig. 5, according to experimental parameter Set #1 in Table 1. As shown in Fig. 5, the arc profile was changed at different degrees with the increase of the external magnetic field current.

Figure 5A illustrates the plasma-GMAW-P arc profile without the applied external magnetic field. As seen in Fig. 5A, when the GMAW-P current was in the pulse base phase, the plasma arc was completely perpendicular to the welding workpiece due to the feature of arc stiffness by itself. However, the plasma arc was inclined forward when the GMAW-

P current was in the pulse peak phase, which was mainly attributed to the improvement of the repulsive force between the two arcs due to the increase of the GMAW-P current in the pulse peak phase. Moreover, the plasma arc was perpendicular to the welding workpiece again when the GMAW-P current was in the pulse peak phase once again.

The morphology of the hybrid arc changed with the increase of the external magnetic field current. The morphology of the plasma-GMAW-P hybrid arc at different magnetic field currents varying from 0.5 to 5 A in 0.5 A increments is illustrated from Fig. 5B to K, respectively. When the magnetic field current didn't exceed 1 A, the plasma arc was always perpendicular to the welding workpiece in the pulse base phase of the GMAW-P current. This may be because the Lorentz and repulsive forces were so much smaller that the plasma arc was still perpendicular to the welding workpiece due to arc stiffness, resulting in the least coupling between the plasma and GMAW-P arc. However, the coupling degree increased when the GMAW-P current was strength-

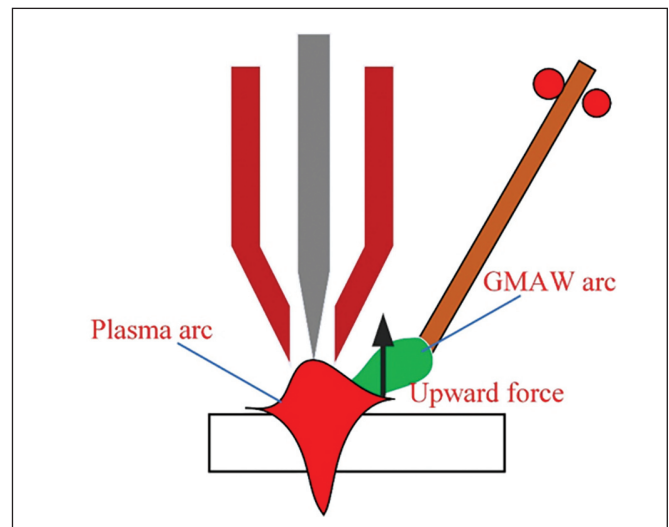


Fig. 7 — Schematic diagram of forces in the welding process.

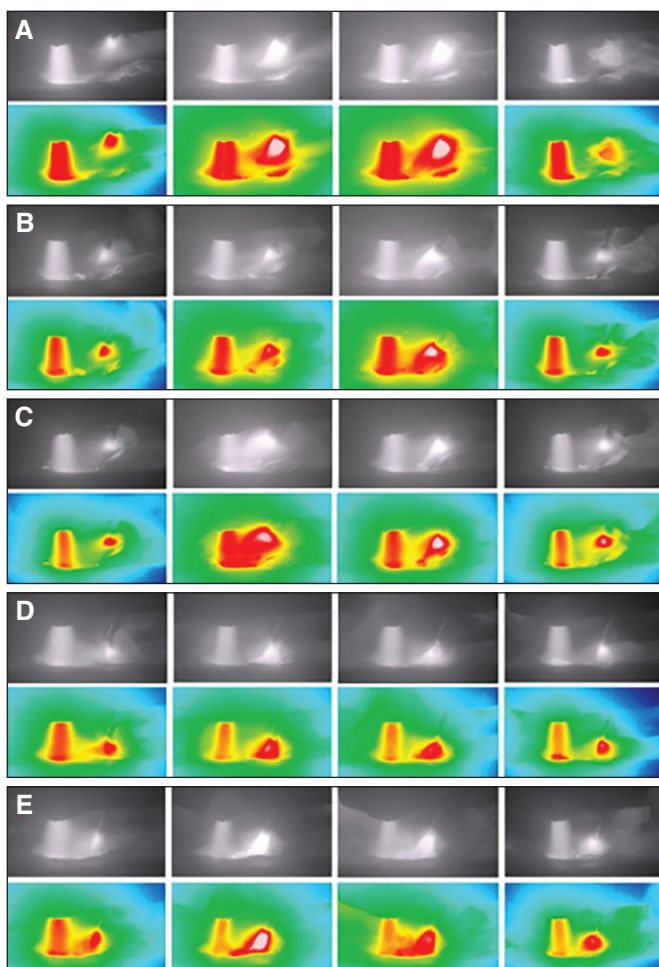


Fig. 8 — Schematic diagram of the plasma-GMAW-P arc profile at different GMAW-P welding currents. A — 80 A; B — 120 A; C — 160 A; D — 200 A; E — 240 A.

ened in the pulse peak phase, mainly attributed to the enlarging of the GMAW-P arc column area.

Plasma-GMAW-P arc profiles with magnetic field currents varying from 1.5 to 5 A are depicted from Fig. 5D to K, which show that the plasma arc was biased to the left side of the GMAW-P arc under the action of Lorentz force in the pulse base phase of the GMAW-P current. When the GMAW-P current remained in the pulse peak phase, the plasma and GMAW-P arc were changed as follows: the magnetic field current increasing from 1.5 to 4 A, the plasma arc was perpendicular to the welding workpiece. This was mainly because the GMAW-P current was increased in the pulse peak stage, which strengthened the repulsive force between the plasma and GMAW-P arc. As a result, the plasma arc moved far away from the GMAW-P arc. Nonetheless, under the combined action of the Lorentz force and the arc stiffness of the plasma arc, the plasma arc was perpendicular to the workpiece. However, when the magnetic field current was 4.5 and 5 A, separately, the plasma arc was still biased to the GMAW-P arc in the pulse peak phase of the GMAW-P current. This was because even if the increase of the GMAW-P current increased the repulsive force, it was still less than the Lorentz force. Besides, compared to the

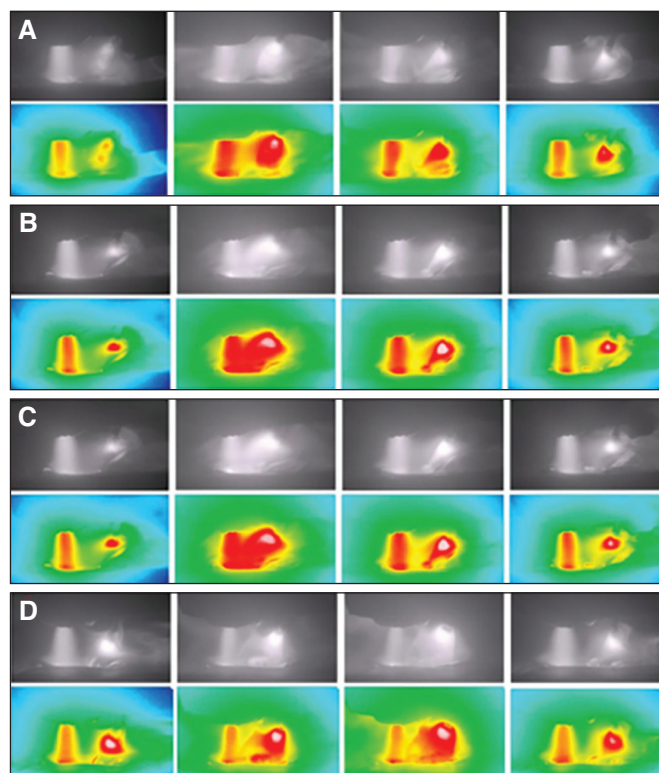


Fig. 9 — Schematic diagram of the plasma-GMAW-P arc profile at different plasma flow rates. A — 2 L/min; B — 3 L/min; C — 4 L/min; D — 5 L/min.

arc profile at different magnetic field currents, when the magnetic field current was more than 1 A, the coupling degree between the plasma and GMAW-P arc was approximately no longer increased in the pulse peak phase.

The Effect of the Plasma Welding Current on the Plasma-GMAW-P Arc Profile

To explore the effect of the plasma welding current on the plasma-GMAW-P arc profile, the successive images of the arc profile in the one-pulse period are shown in Fig. 6 according to experimental parameter Set #2 in Table 1. By comparison, the plasma-GMAW-P arc profile was changed as follows: due to the existence of the external magnetic field, the plasma arc was always perpendicular to the welding workpiece whether the GMAW-P current was in the pulse base phase or peak phase. When the plasma welding current increased from 80 to 120 A, the plasma arc column and diffusion angle increased, which increased the coupling degree of the hybrid arc. However, when the plasma welding current was increased from 140 to 160 A, the coupling degree of the hybrid arc weakened and the coupling position between the plasma and the GMAW-P arc improved, which may be attributed to the increase of the plasma arc column and the diffusion angle. Meanwhile, a partial plasma arc was located below the GMAW-P arc, which produced the upward force on the GMAW-P arc in Fig. 7. Therefore, the coupling position of the hybrid arc improved. However, the coupling degree weakened with the increase of the repulsive force.

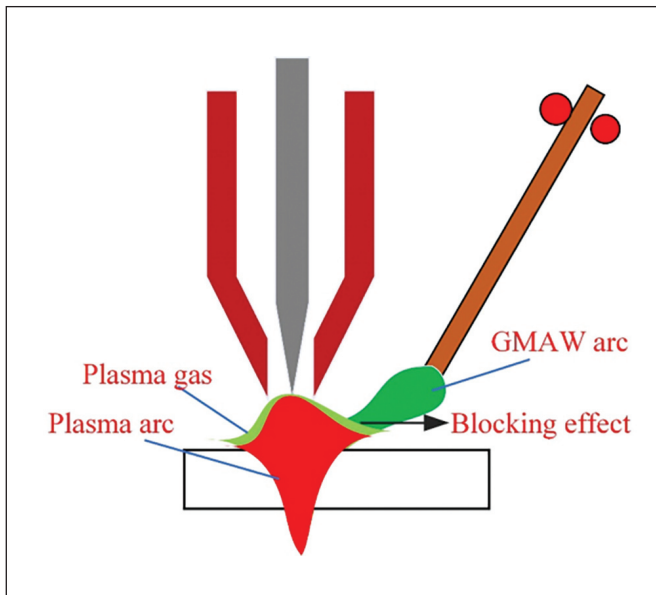


Fig. 10 — Schematic diagram of the increase of plasma gas.

The Effect of the GMAW-P Current on the Plasma-GMAW-P Arc Profile

To explore the effect of the GMAW-P current on the plasma-GMAW-P arc profile, the successive images of the arc profile in the one-pulse period are shown in Fig. 8, according to experimental parameter Set #3 in Table 1. When the GMAW-P current was in the pulse base phase, the plasma arc was still perpendicular to the workpiece even if the GMAW-P current was increased. This indicated that the increased repulsive force was less than the Lorentz force. Besides, the plasma arc also had the feature of arc stiffness, and the hybrid arc profile was also changed in the pulse peak phase of the GMAW-P current. When the GMAW-P current was less than 160 A, the coupling degree of the hybrid arc was increased with the strengthening of the GMAW-P current. Whereas, the plasma arc was still perpendicular to the workpiece, which was similar to the condition in the pulse base phase. When the GMAW-P current was more than 160 A, the coupling degree of the hybrid arc decreased as the GMAW-P current increased. This was because the repulsive force grew due to the increase of the GMAW-P current.

The Effect of Plasma Gas Flow on the Plasma-GMAW-P Arc Profile

Figure 9 depicts the plasma-GMAW-P arc profile at different plasma gas flows, according to experimental parameter Set #4 in Table 1. As seen in Fig. 9, when the GMAW-P current was in the pulse base phase, the plasma arc was perpendicular to the welding workpiece by Lorentz force under the function of the external magnetic field. However, when the GMAW-P current was in the pulse peak phase, the plasma arc was changed as follows: Firstly, as shown in Fig. 9A, when the plasma flow rate was 2 L/min, the plasma arc tilted forward in the pulse peak phase of the GMAW-P current.

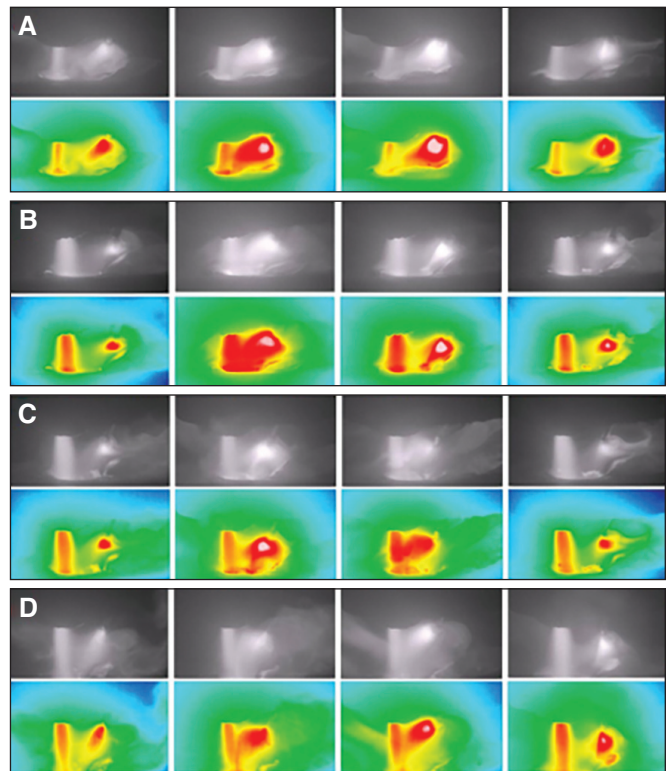


Fig. 11 — Schematic diagram of the plasma-GMAW-P arc profile at different nozzle heights. A — 5 mm; B — 6 mm; C — 7 mm; D — 8 mm.

This was mainly because the Lorentz force was less than the arc repulsion force. Secondly, as shown in Fig. 9B, the coupling degree between the plasma and GMAW-P arc was the largest when the flow rate of plasma gas raised to 3 L/min. However, the coupling degree between the GMAW-P and plasma arc decreased when the flow rate of plasma gas was 4 and 5 L/min as shown in Fig. 9C and D, respectively. The main reason was with the increase of the plasma gas flow rate, the plasma gas outside the plasma arc column was significantly increased in Fig. 10, then the blocking effect on the GMAW-P arc was generated. As a result, the coupling degree between the plasma and GMAW-P arc was reduced.

The Effect of Nozzle Height on the Plasma-GMAW-P Arc Profile

Figure 11 depicts the plasma-GMAW-P arc profile at different nozzle heights, according to experiment parameter Set #5 in Table 1. When the GMAW-P current was in the pulse base phase, the hybrid arc profile was changed as follows: when the nozzle height was 5 and 6 mm, the plasma arc was perpendicular to the welding workpiece. However, when the nozzle height increased to 7 and 8 mm, the plasma arc was inclined to the side of the GMAW-P arc. There were two reasons for this: one was the action of Lorentz force in the external magnetic field, and the other was the increase of arc length decreased the stiffness of the plasma arc. Therefore, the deviation degree of the plasma arc increased with the increase of nozzle height. Besides, the plasma and

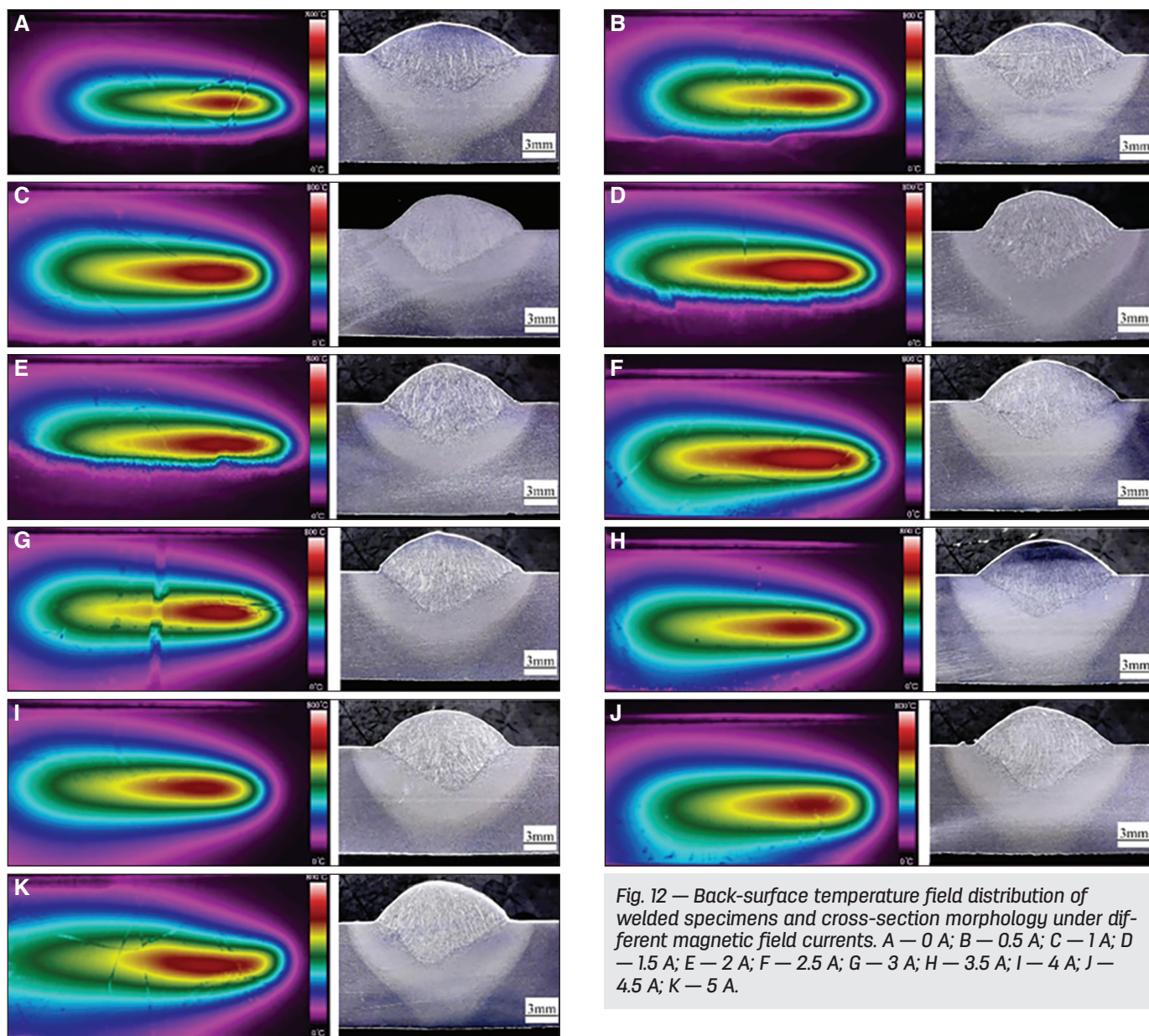


Fig. 12 — Back-surface temperature field distribution of welded specimens and cross-section morphology under different magnetic field currents. A — 0 A; B — 0.5 A; C — 1 A; D — 1.5 A; E — 2 A; F — 2.5 A; G — 3 A; H — 3.5 A; I — 4 A; J — 4.5 A; K — 5 A.

GMAW-P arc were coupled when the GMAW-P current was in the pulse peak phase. The coupling degree between the plasma and GMAW-P arc was the largest when the nozzle height was 6 mm. The coupling position of the two arcs increased with the increase of nozzle height, which was attributed to the increase of the plasma arc column and the diffusion angle as a result of raising the nozzle height. Part of the plasma arc was located at the bottom of the GMAW-P arc in Fig. 7, which produced an upward thrust on the GMAW-P arc, causing the increase of the coupling position.

Analysis of Temperature Field Based on Infrared Thermal Imaging Technology

Figure 12 illustrates the back-surface temperature and cross-section morphology of surfacing specimens, both taken at the same time, under different magnetic field currents. Be-

cause the welding workpiece had a certain distance from the infrared thermal imaging, the back-surface temperature of all measured workpieces was between 0° and 800°C.

According to the change of the temperature field, the maximum and minimum temperatures were extracted. The correlative curves of the joint penetration at the same time as the maximum temperature of the back surface, as well as the average temperature of the back surface at different magnetic field currents are illustrated in Fig. 13A and B, respectively. The maximum temperature varied mainly from 580° to 700°C. When the magnetic field current was 1.5 A, the maximum temperature reached 691°C, increased by 6.7% compared to the maximum temperature without the magnetic field. Besides, the joint penetration was obviously improved. The curve between the maximum temperature of the back-surface sample and joint penetration at the same magnetic field current had no obvious change. Figure 13B sketches the relevant curve of joint penetration and the av-

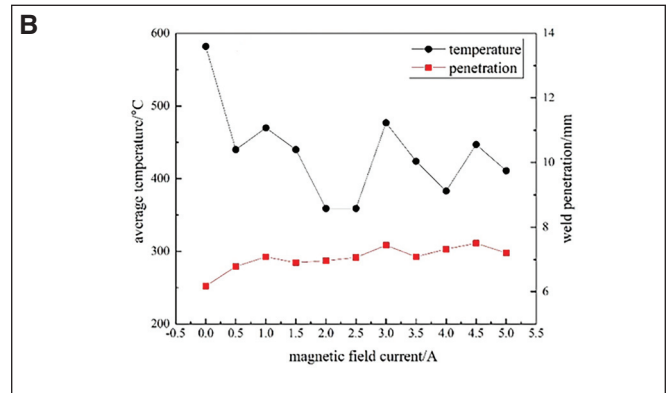
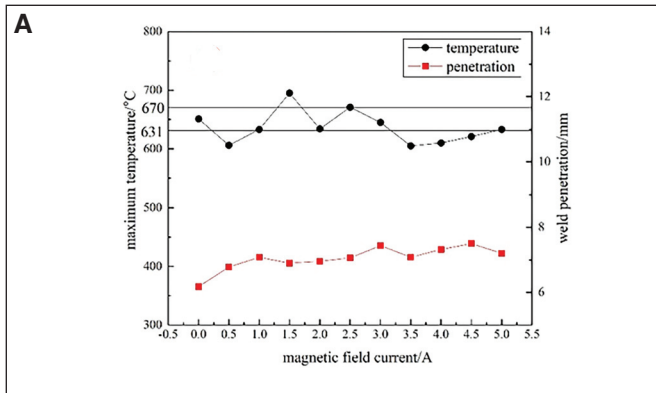


Fig. 13 — The correlative curves of joint penetration and the back-surface temperature at different magnetic field currents. A — The correlative curve of the joint penetration and the maximum temperature; B — the correlative curve of the penetration and the average temperature.

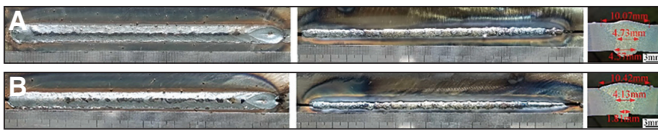


Fig. 14 — Macro morphology and cross sections of welded joints at different magnetic field currents. A — 0 A; B — 2 A.

erage temperature of the back surface at the different magnetic field currents, which was considered as approximately the inverse proportion between the average temperature and joint penetration. It is possible the reason was that the hybrid arc shrunk and coupled under the effect of the magnetic field, causing the more concentrated arc heat source. Therefore, the heat going into the incoming workpiece increased, urging the increased joint penetration and the decreased average temperature.

To verify the advantage of the external magnetic field further, a butt joint was welded with the magnetic field currents of 0 and 2 A. The other detailed welding parameters were fixed

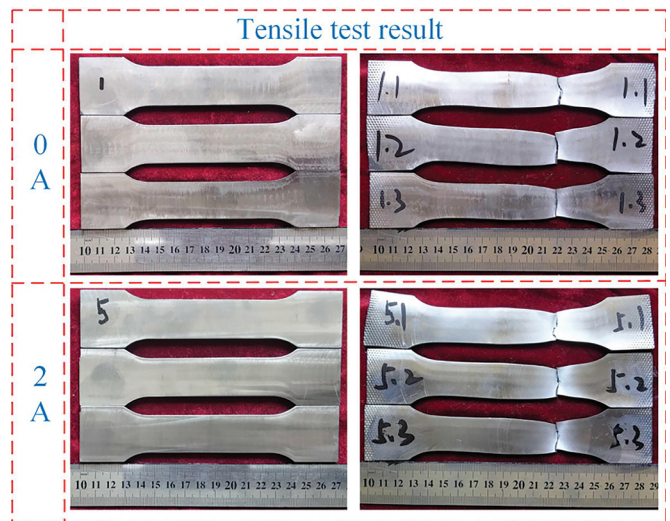


Fig. 15 — Schematic of broken specimens after tensile test at different magnetic fields.

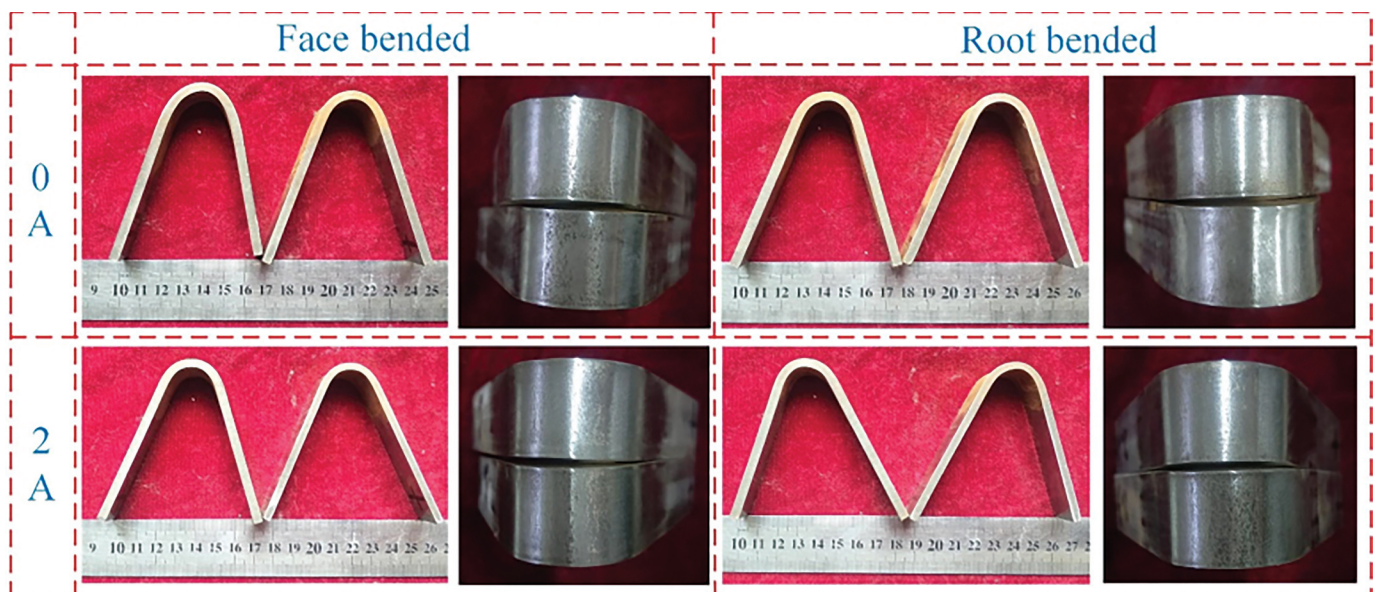


Fig. 16 — Bended butt joint specimens at different magnetic field currents.

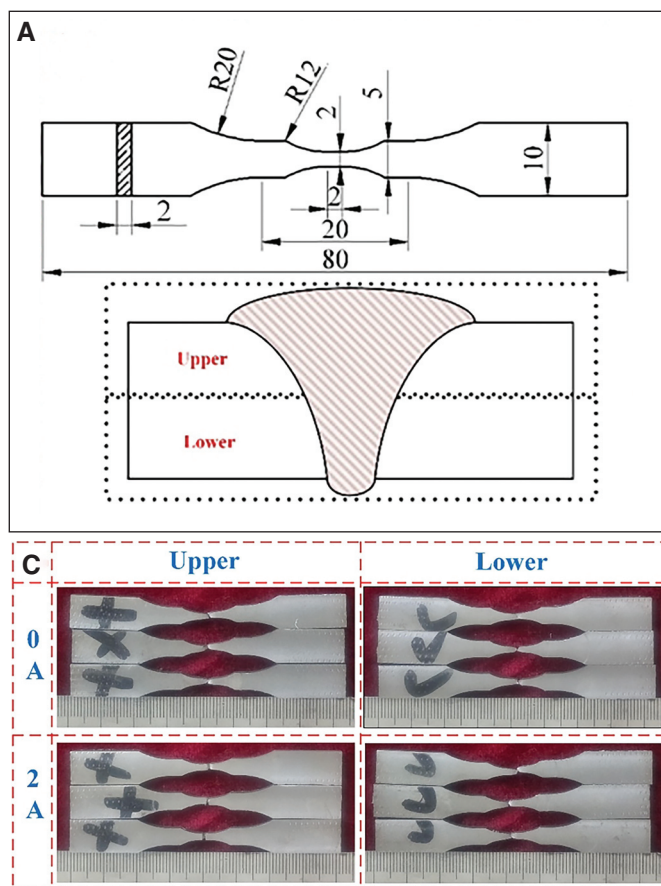


Fig. 17 — The tensile test results of the fusion zone. A — Schematic diagram of tensile samples and the sampling locations; B — the tensile strength at different welding currents; C — the macroscopic picture of fractured tensile samples.

on experimental parameter Set #1 in Table 1. Weld formation, microstructure, and mechanical properties tests of butt joints at the two currents were compared.

Variation in Weld Appearance

Figure 14 depicts the surface appearance and cross sections of welded joints at different magnetic field currents. Compared with the front side and back side of the weld joints, it was found that smooth and uniform surfaces were acquired in two ways. The clear fish scale appeared obviously in the weld surface without the magnetic field. Meanwhile, the weld width of the upper part of the welded joints was increased from 10.07 to 10.42 mm with the magnetic field current of 2 A, increasing the ratio of depth to width. However, due to the effect of the coupling arc, the weld width of the middle and the lower part of the welded joints decreased from 4.73/4.57 to 4.13 mm/1.81 mm, respectively, which increased the ratio of depth to width of the welded joints.

Variation in Mechanical Properties

Tensile and Bending Tests

Figure 15 shows the tensile test results at different magnetic field currents. It was found that all the broken speci-

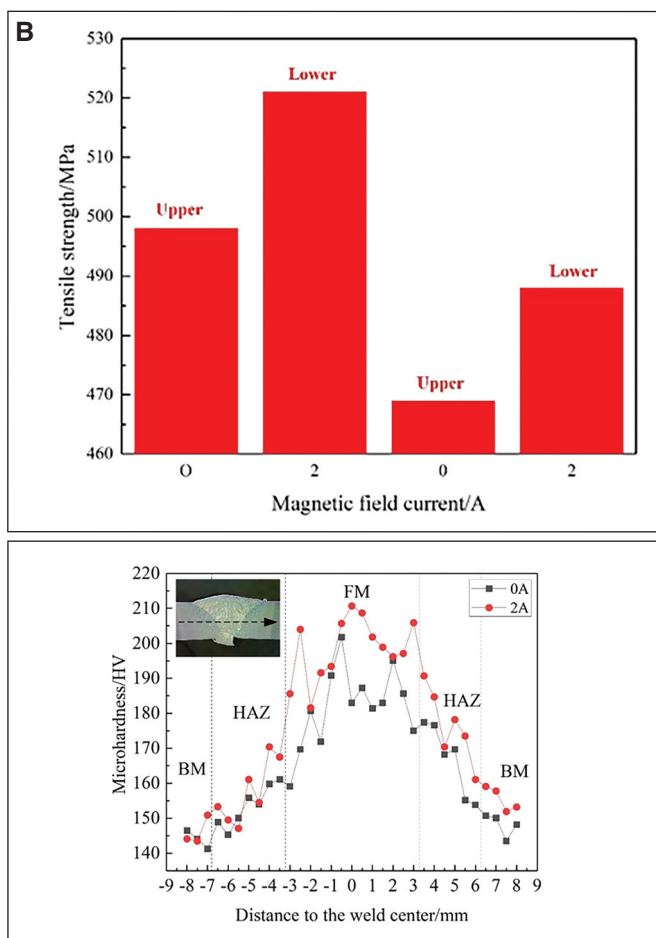


Fig. 18 — Microhardness profile on cross sections of weld joints at different magnetic field currents.

mens were fractured at the base metal in two ways. Figure 16 illustrates the macro morphology of the welding joints at different magnetic fields after the bending test. The bending degrees of two joints were approximately similar.

Tensile Test on Fusion Zone of Joints

Compared to the tensile and bending tests, the results of all the tensile and bending specimens at different magnetic field currents were similar. Therefore, to verify the advantages of the magnetic field, some novel test specimens were obtained in Fig. 17A, which could determine the strength of the fusion zone. The tensile test results of the fusion zone are sketched in Fig. 17B and C. The result showed that when the magnetic field current was 2 A, tensile strength on the upper and lower part of the tensile samples were 521 and 488 MPa, respectively, which were 4.6% and 3.2% higher than those without magnetic field.

Hardness Profile

The microhardness of welded joints at different magnetic field currents is depicted in Fig. 18. As shown in Fig. 18, the black arrow shows the direction and location of hardness measurements. By comparison, the microhardness of weld-

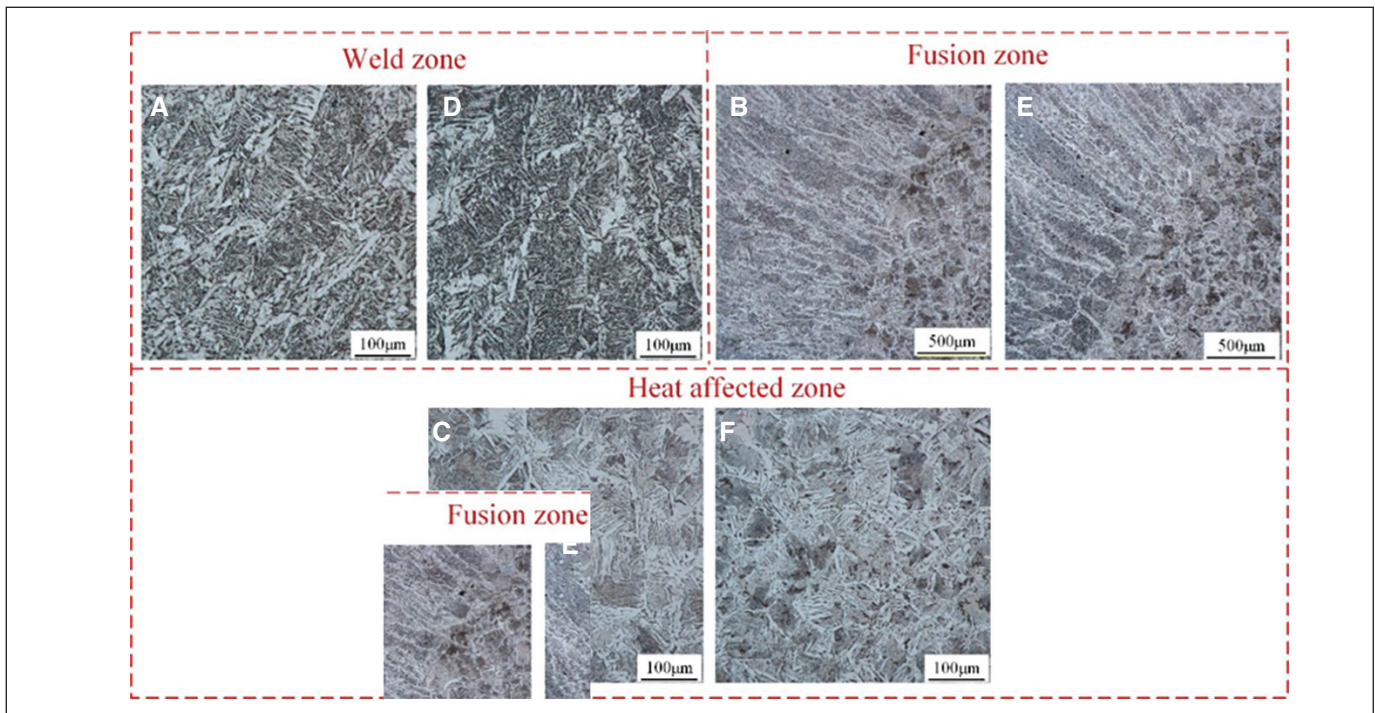


Fig. 19 — Optical microstructures of welded joints at different magnetic field currents. A–C — 0 A; D–F — 2 A.

ed joints improved with the application of the external magnetic field.

Microstructure

Optical microstructures and compositions directly determined the performance of welded joints (Ref. 27). Figure 19 depicts the optical microstructure of welded joints at different magnetic field currents, including the weld zone, fusion zone, and heat-affected zone (HAZ). As seen in Fig. 19, compared to the weld zone at different magnetic fields, the acicular ferrite slightly increased with the increase of magnetic field intensity. The size of the epitaxial growth increased, and the grain size in the HAZ decreased when the magnetic field current reached 2 A, which was possible due to the arc coupling stirring the weld pool.

Conclusion

The conclusions were as follows:

1. There was an obvious distinction in the plasma-GMAW-P arc profile at different welding parameters. It was found that the plasma and GMAW-P arcs were coupled by the Lorentz force, and the coupling degree of the two arcs increased with the strengthening of the magnetic field current. When the magnetic field current was greater than 1 A, the arc profile was changed slightly with the increase of the magnetic field intensity. Besides, fixed on the magnetic field current of 1 A, the coupling degree first increased and then decreased with the increase of the plasma current, GMAW-P current, plasma gas flow rate, and nozzle height, respectively.

2. The correlative curves between the back-surface temperature and joint penetration illustrated that the maximum temperature had no obvious effect on joint penetration.

However, the average temperature had an inverse effect on joint penetration at different magnetic field currents. A possible reason was that the heat of the coupled arc was more concentrated under the action of Lorentz force. Therefore, the heat transferred into the workpiece was increased, causing the increase of the penetration and the decrease of the temperature on the back of the surfacing specimen.

3. Compared with the average plasma-GMAW-P, the ratio of depth to width of welded joints increased with the increase of magnetic field current. Under the action of the external magnetic field current, all tensile specimens were fractured at the base metal and the bending degree of two joints was similar. The weld fusion zone joint tensile test result showed that when the magnetic field current was 2 A, tensile strength on the part and the lower part of the tensile samples were 521 and 488 MPa, respectively, which were 4.6% and 3.2% higher than those without magnetic field. The hardness test showed that the hardness of the weld zone was higher than that without the magnetic field. The reason was that more acicular ferrites in the weld zone were generated under the magnetic field.

Acknowledgment

The work was financially supported by major scientific and technological innovation projects in Shandong Province (2019JZZY010366) and Young Taishan Scholars Program of Shandong Province (tsqn20161062).

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Silicate Island Formation in Gas Metal Arc Welding

An electromagnetic levitation system was used to study the growth kinetics of the silicate islands

BY R. DERRIEN, E. M. SULLIVAN, S. LIU, E. MOINE, AND F. BRIAND

ABSTRACT

Because formation of silicate islands during gas metal arc welding is undesirable due to decreased productivity and decreased quality of welds, it is important to understand the mechanism of the formation of these silicate islands to mitigate their presence in the weld. The effects of welding parameters on the silicate formation rate were studied. Results showed that the applied voltage and oxidizing potential of the shielding gas were the parameters that most strongly influenced the amount of silicates formed on the surface of the weld bead. High-speed video was used to observe the formation of silicate islands during the welding process, which showed that the silicates were present at each stage of the welding process, including the initial melting of the wire electrode, and grew by coalescence. A flow pattern of the silicate islands was also proposed based on video analysis. An electromagnetic levitation system was used to study the growth kinetics of the silicate islands. Silicate coverage rate was found to increase with increasing oxidizing time, increasing oxidizing potential of the atmosphere, and increasing content of alloying elements except for Ti.

KEYWORDS

- Gas Metal Arc Welding • Silicates • Flux-Cored Wires
- Oxidation Kinetics

cored wires, which consist of a metal alloy sheath containing a powdered mixture of alloying elements, metals, and minerals to impart certain properties to the weld. Welding with electrodes of certain compositions can lead to the formation of silicate islands (Refs. 1–7) on the surface of the weld bead, which can result in inclusions within the weld bead during multipass welding (if thorough cleaning is not performed) and the formation of pores, both of which can impair the mechanical performance of the welded joint. Silicate islands also cause arc destabilization during welding due to their low electrical conductivity. The number of silicates formed, the degree of silicate adhesion to the weld bead, and the position of the silicate islands on the weld bead all depend on the welding process parameters (Refs. 8–13). The removal of these silicate particles from the bead surface, whether in single pass or multipass welding, becomes imperative. The added processing step also adds cost to the manufacturing process.

To mitigate the formation of silicates on the weld bead surface, an understanding of the underlying mechanisms of their formation is required. Particularly, the chemical reactions that occur during the welding process will directly govern the formation of silicate islands. The flow of these reaction products in the molten weld pool will determine the spatial distribution of the silicate islands on the surface or the interior of the solidified weld.

Chemical Reactions Occurring in GMAW

The composition of a weld is directly influenced by the composition of the molten base metal and the composition of the metal contributed by the melting of the electrode. During the GMAW process, chemical reactions occur during the growth of the metal droplet at the electrode tip, during the transfer of the metal droplet to the weld pool, and within the weld pool itself. The first two steps described above occur in the welding arc. To categorize the chemical reactions, the weld system can be separated into the following four regions of interest: 1) The molten electrode tip; 2) the detached metal droplet; 3) the hot weld pool directly under the arc; and 4) the cold, solidifying weld pool. These regions are illustrated schematically in Fig. 1.

Introduction

Gas metal arc welding (GMAW) is an automatic or semi-automatic welding process involving the establishment and sustainment of a gas-shielded electric arc between a continuously fed, consumable wire electrode and the metallic components to be joined. Given the relative ease and speed of the GMAW process, this type of welding has found widespread use in the welding industry. The shielding gas and the welding wire electrode are the two primary components of the GMAW process that can be altered to influence the properties of the weld. Various types of consumable wire electrodes are used in GMAW, including solid alloy wires and

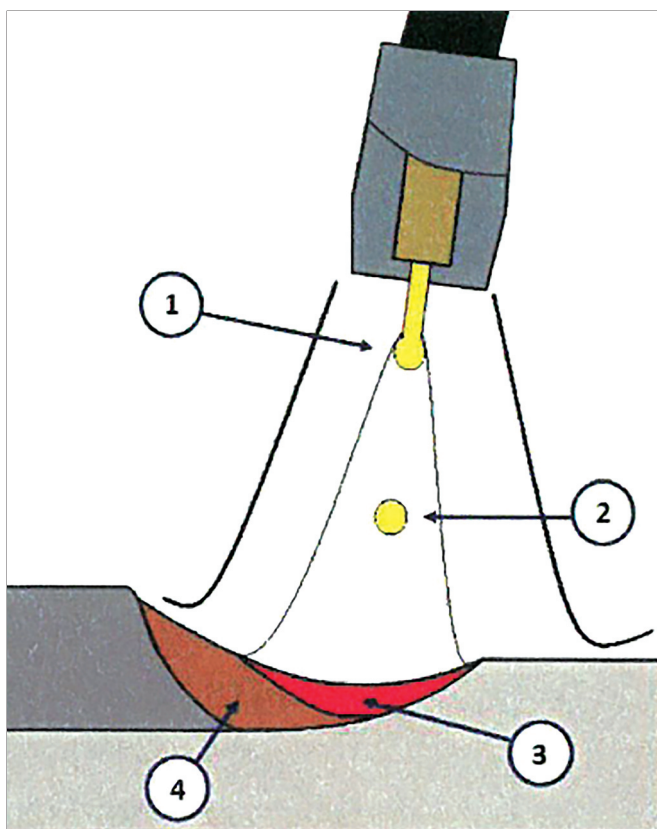


Fig. 1 — Illustration showing the four distinct regions of a gas metal arc weld: 1) The molten electrode tip; 2) the detached metal droplet; 3) the hot weld pool directly under the arc; 4) the cold, solidifying weld pool.

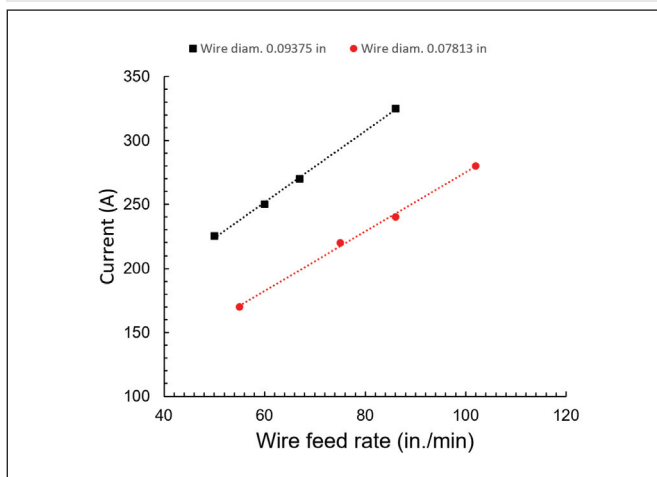


Fig. 3 — Welding current (A) vs. wire feed rate (in./min) for steel powder-cored wires used in GMAW under similar conditions to those in this study.

The molten electrode tip has the highest temperatures of the weld system due to the high current density. As such, there is a greater driving force for the occurrence of thermochemical and electrochemical reactions at the electrode tip; consequently, the reactions at the electrode tip are expected to have the largest influence on the weld metal composition. Once a molten droplet is detached from

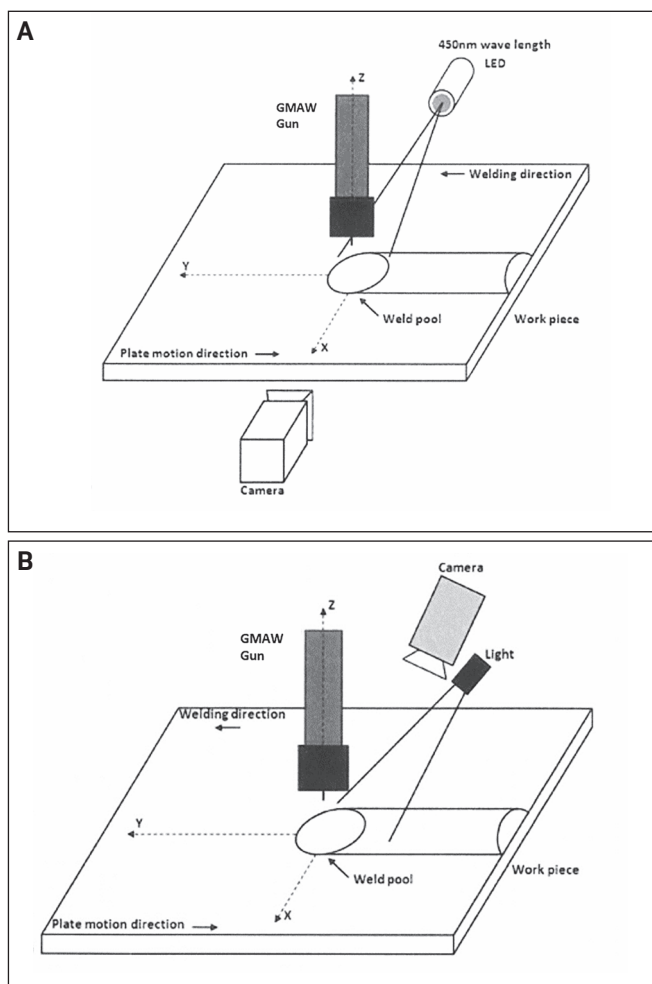


Fig. 2 — Schematic setup of the high-speed video recording system: A — Setup includes monochromatic LED lighting to record the arc behavior and weld pool from the side; B — setup captures the weld pool flow from above.

the electrode tip, it becomes electrically neutral. Only thermochemical reactions continue, and the extent of the reactions will depend exclusively on the chemical composition of the droplet, the chemical potentials of the different species found in the arc, the time of flight of the droplet from the electrode tip to the molten weld pool, and the temperature of the droplet. Grong et al. (Ref. 10) established two distinct regions of the weld pool, hot and cold, according to the relative temperatures of these regions. In the weld pool region immediately under the electrode, the temperature is expected to be high, and thus will constitute the hot region of the weld. The cold region will be located in the trailing edge of the weld pool. In the hot portion of the weld pool, both thermochemical and electrochemical reactions can occur, and oxidation and reduction may take place simultaneously.

Due to the strong turbulence in the molten weld pool, temperature-induced density differences in the molten metal, and density differences between the molten metal and reactions products, the resulting reaction products (e.g., oxides, nitrides, or sulfides) are separated from the molten metal. The particles will flow in the molten pool

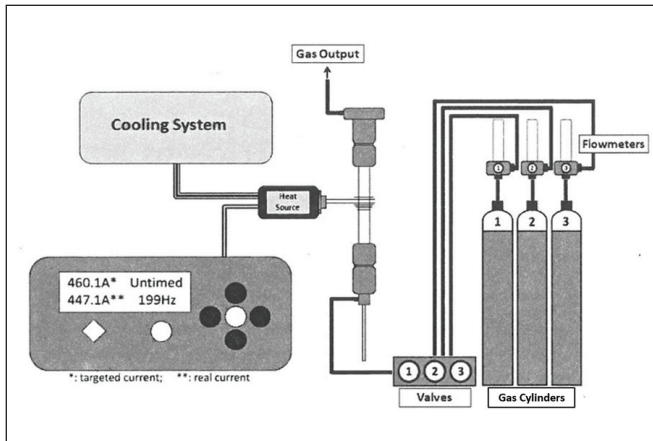
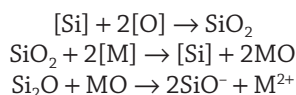


Fig. 4 — Schematic setup of the EML system. The power source used was an EASYHeat 3542 HV AT capable of 4.2 kW.

following the natural convection of the weld pool, from the hot to the cold region. Additionally, in the cold portion of the weld pool, further reactions are expected to continue since alloying elements are expected to form oxides from the dissolved oxygen in the metal due to decreasing solubility of both species. Thus, oxides formed in this region tend to remain in the weld bead as a result of the lower turbulence here. In GMAW, the direct current electrode positive (DCEP), or “reverse polarity,” is commonly used. In this situation, the negatively charged workpiece emits electrons, which enter the electrode, imparting about ⅔ of the welding process heat to the electrode. The melting of the electrode may also cause metal ions to be emitted from the electrode, which then travel to the workpiece (Ref. 14). Metal ions with a greater resistivity will have more interaction with the electrons in the arc, which leads to higher resistivity metal ions to concentrate at the positively charged electrode while the lower resistivity metal ions tend to migrate towards the negatively charged workpiece. This phenomenon governs the reactions that then occur at the electrode and workpiece.

The reaction between silicon, which is a main ingredient of the silicate islands in GMA welds, and oxygen in the cold zone of the weld pool can be described by the following three reactions below (Ref. 15).



In these equations, square brackets represent elemental concentrations dissolved in the molten iron, charged formulae represent ionic species in the form of slag, and all other neutral formulae represent chemical compounds in different stages of reaction. The reactions involving silicon can be paired with reactions of other alloying elements (M) to identify the silicate-forming reactions. It is likely other reactions are occurring in the region between the electrode tip and the molten weld pool with the formation of a number of silicates (e.g., $\text{MnO} \cdot \text{SiO}_2$, $\text{MgO} \cdot \text{SiO}_2$, $\text{TiO} \cdot \text{SiO}_2$ ([Ref. 1])). In GMAW of steel, the silicates that form are commonly Fe- and Mn-containing (Refs. 4, 5, 16).

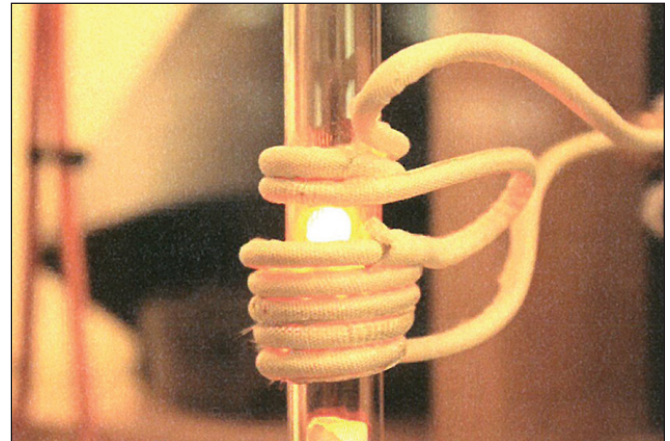


Fig. 5 — The induction coil and levitation chamber used in the electromagnetic levitation experiments.

Experimental Methods

Multiple experimental setups were used to study and characterize the formation of silicate islands during GMAW. A high-speed video system was used to observe the behavior of the silicate islands at different stages of the welding process. Several iterations of welding experiments and weld analyses were also performed to determine the effect of welding parameters on the formation of silicate islands. An electromagnetic levitation (EML) system was used to examine the effects of various shielding gas compositions on the oxidation of molten metal droplets.

Calculation of Silicate Formation Rate

The silicate formation rate (SFR) is an indicator of the amount of silicate produced during the welding process, yielding the mass of silicate formed per 100 g of welding consumable used. Therefore, the silicate formation rate can be used to compare the propensity of different welding consumables in exhibiting silicate islands on the weld surface. Immediately after welding, an aluminum sheet was placed over the weld to prevent silicate islands from being ejected away from the weld bead surface following solidification and during cooling of the weld metal. Even if ejected, the particles would tend to remain on the weld surface under the aluminum foil tent. After cooling, the silicate islands were removed from the weld bead and weighed to within a tenth of a milligram. The SFR was then calculated by using Eq. 1,

$$\text{SFR}(\%) = 100\% \cdot W_s / T_s \cdot \text{WFR} \cdot W_w \quad (1)$$

where W_s is the weight of the silicate recovered from the weld, T_s is the elapsed welding time starting from arc initiation, WFR is the wire feed rate, and W_w is the linear density of the welding wire (g/m), which is measured by weighing small wire segments of a known length. It should be noted that the WFR also dictates the welding current. The SFR values obtained for different weld systems (similar consumable but different welding parameters or filler metals) are then compared to determine the relative propensity of silicate island formation of each system.

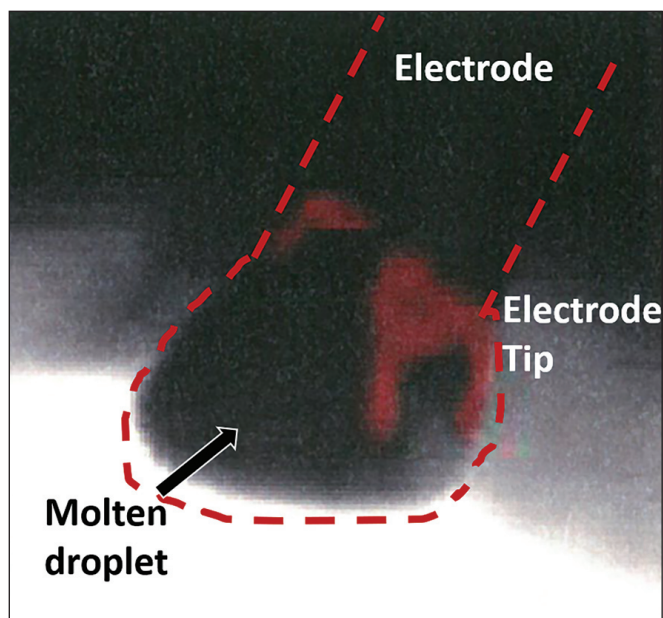


Fig. 6 — Still frame from the high-speed video recording of the electrode tip during GMAW. Silicate particles can be seen (artificially colored red) on the surface of the melted electrode tip.

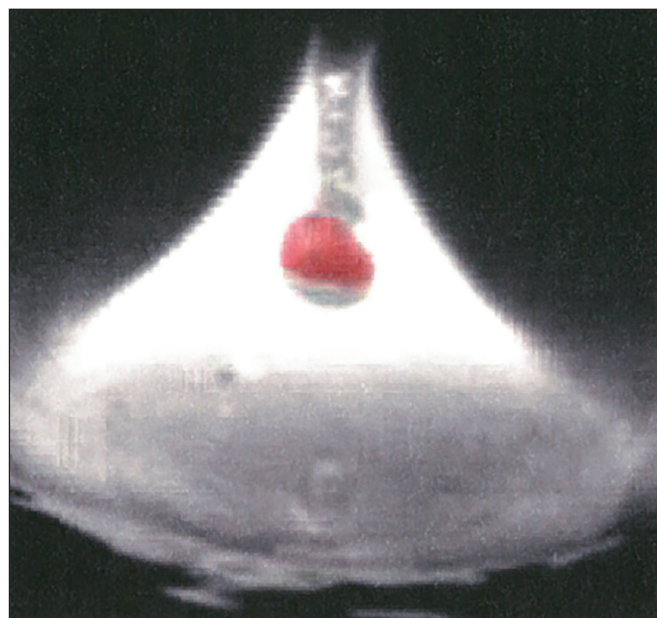


Fig. 7 — Still frame from a high-speed video recording showing the presence of silicates (artificially colored red) on the surface of the droplet detached from the electrode during GMAW.

High-Speed Video Camera System

To closely observe the behavior and formation of the silicate islands during GMAW, an AOS X-PRI high-speed video camera was used to record the metal droplet transfer and weld pool fluid flow during welding — Fig. 2. In Fig. 2A, the GMAW gun and the camera were both kept stationary while the weld plate was translated by a Bug-O GO-FER III carriage unit. To reduce the glare from the arc, a 450-nm-wavelength LED was used in conjunction with a camera filter that only allowed transmission of 450-nm light. The setup shown in Fig. 2B was used to film the movement of the silicate islands on the surface of the weld pool. In this setup, a high-intensity white light was used to illuminate the weld pool. The camera was positioned such that the gun nozzle obscured the arc to improve the quality of the images.

Materials

For the examination of the SFR for different welding parameters, several different welding wire compositions and shielding gases were used. The base metal in each welding experiment was ASTM A709 Grade 36 steel of 1 cm (0.4 in.) thickness.

Table 1 lists the different chemical compositions of the shielding gases used in this study. The different O_2 and CO_2

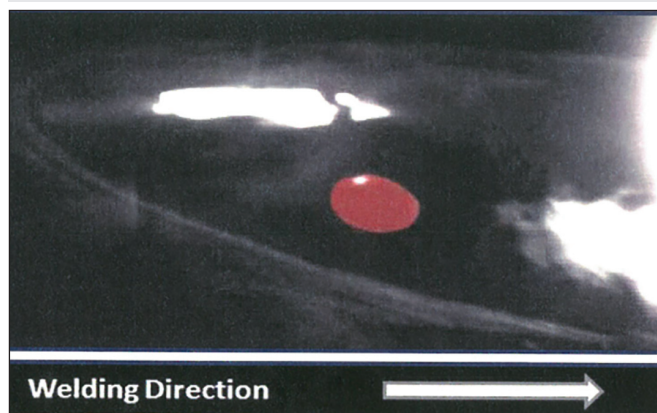


Fig. 8 — Still frame from a high-speed video recording showing silicates (artificially colored red) floating on the surface of the "cold" weld pool during GMAW.

contents provided different oxidation potentials to the shielding gases, which were expected to result in different amounts of silicate formation. Each of the wires contained a metal powder blend as the core ingredient. Tables 2 and 3 give the chemical compositions of the various welding wires used. The experimental cored wires were prepared on a wire mill at the Colorado School of Mines, Golden, Colo., specifically to examine the effects of silicon, manganese, alu-

Table 1 — Chemical Compositions of the Shielding Gases Used in the Silicate Formation Study

Gas Composition			
100% CO_2	8% O_2 -92% Ar	100% He	100% Ar
25% CO_2 -75% Ar	5% O_2 -95% Ar	10% He-90% Ar	10% CO_2 -5% O_2 -85% Ar
10% CO_2 -90% Ar	2% O_2 -98% Ar	5% He-95% Ar	2% O_2 -8% He-90% Ar

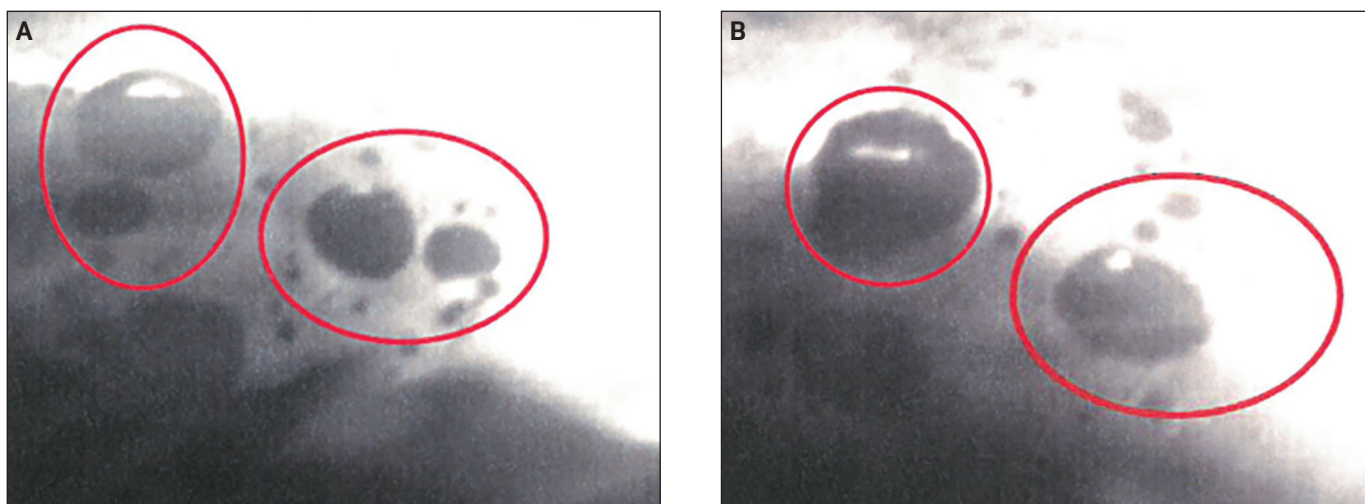


Fig. 9 — Still frames from a high-speed video recording of GMAW showing four silicate particles A) before and B) after coalescence into two silicate islands.

minum, and titanium on SFR. Each wire had a diameter of 1.14 mm (0.045 in.) except for wire E, which had a diameter of 1.4 mm (0.055 in.). The compositions of the wires made at Colorado School of Mines are given in Table 2 and were calculated via mass balance using the known composition of the powder core and the wire sheath. The compositions of additional cored wires prepared by the Technical Centre for Welding Applications of Air Liquide in Paris, France, are given in Table 3. The diameters of these wires are given in Table 4.

Figure 3 shows the welding current vs. WFR for metal powder-cored wires in GMAW under similar conditions to those used in this work. The welding parameters used for the determination of the effect of WFR and polarity on SFR are given in Tables 5 and 6 and were extracted from the data given in Fig. 3.

Electromagnetic Levitation System

The kinetics of silicate formation under different shielding gases were examined using an EML system. Such a system allows the formation of the silicate islands to be observed in the absence of a substrate, which could potentially react with the molten metal droplet. The system consists of a cooling unit, a power supply, a gas flow system, and a levitation chamber — Fig. 4. The cooling unit flows water through the copper induction coil to avoid melting of the coil while the power supply provides the current to induce the electromagnetic field for levitation. The gas system consists of three separate gas flows for the control of the composition and the flow rate of gas through the levitation chamber. Helium, which has a high thermal conductivity, was used to control the temperature of the droplet sample.

Table 2 — Composition of Welding Wires (in wt-%) Fabricated at Colorado School of Mines

Element	CSM 12 %	CSM 14 %	CSM 15 %	CSM 16 %	CSM 17 %	CSM 18 %	CSM 19 %	CSM 20 %
C	0.020	0.021	0.024	0.019	0.041	0.010	0.020	0.013
Si	0.792	0.852	0.913	0.174	0.219	0.137	0.227	0.215
Mn	0.710	1.385	1.464	0.616	1.380	0.552	1.408	1.375
P	0.009	0.010	0.010	0.010	0.009	0.009	0.009	0.009
Si	0.014	0.014	0.011	0.010	0.011	0.019	0.018	0.017
Cr	0.028	0.032	0.033	0.027	0.030	0.040	0.044	0.044
Ni	0.020	0.022	0.021	0.020	0.020	0.023	0.024	0.023
Al	0.006	0.006	0.071	0.032	0.004	0.006	0.055	0.046
Co	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003
Cu	0.017	0.019	0.018	0.016	0.017	0.015	0.015	0.015
Nb	0.008	0.008	0.009	0.008	0.008	0.001	0.001	0.001
Ti	0.035	0.005	0.050	0.023	0.023	0.004	0.005	0.005
V	0.010	0.010	0.010	0.010	0.011	0.010	0.011	0.011
Zr	0.001	0.002	0.002	0.001	0.002	0.001	0.003	0.002
B	0.004	0.004	0.004	0.002	0.003	0.002	0.003	0.003

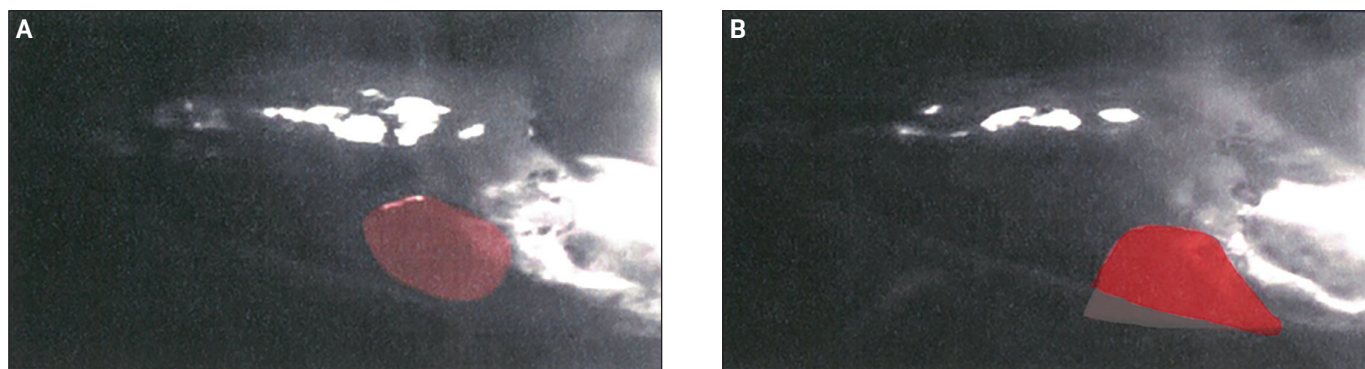


Fig. 10 — Still frames from the high-speed video recording showing a silicate island: A — Before attachment (floating on the surface of the weld pool); B — after attachment to the edge of the weld pool.

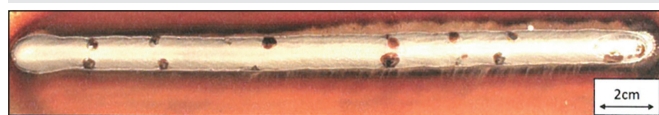


Fig. 11 — Photograph of a weld with silicate islands present on the surface and along the edge of the bead.

Argon was used with O₂ or CO₂ in varying amounts to provide gas atmospheres of various oxidation potentials.

The levitation chamber was a borosilicate glass tube with an outer diameter of 15.87 mm (0.625 in.) and an inner diameter of 12.72 mm (0.501 in.). The induction coil was wrapped around the chamber, as shown in Fig. 5. Shielding gas flowed up from the bottom of the chamber, helping to support the levitating droplet. A Metis MS09 pyrometer with a spot size of 0.35 mm was used to monitor the temperature of the droplet. The average mass of the droplet samples was measured to be 1.5 g. The droplets were obtained by the inert gas arc button melting of segments of the welding wires.

The droplets were maintained in a molten state under different gases for varying lengths of time (0 to 25 s) to examine the kinetics of silicate island formation on the droplets. A

high-speed video camera was used to record the flow behavior of the molten metal and silicates during levitation. After levitation and upon solidification, the surface area of each droplet that was covered by silicates was measured.

Results and Discussion

Silicate Island Flow within the Weld Pool

Figure 6 is a still frame extracted from the high-speed video of the electrode tip exhibiting globular transfer during GMAW. The diameter of the molten tip shown was larger than that of the electrode. A silicate layer (colored red artificially in the photograph) was clearly present in the “neck” of the melted portion of the electrode. The silicate particles tend to concentrate in the neck due to fluid flow on the surface of the droplet and the lower density of the silicate particles. Such motion causes the silicate particles to grow and coalesce. Subsequently, the silicates attach to the solid part of the electrode wire tip, which is at a lower temperature than the molten droplet. The flow behavior observed in these experiments is similar to that predicted by Wang’s modeling work (Ref. 17). The initial for-

Table 3 — Composition of Welding Wires (in wt-%) Supplied by Air Liquide

Element	Wire A %	Wire B %	Wire C %	Wire D %	Wire E %	A36 (base metal) %
C	0.060	0.010	0.060	0.096	0.065	0.190
Si	0.430	0.770	0.830	0.770	0.640	0.230
Mn	0.910	1.290	1.330	1.430	1.520	0.770
P	0.012	0.010	0.008	0.012	0.012	0.015
S	0.008	0.019	0.010	0.010	0.019	0.040
Cr	< 0.01	0.035	< 0.01	0.022	0.024	0.200
Ni	0.010	0.024	0.010	0.015	0.019	0.160
Al	< 0.1	0.002	< 0.01	0.002	0.004	0.000
Co	< 0.01	0.006	< 0.01	0.005	0.005	0.000
Cu	0.210	0.018	0.250	0.087	0.310	0.340
Nb	< 0.01	0.008	< 0.01	0.011	0.007	0.000
Ti	< 0.01	0.005	< 0.01	0.011	0.180	0.000
V	< 0.01	0.007	< 0.01	0.003	0.003	0.005
Zr	0.000	0.001	0.000	0.003	0.001	0.000

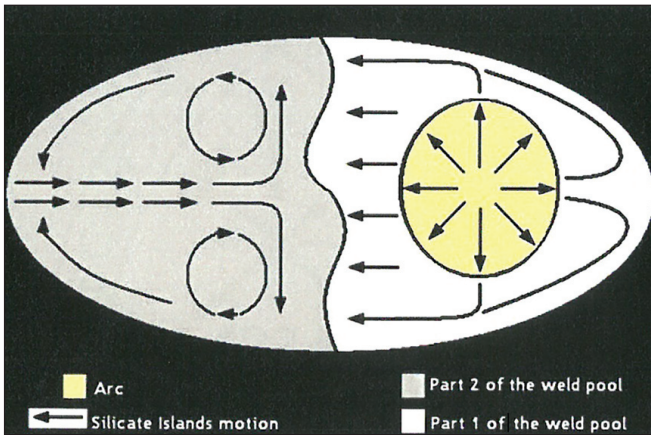


Fig. 12 — Schematic diagram of the observed flow pattern of the silicate islands on the surface of the weld pool. The gray area indicates the presence of an oxide layer.

mation of the silicates in the molten electrode is conceptualized the following way: upon melting, the elements present in the filler wire and the wire core (Mn, Ti, Mg, Ca, etc.) capture oxygen from the surrounding atmosphere, and small groups of silicates form. The convective forces in the molten droplet caused these silicate groups to interact and coalesce into the large islands present on the molten electrode tip seen in the videos. Once the droplet detached, it was seen that the silicates attached to the solid wire separated in two (Fig. 7); one part remained on the electrode tip and the other part partially covered the droplet in transfer. This observation confirms that silicates were already present on the surface of the droplets before they entered the weld pool.

Next, the droplet entered the “hot” part of the weld pool, where the silicate islands could be seen floating outward to the periphery of the arc. The impact of the droplet into the molten

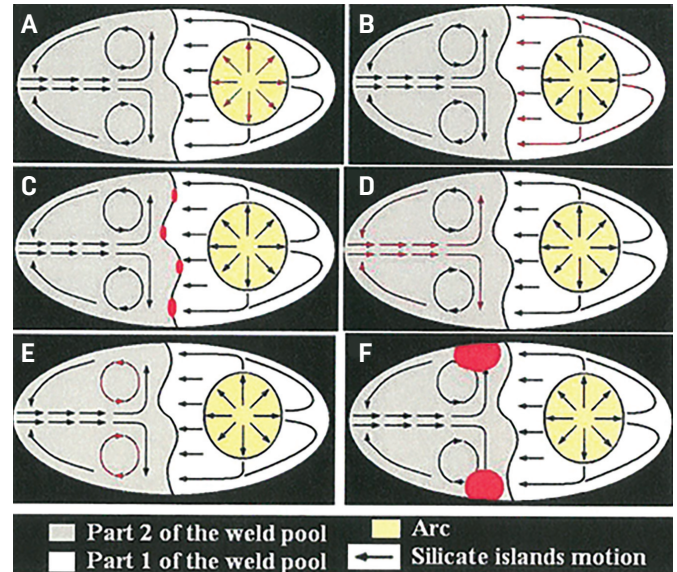


Fig. 13 — Step-by-step schematic of the silicate flow on the surface of the weld pool: A — Silicates radiate outward almost instantaneously from the arc; B — the silicates are pushed to the hot/cold border by liquid flow; C — the silicates stay at the hot/cold border. Molten metal flow moves the silicates to the sides of the weld pool; D — some silicates trail the weld pool along with an oxide layer. In this case, the Marangoni flow will push them to the trailing edge of the weld pool and then circulate them back to the hot/cold border; E — silicates may also move circularly by the side of the weld pool, where silicate coalescence occurs; F — once the silicate island has grown sufficiently, it attaches to the side of the weld pool and solidifies.

pool created a liquid current that pushed the molten metal away from the center of the arc. Such behavior was predicted by the velocity field simulation work of Hu et al. (Ref. 18). Within the molten weld pool, alloying elements such as silicon and manganese are expected to form oxides from dissolved oxygen due to the lower solubility of oxygen in iron with decreasing temperature, which results in a larger amount of oxygen available for reaction. Liquid oxide particles are expected to float to the surface of the weld pool due to the density difference between the liquid oxides and the liquid iron. Oxide movement to the surface of the weld pool is also assisted by slag formation and fluid flow “stirring” in the hot part of the weld pool. The newly formed oxide particles will coalesce with those that arrived from the transferred molten droplets. Once a silicate has entered the cold part of the weld pool, less stir-

Table 4 — List of Wire Diameters and Linear Density of the Experimental Welding Wires Supplied by CTAS Air Liquide

Name of Wire (Diameter, in.)	Linear Density (g/m)
A (0.045)	7.8782
A (0.052)	10.3872
B (0.047)	8.1123
C (0.035)	4.8838
D (0.047)	8.6277
E (0.055)	8.1123

Table 5 — Welding Parameters Used in the Polarity Study (DCEP) (Asterisks indicate values that were calculated from estimations extracted from Fig. 3 for powder-cored wires of similar diameters.)

Wire Diameter (in.)	WFR (in./min)	Current (A)*	Deposition Rate (kg/h)*	Heat/Filler Mass (kJ/g)*
0.045	160	260	7.9	6.9
0.045	198	301	9.9	6.4
0.045	260	368	13.0	5.9
0.052	160	275	8.9	6.5
0.052	198	319	11.1	6.0
0.052	260	390	14.7	5.6

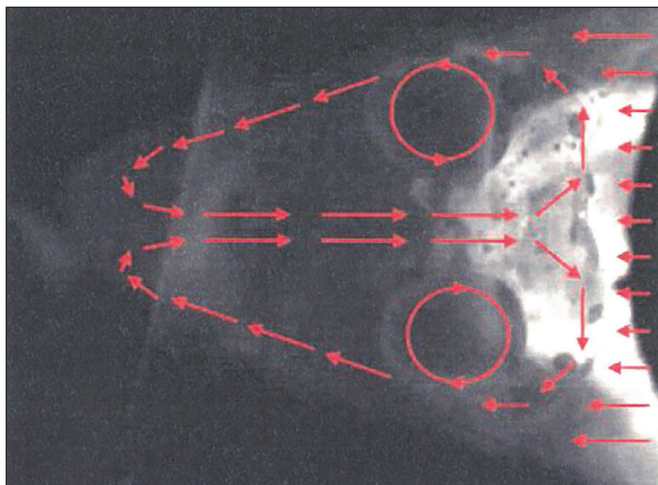


Fig. 14 — Still frame of the cold part of the weld pool. The flow pattern of the silicates has been overlaid in red.

ring is observed, causing the silicates to migrate to the edge or center of the weld pool where they then solidify — Fig. 8.

The high-speed video camera setup also revealed flow behavior of the silicate islands, which were present in every stage of the GMAW process. Silicate particles were observed to circulate and coalesce, eventually consolidating into larger silicate islands — Fig. 9. These larger silicate islands were then observed to attach to the side of the weld pool, where they then began to solidify — Fig. 10. An example of silicates solidified along the edge of the weld bead can be seen in Fig. 11.

Another type of solidification behavior observed involved solidification of silicate particles along the weld pool such that a line of silicates was formed along the weld toe. The silicate islands were also seen to attach to the trailing edge of the weld pool, which led to silicate solidification along the centerline of the weld.

The velocity of the liquid metal flow within the weld pool dictated the motion of silicates on the surface. From exhaustive examination of the high-speed videos of the GMAW weld pool, Fig. 12 was developed to describe the observed behavior of silicate flow on the surface of the weld pool. Part 1 (white) represents the hot part of the weld pool immediately under the welding electrode, while Part 2 (gray) represents the cold part of the weld pool. The hot part of the weld pool was observed to be shiny and free of slag, shielded only by the cover gas. Part 2, conversely, was observed to be covered by a layer of FeO, which was determined by energy dispersive spectroscopy (EDS). Due to the abundance of Fe at the initial stage of melting, FeO formed first. FeO islands then collided in the melt pool with other oxide particles, which were seen in the high-speed video to have a different appearance than the FeO and formed at much smaller amounts than FeO. Once the silicate particles carried by the transferred droplet impacted the weld pool, they were quickly dispersed radially outward from the center of the arc. Liquid flow then pushed the silicates toward the trailing edge of the weld pool (i.e., to the border between the hot and cold part of the weld pool). The silicates only remained in this region for a very short period of time. Subsequently, the Marangoni (surface tension-driven) flow of the molten pool carried the silicate particles to the side of the weld pool, where they then followed two different trajectories. The first path followed the direction predicted by the surface ten-

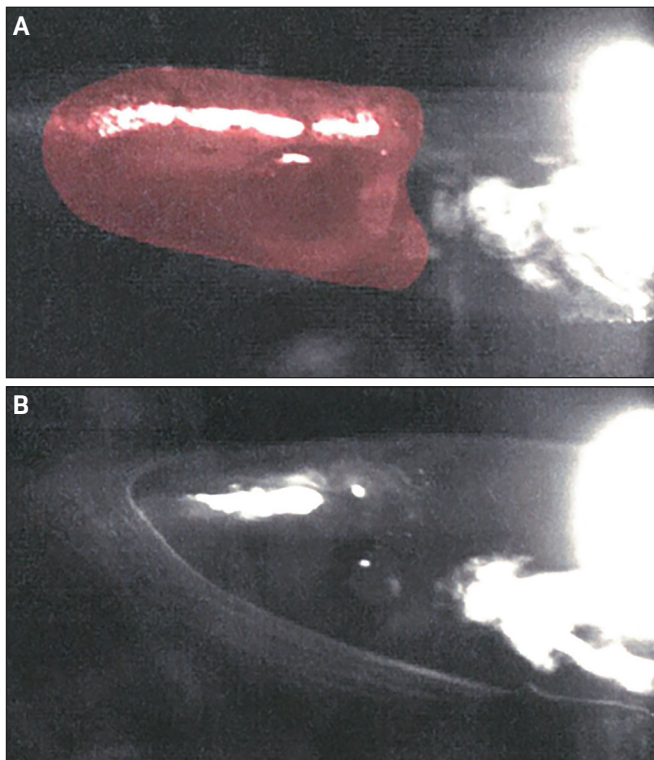


Fig. 15 — Still frames of the cold part of the weld pool showing the following: A — A weld pool with the presence of a thick oxide mass at the trailing edge of the weld pool; B — a weld pool without the thick oxide mass at the trailing edge.

sion gradient (Marangoni flow), according to which the silicates were first brought to the trailing edge of the weld pool and then carried back to the hot/cold border. The other trajectory was an eddy current path that rotated towards the sides of the weld pool. Within this eddy current, the silicates moved circularly and coalesced to form larger silicate islands. Observation shows that once a silicate island grows to a diameter of approximately 5 mm, its flow becomes sluggish, and the silicate moves toward and attaches to the edge of the weld pool, which is colder and where the silicate island solidifies. These two paths have been illustrated in Fig. 13. In addition, Fig. 13 shows the silicates “radiating” outward from the arc location upon transference to the melt pool, after which they are pushed to the border between the hot/cold regions, where Marangoni flow can keep them until solidification completes. In the other case, silicates may also move circularly by the side of the weld pool, where they potentially coalesce and attach to the side of the weld pool. The flow paths in the cold part of the weld pool have been overlaid on a still frame of a GMAW weld pool in Fig. 14. High-speed video analysis assisted in the determination of the following preferred locations of the silicate islands: along the weld edge, the weld toe, and the weld centerline.

Characterization of the Oxide Layer

The formation of a continuous FeO layer on the surface of the solidifying weld pool is expected. The amount of oxide layer present decreased with decreasing oxidation potential of the shielding gas. Under certain experimental parameters, the

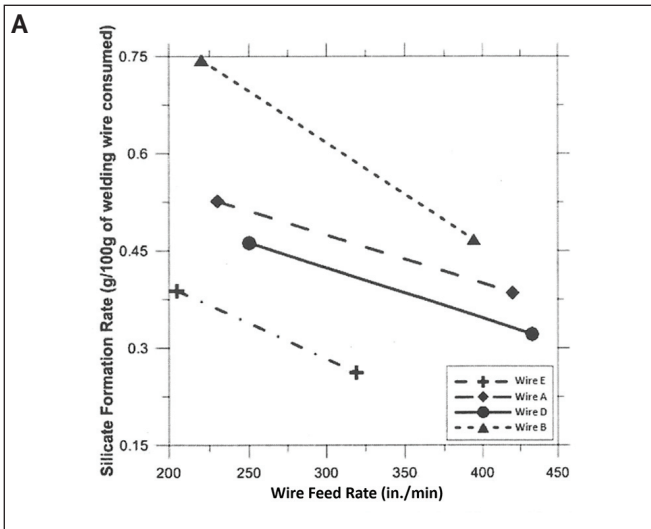


Fig. 16 — A — Effect of wire feed rate on silicate formation rate for four welding wires of different composition with the same wire diameters; B — effect of wire feed rate on the silicate formation rate of welding wires of different diameters for wire A; C — effect of wire diameter on SFR at varying voltages and wire feed rates for wire A. The WFR is given in the legend. #3 indicates a higher voltage than #2, which is a higher voltage than #1.

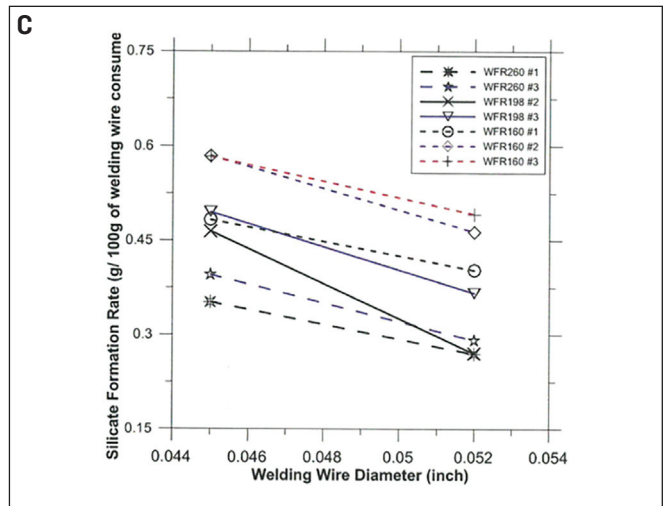
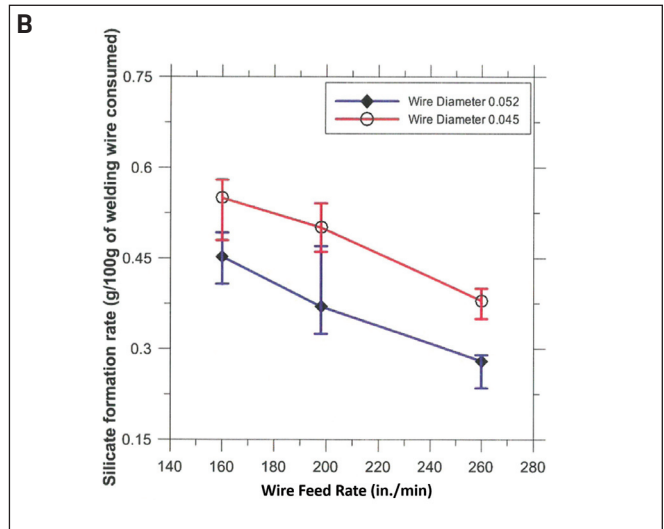
oxide layer appeared thicker on the trailing part of the weld pool. Within the FeO layer, other oxides were expected to form and grow. These dispersed oxides comprised the silicate islands that can be seen by visual examination.

Energy dispersive spectroscopy was performed on the slag layer, which was revealed to be a layer of FeO.

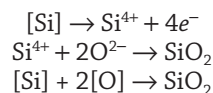
As mentioned previously, the weld pool can be divided into a “hot” and “cold” part, and the trailing edge was often covered by a thin oxide layer. However, in some systems, a third part of the weld was exhibited in the form of a thicker oxide layer, which had very low mobility on the surface of the weld pool, as shown in Fig. 15.

Effect of Wire and Welding Parameters on SFR

The data obtained from the experiments demonstrated a general trend of decreasing SFR with increasing wire feed rate — Fig. 16A. This result was unexpected at first examination given that increasing the wire feed rate would increase the welding current and heat input to the weld, which



were expected to increase the rate of reaction of the following electrochemical and thermochemical reactions:



One hypothesis to explain this observation is that increasing the welding current causes more vaporization of the oxide layer, which decreases the amount of silicates formed on the surface (Ref. 19). An alternative explanation involves

Table 6 — Welding Parameters Used in the Polarity Study (DCEN) (Asterisks indicate values that were calculated from estimations extracted from Fig. 3 for powder-cored wires of similar diameters.)

Wire Diameter (in.)	WFR (in./min)	Current (A)*	Deposition Rate (kg/h)*	Heat/Filler Mass (kJ/g)*
0.045	160	352	7.9	9.3
0.045	198	426	9.9	9.0
0.045	260	548	13.0	8.8
0.052	372	275	8.9	8.7
0.052	198	451	11.1	8.5
0.052	260	581	14.7	8.3

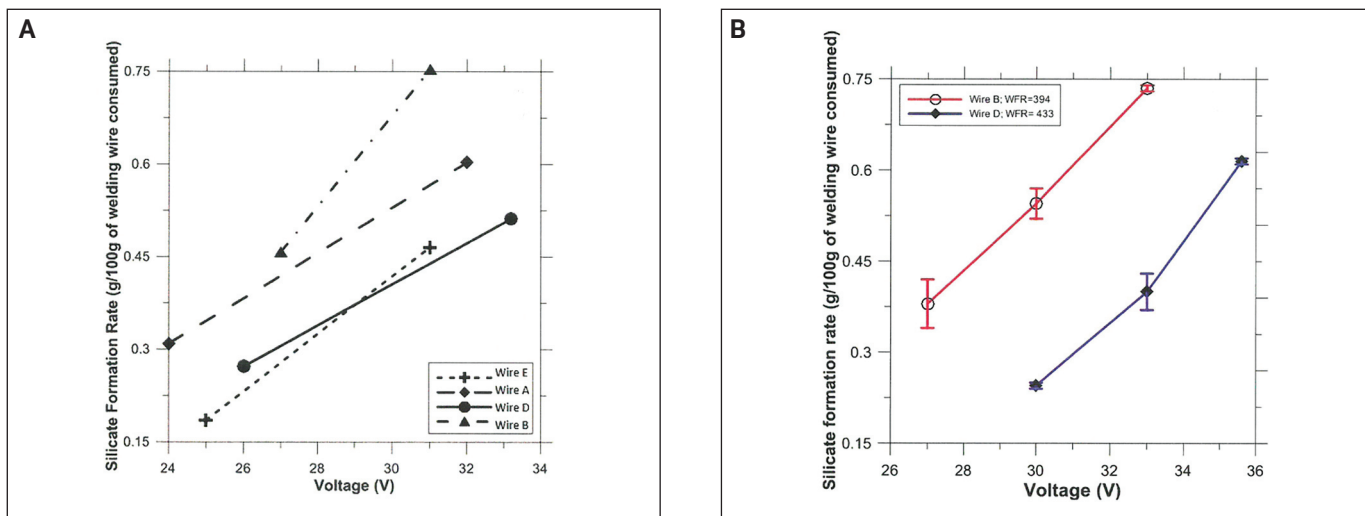


Fig. 17 — A — Effect of voltage on SFR for four welding wires of different composition; B — effect of voltage on SFR for two welding wires of different composition and at two different wire feed rates.

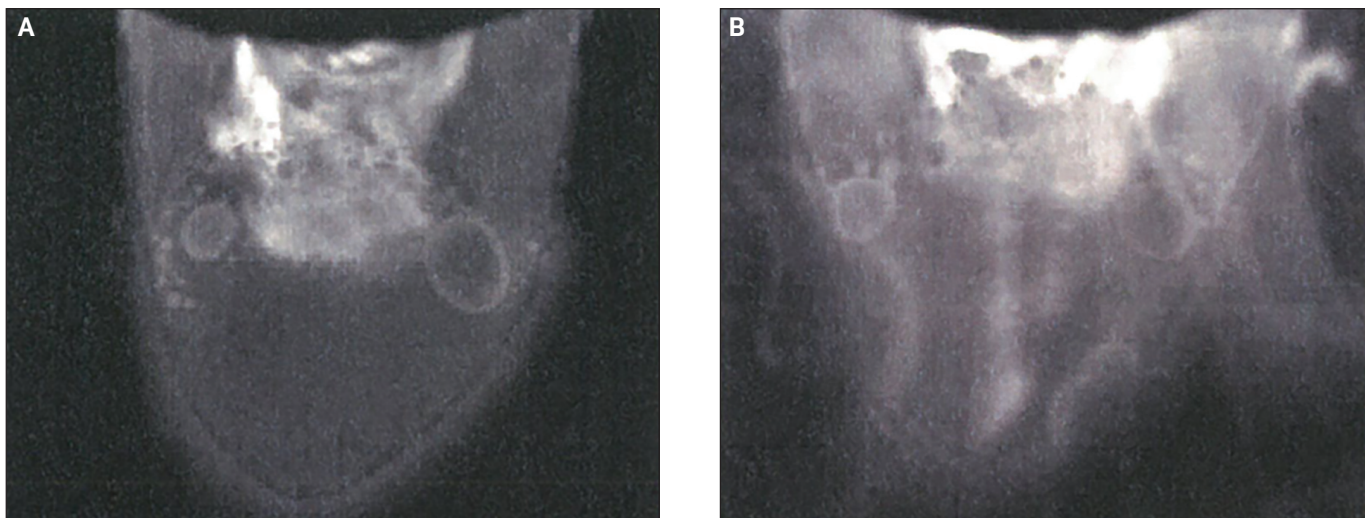


Fig. 18 — Still frames from high-speed recordings of GMAW taken from above the weld pool. These images show the cold part of the weld pool at A) 26 V and B) 36 V. Silicate island population was larger in the higher voltage weld. The presence of the two silicate islands on both sides of the pool is due to the circulatory flow path of the silicates.

the increase in heat input due to increasing wire feed rate, which would cause more base metal dilution. Consequently, less silicon is expected to react with the oxygen diluted in the liquid metal, leading to decreased silicate formation. No attempts were made in this work to determine the amount of increased vaporization and base metal dilution.

Wire B was seen to produce more silicate islands, which can be attributed to the composition of the wire. Firstly, wire B contains a high amount of silicon to form silicon-based oxides (silicates). Additionally, the flux ingredients contained in each wire were already known to contain oxides, silicates, and metal powders. The metal powder particles might also possess a surface oxide layer, which could inhibit the deoxidizing reactions in the weld pool. During tubular electrode manufacturing, air may also be entrapped within the core, further increasing the oxygen content of the wire. All these potential sources of oxygen and the high amount of silicon can react to form a larger number of sili-

cate islands. Wire A contained low silicon, and thus resulted in a low amount of silicate formation. The addition of microalloying elements and high Mn in wire D appears to have lowered the SFR although the wire silicon content was high. It is believed that the microalloying elements reduced the oxygen available for reaction with silicon to form silicate islands. Wire D contained the largest fraction of microalloying elements. Wire E also had large microalloying content with high Mn but the lowest Si content, therefore having the lowest SFR.

Using a larger wire diameter was found to decrease silicate formation rate as seen in Fig. 16B and C. For the same wire feed rate, a greater current can be carried by larger wire diameters (Ref. 20), which would increase the temperature in the arc and cause more vaporization of oxides (similar to increasing the wire feed rate). Additionally, a larger wire diameter possesses a lower current density, which reduces the extent of the electrochemical reactions occurring at the wire

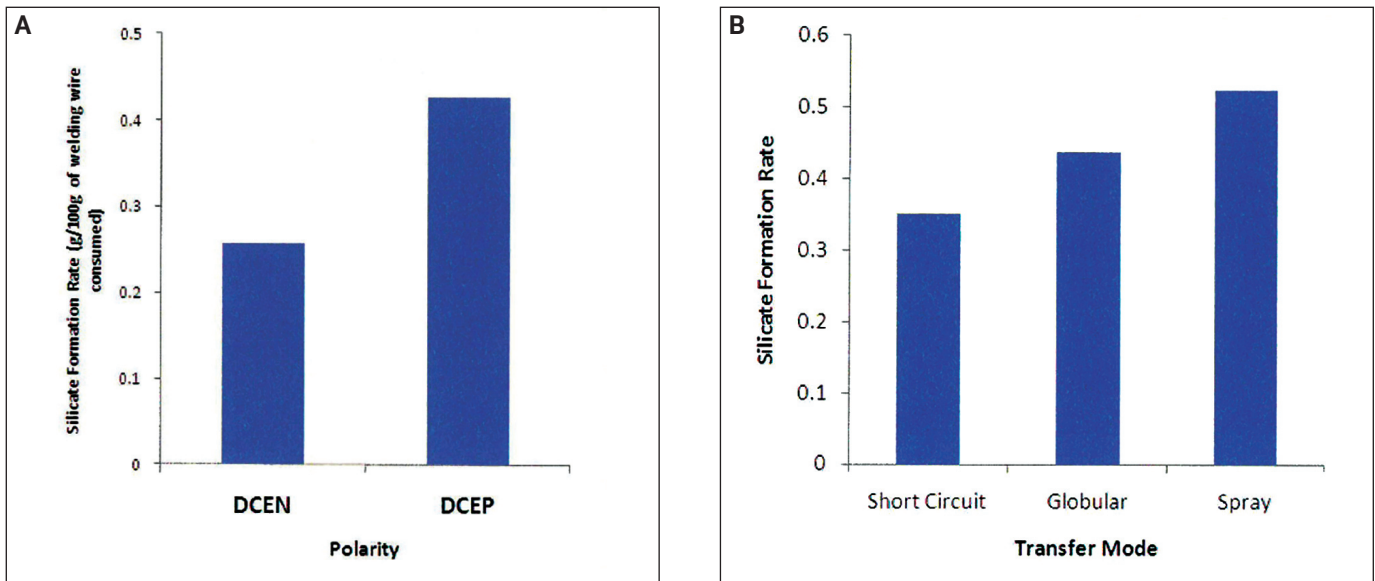


Fig. 19 — A — Effect of polarity on SFR for a single wire composition; B — effect of transfer mode on SFR. Each transfer mode was achieved by adjusting welding voltage and WFR (e.g., high voltage and high WFR/current to achieve spray). The transfer modes were confirmed by analysis of the high-speed video recordings for each weld.

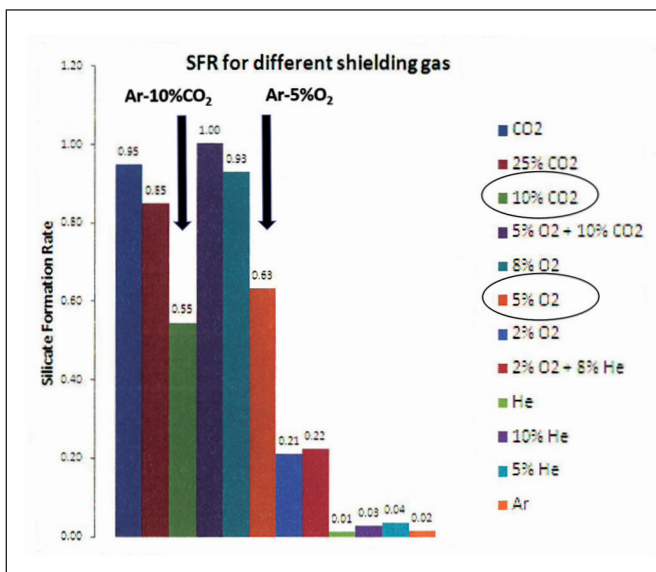


Fig. 20 — Silicate formation rate vs. shielding gas composition.

tip. Thus, to reduce the amount of silicate islands in GMA welds, larger-diameter electrodes would be preferred. The effects of voltage on silicate formation are shown in Fig. 17A and B. Increasing voltage while keeping other welding parameters constant lengthens the arc, which bestows a longer flight time for the molten droplets to traverse the arc, allowing for greater exposure of the molten droplets to oxidation before entering the weld pool.

Higher voltage also widens the arc at its base, which increased the size of the fusion zone, and a greater area of contact between the weld pool and the atmosphere was created. Finally, increasing the voltage raised the temperature of the weld pool, which allowed thermochemical reactions forming oxides and silicates to occur at a greater rate.

Analysis of the high-speed video recordings revealed that more silicate particles flow from the hot to the cold region of the weld pool for higher voltage values — Fig. 18. At 26 V, no silicate islands were observed near the tail end of the solidified weld pool. Increasing the voltage to 36 V, silicate islands could be seen in the vicinity of the edge of the weld pool tail end. Silicates were also seen to grow more quickly at higher voltages.

Welding speed was also examined for its effect on SFR. The general trend observed was decreasing SFR with increasing welding speed. As the welding speed increased, the weld pool elongated and became shallower, which provides a shorter time and smaller contact area for interaction of the liquid metal with the shielding environment. Lower energy is also imparted to the base metal, which lowers dilution of the weld, and smaller amounts of the alloying elements are available for the formation of silicates.

The effect of composition was examined with the CSM wires containing different levels of alloying elements. Increased Si, Al, and Mn content all increased SFR while Ti decreased SFR. As expected, the addition of Si had the strongest effect on increasing SFR. The addition of Ti decreased the SFR by providing a more preferential bonding partner for O₂ than Si. Thus, more titanates were formed in the place of silicates. The relative greater stability of titanium-based oxides compared to silicon-based oxides support the observed SFR decrease with weld titanium addition. The addition of Ni also decreased the SFR. This observation is hypothesized to be due to the formation of Ni-SiC such that less Si is available for silicate formation, but proving this hypothesis was not included in the scope of this work.

Effect of Electrode Polarity on SFR

The effects of polarity on SFR are demonstrated by Fig. 19A. Clearly, reversed polarity or electrode positive (DCEP)

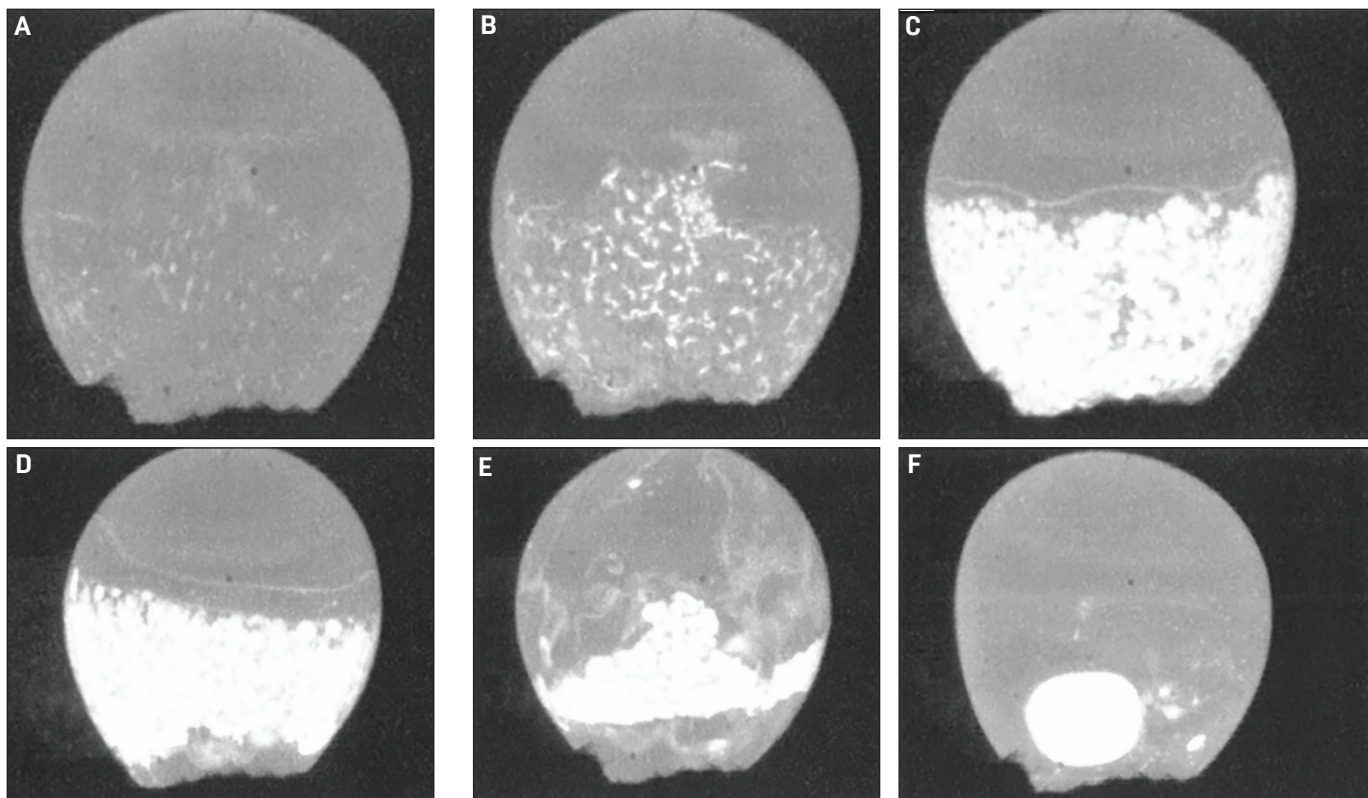
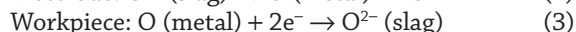
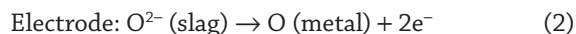


Fig. 21 — Selected still frames at different time lapses from the high-speed video recording of the oxidation of a molten droplet of wire A during electromagnetic levitation in an Ar-2% O₂ atmosphere. Duration of the experiment was 4 s. The formation of oxides on the surface of the droplet can be seen.

caused higher SFRs than direct polarity or electrode negative (DCEN). In DCEP, electron flow toward the electrode will result in greater heating of the electrode. The partitioning of heat between the workpiece and the electrode in DCEP is generally taken to be 70% and 30%, respectively. The effect as described earlier is then expected to also apply to the polarity effect. In DCEP, oxygen accumulated at the electrode while oxygen was removed at the workpiece, as shown by the following reactions:



Additionally, formation of Si⁴⁺ ions at the electrode in DCEP occurred by



These reactions imply that more oxygen was dissolved in the electrode tip, which likely provided more driving force for thermochemical reactions among oxygen, the silicon ions, and other alloying elements in the molten metal, thereby increasing the SFR.

Effect of Transfer Mode on SFR

The transfer mode describes the way by which molten metal was transported to the weld pool. Spray mode, which occurs under high voltage and high current, is a transfer

mode in which the liquid metal droplets are of a smaller diameter than the electrode diameter. In the globular mode, the metal droplets being transferred have a larger diameter than the electrode diameter. In short-circuit transfer, the molten metal droplets were transferred directly from the electrode to the workpiece by direct contact with the weld pool. Short-circuit possessed the lowest heat input of the three transfer modes. Figure 19B shows the effect of transfer mode on SFR.

The spray transfer mode is shown to result in the highest SFR. This behavior was due to the higher surface area of molten metal interacting with the surrounding atmosphere as well as the higher heat present in this mode, which is likely facilitating thermochemical reactions between the molten droplets and any oxygen present.

Effect of Shielding Gas Composition on SFR

Figure 20 shows the effect of the composition of the shielding gas on the SFR. As expected, an inert gas such as pure Ar resulted in a low SFR. The SFR increased significantly with increasing O₂ and CO₂ content. Also expected was a lengthening of the arc as the O₂ content increased (Ref. 21). With a higher concentration of O₂, the arc was expected to stabilize and have a higher temperature due to the exothermic reactions between the O₂ and other elements from the electrode (Ref. 21). The weld pool size also increased as a result, which allowed for a larger contact area for reactions between the pool and the arc atmosphere. It can also be seen from Fig. 20 that Ar-10% CO₂

exhibited a lower SFR than Ar-5% O₂. Onsøien (Ref. 22) attributes the lower oxygen equivalent of Ar-10% CO₂ than Ar-5% O₂ to the decomposition of CO₂ molecules according to



That is, the formation of CO contributes additional shielding and diminishes the ability of oxygen to form oxides in the weld pool, thus lowering the SFR.

Kinetics of Silicate Growth

The following results and observations were made from the oxidation of steel droplets using the electromagnetic levitation system discussed in the experimental methods section. Analysis of the high-speed video recordings allowed for in-depth observation of the reactions occurring on the droplet during levitation. Figure 21 shows a selection of frames extracted from a high-speed recording sequence of droplet levitation in an Ar-2% O₂ atmosphere. Initially, no oxidation was observed. Once the atmosphere reached the sample, a layer of oxide formed on the surface of the droplet and grew until a large portion of the droplet was covered by the layer — Fig. 21A–C. As oxidation progressed, the layer changed in morphology, as seen in Fig. 21D and E. Further progression led to the coalescence of oxide islands on the surface of the droplet — Fig. 21F. By similar analysis of droplet levitation under different oxidizing atmospheres, it was found that as oxidation potential of the shielding gas increased, the initial amount of oxide on the droplet also increased. Under an Ar-8% O₂ atmosphere, nearly the entire surface of the droplet was quickly (on the order of thousandths of seconds) covered by the oxide layer. Also, the sizes of the final oxide islands increased with increasing oxygen potential.

Figure 22 shows the evolution of the amount of oxide layer on the surface of the droplet with oxidation time. As expected, an increase in levitation time increased the surface area covered by oxides. Given that the longest oxidation times tested were several seconds, which is unrealistic compared against the short solidification time in welding, these tests represent extreme cases of silicate coverage.

From SEM/EDS analysis of the droplets oxidized for different lengths of time, it was seen that the first oxide layers formed on the wire A droplet substrate were iron oxide, and the final islands seen (after the change of morphology of the first oxide layer) were silicates. This behavior was likely due to the initial abundance of iron in the oxidizing environment, which formed the first oxide layer. Subsequent oxidation of other elements, such as titanium and silicon, was followed by coalescence of these oxides, which formed the silicates. For inert gas atmospheres, no oxides were observed to form.

These same experiments were repeated with an Ar-10% CO₂ gas, which has a similar oxygen potential as the Ar-5% O₂ gas (based on data from Onsøien [Ref. 22]). Comparing the oxidation behavior under a 5% O₂ atmosphere vs. a 10% CO₂ atmosphere, the droplet in the 10% CO₂ atmosphere exhibited faster formation of surface oxides, which continued to form until the entire droplet was covered. In the 5% O₂ atmosphere, the oxides never attained full coverage of the droplet surface, and the interstitial oxygen percentage was observed to remain nearly constant regardless of oxidation

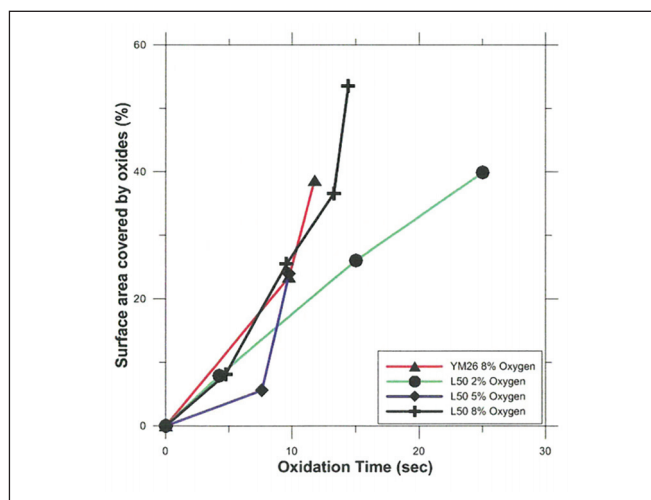


Fig. 22 — Surface area % of the liquid droplet covered by oxides vs. oxidation time.

time, which indicates very favorable oxidation kinetics in this case. In the case of the 10% CO₂ atmosphere, longer oxidation times exhibited less interstitial oxygen. This observation likely indicates an initial rapid oxidation of the sample during which the surface oxide forms. Following the formation of the surface oxide, oxygen exchange between the droplet and the atmosphere was limited. The difference in behavior between the two atmospheres can possibly be explained by the decomposition of CO₂ into O and CO. If CO₂ dissociates into CO and O, the CO could form a protective layer around the droplet that would slow oxidation, actually acting as a shielding gas (Ref. 23). In this case, only the alloying elements directly on the surface can react with the oxygen to form a surface oxide layer. In O₂-containing atmospheres, the oxygen atoms can dissolve in the molten metal and react with alloying elements in the bulk of the droplet. The oxides formed in the bulk then float to the surface and coalesce there with other oxides to form large silicate islands.

Conclusion

In this work, high-speed video recording was used for in-situ observation of oxide formation during welding and electromagnetic levitation. The effects of welding parameters on silicate formation rate were observed. The effects of atmosphere composition, oxidation time, and metal droplet composition on silicate formation kinetics were also studied.

Formation of silicate islands during GMAW are the result of oxidation of alloying elements, including Si, Mn, Ti, and Fe, that are present in the welding system. Due to density differences between liquid steel and the oxides, the oxides float to the surface until solidification. Oxide mixing with pure SiO₂ at the surface leads to the formation of silicate islands.

Silicates were seen to already be present on the surface of detached droplets from the melted electrode tip during welding. These silicates were incorporated into the liquid metal once the droplets fell into the weld pool. Fast liquid flow in the hot part of the weld pool ejected the molten silicates to the cold region of the pool. Once outside the influence of the weld-

ing arc, Marangoni flow directed the silicate particles to the sides and rear of the weld pool, where they take on a rotating flow pattern, which drives coalescence and growth of large silicate islands. Once the silicate islands grow sufficiently, the islands generally attach to the side of the weld pool and solidify. Depending on the flow pattern in the weld pool and the size of the silicate islands, the silicates can solidify along the edges (for larger silicate islands) or along the centerline of the weld.

The most significant effect on silicate formation rate during welding was found by adjusting the O_2/CO_2 composition of the shielding gas; the welding voltage; and the Si, Mn, and Ti content of the welding wire. Increasing these parameters increased the silicon formation rate.

Regarding the kinetics of silicate growth, increasing oxidation time increased the surface area occupied by oxides. Increased oxidation potential of the shielding atmosphere also increased the coverage of oxides. A thin iron oxide layer was seen to form on the surface and then mix and coalesce to form a thicker oxide layer. An intermediate oxide layer was seen to form between the silicate islands and the metal. For an atmosphere containing O_2 and an atmosphere containing CO_2 at the same oxidation potential, oxide formation proceeded differently due to the dissociation of CO_2 to O and CO, with the CO acting as a shielding gas and decreasing the amount of oxidation of the liquid metal. The levitation work indicates that the growth of the silicate can be suppressed with shielding gases of a sufficiently low oxidation potential, which would likely be the best option to prevent the islands from forming. Combined with adjusting the composition of the fillers within specifications, it is likely that silicate island formation can be prevented.

Acknowledgment

The authors wish to acknowledge the support of Air Liquide Technical Centre for Welding Applications for their support in the completion of this work.

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Recreating Ductility-Dip Cracking via Gleeble®-Based Welding Simulation

Simulated strain ratcheting was used to recreate welding thermomechanical histories leading to ductility-dip cracking

BY S. LUTHER AND B. ALEXANDROV

ABSTRACT

Face-centered cubic alloys, such as nickel-based alloys and austenitic stainless steels, are important to many industries, notably nuclear power generation and petrochemical. These alloys are prone to ductility-dip cracking (DDC), an intermediate-temperature, solid-state cracking phenomenon. They experience an abnormal elevated-temperature ductility loss, which leads to cracking upon applying sufficient restraint. A unified mechanism for DDC has been elusive. To learn more about DDC, an experimental procedure has been designed and evaluated for use in future studies. It is a thermomechanical test that replicates welding conditions via simulated strain ratcheting (SSR) using the Gleeble thermomechanical simulator. This study evaluates SSR and aims to establish the procedure is reproducible and adequately optimized for producing DDC. A design of experiments was created with four alloys tested at varying preloads, elevated temperature strains, and a number of thermomechanical cycles. Mechanical energy imposed within the DDC temperature range was used for quantification of the effect of thermomechanical cycling on the DDC response. The materials tested were 310 stainless steel and Nickel 201 base metals as well as nickel-based filler metals 52M and 52MSS. The SSR successfully recreated DDC while maintaining higher fidelity to actual production conditions than past laboratory tests and offered a more controlled environment than large-scale weld tests. Therefore, the SSR will provide a viable experimental procedure for learning more about the DDC mechanism.

KEYWORDS

- Ductility-Dip Cracking (DDC) • Nickel-Based Alloys
- Stainless Steels • Thermomechanical Testing
- Weldability

is being developed. The industry-driven motivation is the mitigation of ductility-dip cracking (DDC) in nickel-based groove welds and structural weld overlays (SWOLs) on nuclear pressure vessel nozzles. This cracking phenomenon has been known to exist for almost 100 years but has not been a major problem in this industry until the relatively recent development of high-chromium filler metals, such as Alloys 52 and 82. Alloy 52M, an Alloy 52 variant, was later selected as an overlay material to protect underlying metals undergoing primary water stress corrosion cracking, and DDC has been observed in all three alloys (Refs. 1, 2). DDC is not fully understood; therefore, fundamental research is needed to elucidate a micro-mechanistic explanation. In general, DDC involves anomalous intermediate-temperature ductility loss. High restraint during welding leads to cracking, especially in multipass welding. The current explanation is stress combined with elevated temperatures encourages grain boundary (GB) sliding. This sliding enables void formation and these voids eventually grow to form cracks, which are free to propagate (Refs. 3–7). Many researchers also contend sulfur plays a key role in initiating cracking (Refs. 8–10). However, clarification is needed on both fronts because the finer details of the mechanisms on the microstructural level are unclear. The utility of clarification is more effectively avoiding DDC in real-world welding. DDC can lead to expensive rework due to the low flaw tolerance in nuclear power.

Design of experiments (DOE) is used in this study. DOE is a statistical analysis technique utilized to minimize the number of samples needed to evaluate the effect of factors on a response. Each factor is tested at two levels, low and high, and at least one replicate is needed, thus leading to a number of experimental runs equal to two times two to the power of the number of factors. For example, this study involves several DOEs with two factors, so each DOE has eight runs. Similar to multiple linear regression, DOE analysis results in an equation with each factor multiplied by a coefficient, and each coefficient's significance is represented by a P-value.

Introduction

Background

A thermomechanical simulation designed to imitate the multipass welding conditions experienced by austenitic alloys

Literature Review

Numerous researchers have developed ways to artificially

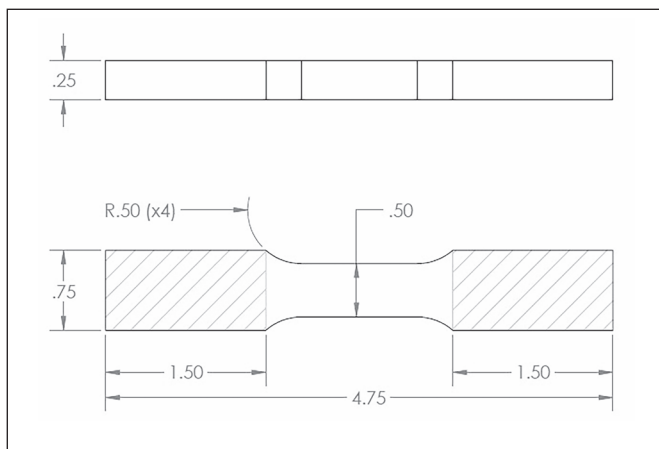


Fig. 1 — Geometry used for tensile samples. Dimensions are in inches.

produce DDC in metals of interest. One specifically designed to study DDC is the strain-to-fracture (STF) test (Ref. 11). Others that have been used to study DDC include the programmable-deformation-crack (PVR), hot ductility, hot tensile, and fissure bend tests, though these were not originally designed for DDC (Refs. 12–15). Through this body of research, it is possible to rank DDC-susceptible alloys relative to one another, and each has contributed insight into the mechanism. However, information has also been gained by welding large imitation mockups to create DDC as it would form in the field. Researchers who use these methods often argue artificial laboratory tests are lacking because they do not mimic actual welding conditions (Refs. 15, 16). Even the prolific susceptibility ranking completed using STF only provides this ranking on the basis of relative comparison of crack counting rather than a holistic theory capturing the unexplained micromechanistic details of DDC. Both the externally restrained laboratory tests and the self-restrained field methods have made significant contributions to the understanding of DDC. However, further research will attempt to mimic production conditions, thereby addressing the fidelity issues of past laboratory tests. It will also utilize a highly controlled and reproducible test procedure and a sample design, which is easily characterized, to overcome drawbacks of available field tests. Thus, a new laboratory test method has been developed with inspiration from McCracken and Tatman's narrow groove weld test (Ref. 16). They demonstrated the ability to correlate DDC crack locations in a narrow groove weld with areas of high strain accumulation, or strain ratcheting, as predicted by a finite element analysis model using Sysweld™. The newly developed experimental procedure, described in the experimental methodology section, generally applies this strain ratcheting approach to a weld-metal-containing sample, which is heated using a welding temperature profile experienced in multipass welding. This procedure is termed simulated strain ratcheting (SSR).

One area where DDC knowledge is lacking is in explaining certain features that can be found on DDC fracture surfaces called thermal faceting. Achieving this end is not the purpose of this article; however, a brief introduction to the phenomenon is given here to provide background on some



Fig. 2 — Final Nickel 201 samples used in SSR testing with the welded gauge section.

of the results presented herein. Thermal faceting is known to occur predominantly in austenitic alloys, and it simply refers to a change in equilibrium crystal shape, which happens at elevated temperatures to minimize surface or interfacial energy (Ref. 17). Thermal faceting manifests as very small terraces or steps on the order of 50–200 nm in size, which can be present along GBs or on fracture surfaces. Incidentally, this change occurs in the DDC temperature range. Very little research has been done to see if this phenomenon has any significance to DDC or if it is just coincidence. Future work in this project will further investigate the topic.

Objective

The overarching goal of this research is to advance the fundamental understanding of DDC toward a mechanistic explanation for cracking through exploring the potential involvement of localized GB phenomena, such as sulfur-induced amorphization and GB faceting. To reach this end, material properties will be identified and quantified that directly relate to DDC cracking susceptibility and GB decohesion or sliding. This will be made possible by simulating thermomechanical welding conditions in austenitic alloys to study DDC and strain ratcheting, or by using SSR. This new procedure has been designed to mimic production conditions to reduce the artificiality of past testing and ultimately clarify the micromechanistic details of DDC. In this study, the authors describe the process of creating and optimizing the SSR procedure, which will be used in future research on this subject.

Experimental Methodology

Materials and Test Sample Preparation

The chemical composition of each material used in this study is shown in Table 1. These alloys were selected because they represent a range of DDC susceptibilities according to past research. The order from least to most susceptible is Alloy 52MSS, 310 stainless steel (SS), Alloy 52M, and Nickel 201 (Refs. 11, 18, 19). The proposed SSR procedure

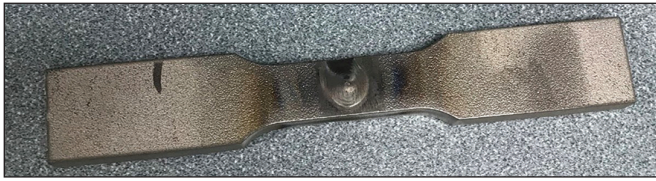


Fig. 3 — Image of final 310 SS sample with the welded gauge section and spot weld.

was expected to produce more severe cracking in the more susceptible alloys to demonstrate its sensitivity to DDC susceptibility, and it was expected to do so consistently to prove its reproducibility. 310 SS and commercially pure Nickel 201 base metals were obtained in the form of 0.25-in. rolled plate. Bead-on-plate (BOP) welds were completed autogenously using gas tungsten arc welding (GTAW) according to the parameters shown in Table 2. Welds were spaced such that dog-bone tensile samples could be extracted with weld metal centered in the gauge section.

Figure 1 shows the geometry used for these tensile samples, and Fig. 2 is an image of the final Nickel 201 samples. After preliminary testing with Nickel 201 showed an absence of DDC, spot welds were added to the front and back of the center of the gauge section of the 310 SS samples us-

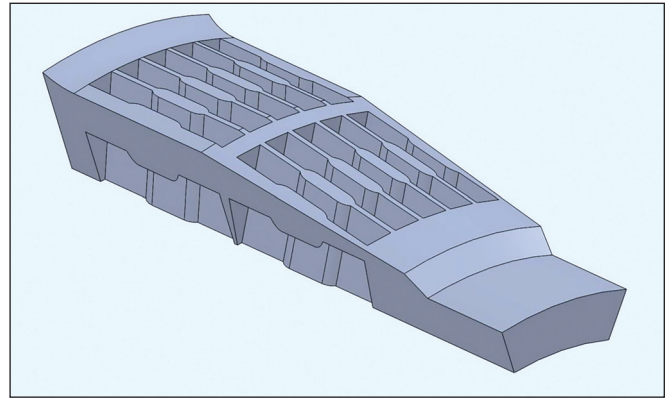


Fig. 4 — Computer-aided design drawing of the machining plan for the Alloy 52M overlay.

ing autogenous GTAW with the parameters in Table 2, and samples were extrinsically strained during heating. Figure 3 shows an image of the final 310 SS samples. Nickel-based filler metal 52M was obtained by machining samples from a mock-up SWOL used for successful welding qualification. The samples were made entirely of weld metal. Figures 4 and 5 show the process of extraction of these samples. Nickel-based filler metal 52MSS samples were created by

Table 1 — Material Compositions (wt-%) of 310 SS, Ni 201, Alloy 52M, and Alloy 52MSS

Element	310 SS	Ni 201	Ni 52M	Ni 52MSS
Al	—	—	0.059	0.29
B	—	—	< 0.0001	—
C	0.045	0.018	0.034	0.03
Co	0.270	—	0.018	0.001
Cr	25.41	—	30.1	28.7
Cu	0.20	0.01	0.22	0.04
Fe	53.147	0.004	9.47	5.42
Mn	0.86	0.25	0.76	0.44
Mo	0.28	—	0.15	3.49
N	0.038	0.28	—	—
Nb	0.006	—	0.83	1.31
Ni	19.15	99.47	57.9	58.1
P	0.023	0.001	0.007	0.014
S	0.001	0.0002	0.015	0.001
Si	0.57	0.08	0.09	0.15
Ta	—	—	—	1.66
Ti	—	—	0.22	0.23
W	—	—	0.071	—
Zr	—	—	0.002	—
Others	—	—	0.056	0.124

Table 2 — GTAW Parameters Used for BOP and Spot Welding

Weld Type	Arc Voltage	Travel Speed	Downslope	Current	End Current	Shielding Gas	Gas Flow Rate
BOP	12 V	3 in./min	N/A	200 A	N/A	99.995% Ar	40 ft ³ /min
Spot	12.5 V	N/A	12.7 s	120 A	20 A	99.995% Ar	40 ft ³ /min

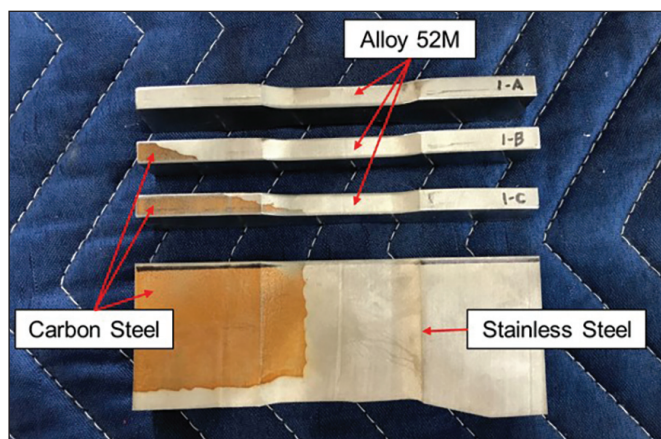


Fig. 5 — Final machined 52M samples.

groove welding 0.25-in. Alloy 690 plates in a butt joint configuration, then extracting samples in a manner similar to the 310 SS and Nickel 201. A cold wire pulsed GTAW process was used on two Alloy 690 base plates in the butt joint configuration, each with a 45-deg bevel and a $\frac{3}{4}$ -in. flat at the root. Welding parameters for the Alloy 52MSS plates are presented in Table 3. Circular notches of 0.25 in. in diameter were added to the gauge sections of the Alloy 52MSS samples in the weld metal after failure was observed in the base metal during preliminary testing. Figure 6 shows the final Alloy 52MSS sample geometry used in testing.

Testing Procedures

Samples were loaded into the Gleeble thermomechanical simulator after a single Type-K thermocouple was attached to the center of the gauge section. Stainless steel blocks with carbide grips were used to secure the sample in the Gleeble jaws. The U-jacks in the chamber were first handtightened to settle the blocks against the U-jacks and the grips onto the sample. Then, an approximately 70% room temperature yield strength tensile load was applied to the sample until the force remained steady to ensure the blocks were fully mating with the jaw surface. U-jacks were tightened to their final position while the hydraulic system was still engaged. A dilatometer was then attached to the center of the gauge section such that the arms of the dilatometer were in-line with the thermocouple and the linear variable displacement transformer position was at its center point. The dilatometer measured changes in the transverse cross section. This reading was converted to an axial measurement in-line with the loading direction during data



Fig. 6 — Final 52MSS sample with circular notches in the weld metal.

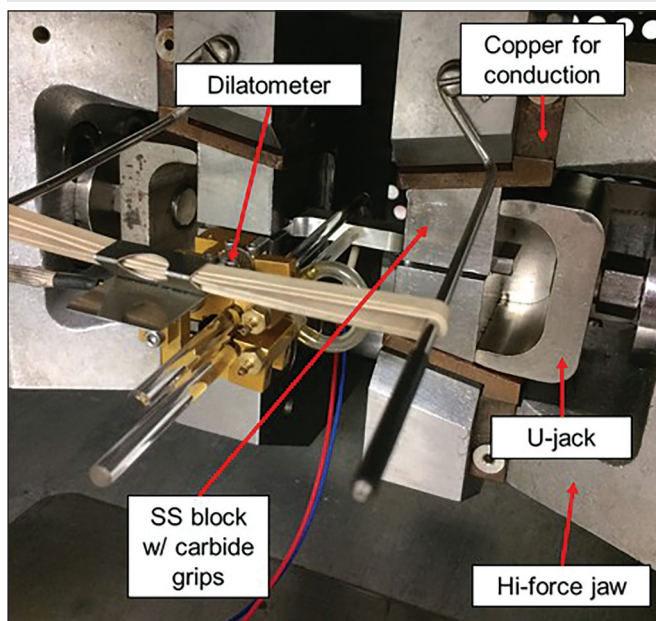


Fig. 7 — Image of SSR setup in the Gleeble chamber.

processing using the materials' Poisson's ratio.

Figure 7 is an image of the experimental setup in the Gleeble chamber. The Gleeble chamber was sealed and the roughing vacuum was used until the chamber pressure readout was less than 0.05 torr. In addition, 99.998% argon was pumped into the chamber at 40 ft³/min until a partial vacuum of 400 torr was reached. The chamber was once more pumped down and refilled with argon at the same parameters to ensure a more complete oxygen purge (Ref. 18). Finally, the SSR user-defined Gleeble script was executed and testing commenced.

The basic SSR procedure involves simulation of multiple welding thermal cycles combined with fixed displacement plus tensile stress preload and/or on-heating extrinsic straining within the DDC temperature range. The aim is to replicate the thermomechanical history in highly restrained multipass welds. A welding thermal cycle, which was obtained from the

Table 3 — Multipass Welding Parameters Used for 52MSS Groove Welds

Layer	Number of Beads	Layer Depth	Current	Voltage	Travel Speed	Wire Feed Speed
Butter	0	0.27 in.	—	—	—	—
1	3	0.209 in.	165/145 A	9.2 V	3.2 in./min	30/30 in./min
2	3	0.136 in.	165/145 A	9.2 V	3.2 in./min	30/30 in./min
3	3	0.075 in.	165/145 A	9.2 V	3.2 in./min	30/30 in./min
4	3	0.028 in. (above flush)	85/165 A	9.9 V	3.0 in./min	41/41 in./min

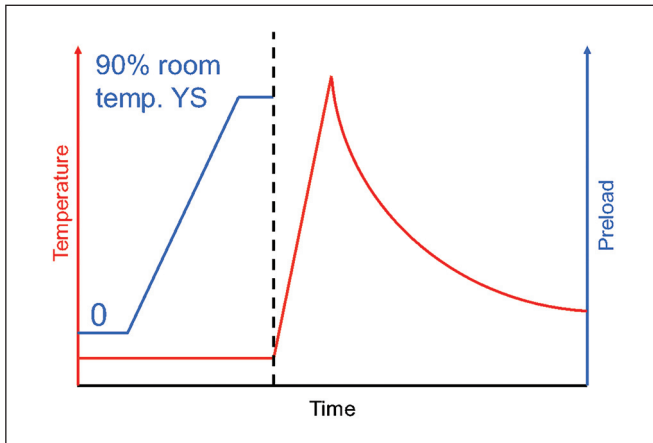


Fig. 8 — Schematic of a single preloaded SSR cycle.

thermocouple data recorded during multipass welding, was applied to the test sample. A peak temperature was selected, which allows the material to pass through the DDC temperature range without reaching the solidus temperature. This temperature corresponds to a point about 50°–100°C below the 99% fraction solid temperature predicted by a Scheil solidification simulation in Thermo-Calc using the material composition of the sample. The peak temperature for Nickel 201, 310 stainless steel, and Alloy 52M was 1200°C, and the peak temperature for Alloy 52 MSS was 1100°C. Heating occurred at about 140°C/s and air cooling was about 3°–6°C/s depending on the material. After reaching peak temperature, the sample was free cooled to 100°C before the next cycle began.

After the desired number of thermomechanical cycles was reached, the hydraulic system was turned off, the chamber was vented and opened, and the sample was retrieved from the Gleeble. Data processing of SSR outputs was completed using MATLAB® R2019a. These outputs included stroke, time, temperature, force, power angle, and dilatometer reading at 10 Hz during testing.

Design of Experiments

The basic SSR procedure was applied in three separate

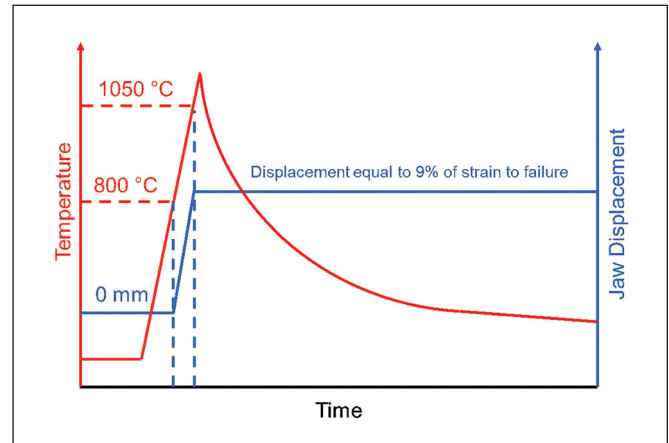


Fig. 9 — Schematic of a single thermal cycle from an SSR test.

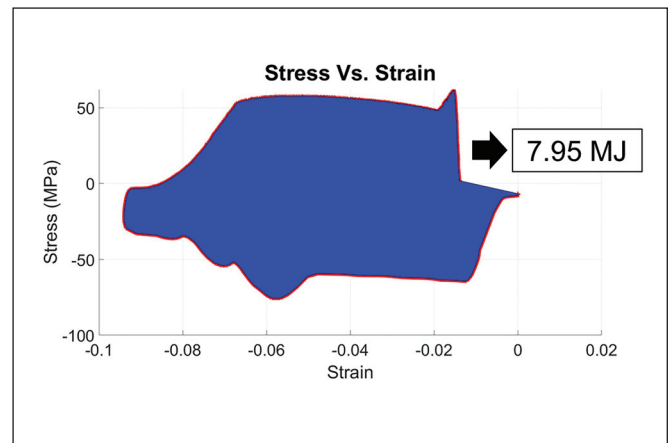


Fig. 10 — Example of the integrated stress/strain curve to calculate the imposed mechanical energy. Taken from 310 SS sample 1, 0 DDC strain, and 1 cycle. Result is shown in mega-joules (MJ).

two-factor DOE studies to evaluate the effect of number of applied thermomechanical cycles, room temperature preload, and strain ratcheting on the DDC response in welds of the four tested alloys.

Table 4 — DOE Setup

Sample Number	Number of Thermomechanical Cycles	DOE 1: Nickel 201		DOE 2: Alloy 52M		DOE 3: 310 SS, Alloy 52MSS		
		DDC Strain, %	Preload, %	DDC Strain, %	Preload, %	310SS DDC Strain, %	52MSS DDC Strain, %	Preload, %
1	1	0	0	1.35	0	0	0	0
2	1	0	90	1.35	90	2.7	0.9	0
3	10	0	0	1.35	0	0	0	0
4	10	0	90	1.35	90	2.7	0.9	0
5	1	0	0	1.35	0	0	0	0
6	1	0	90	1.35	90	2.7	0.9	0
7	10	0	0	1.35	0	0	0	0
8	10	0	90	1.35	90	2.7	0.9	0

Note: Nickel 201 did not have any DDC strain applied and the preload for DOE 3 was 0% for all tests.

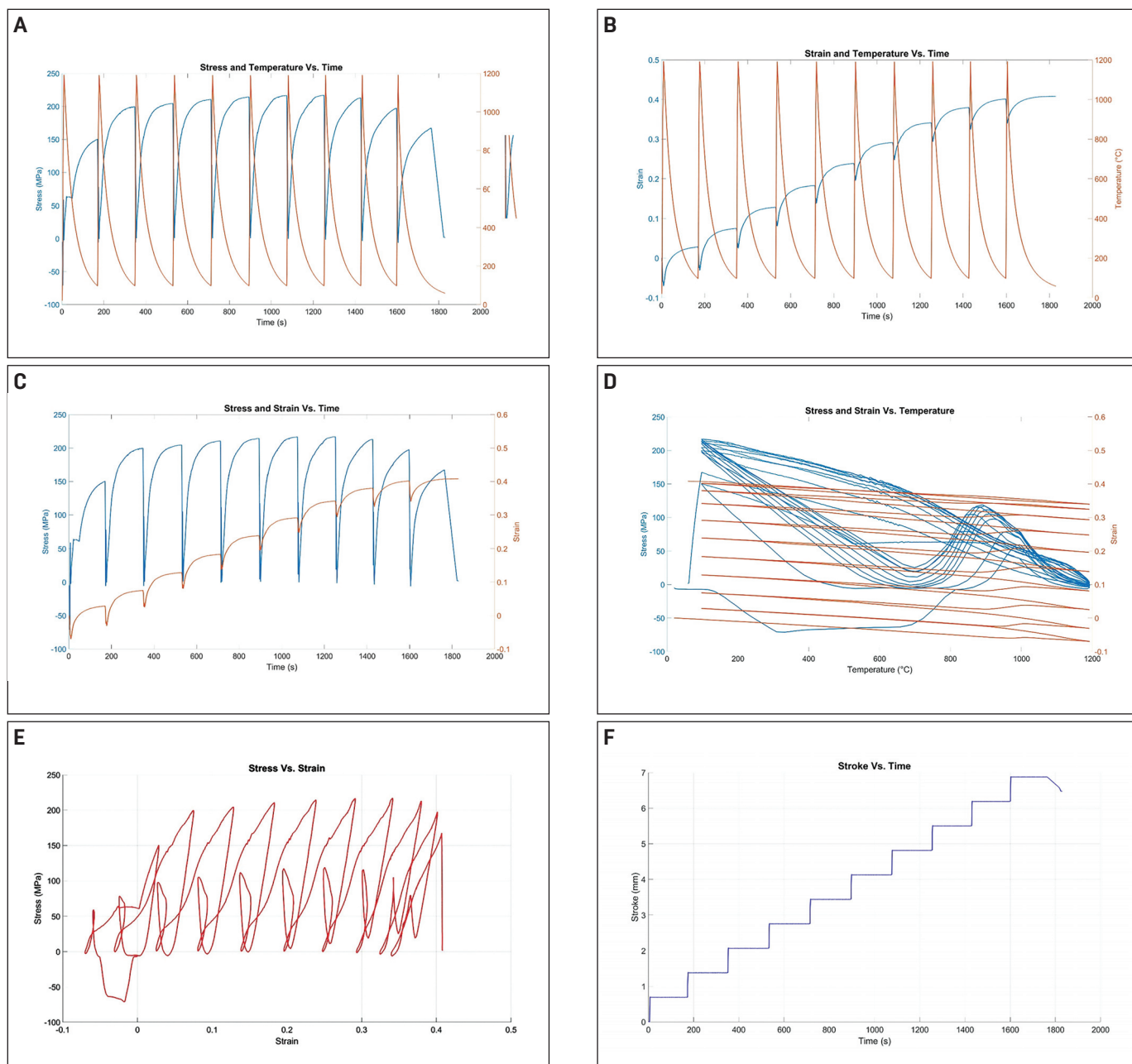


Fig. 11 — Graphed SSR data from 310 SS sample 4: A — Stress and temperature vs. time; B — strain and temperature vs. time; C — stress and strain vs. time; D — stress and strain vs. temperature; E — stress vs. strain; F — stroke vs. time.

The DOE test matrices are shown in Table 4. The number of thermomechanical cycles was a factor in all three DOEs and varied between 1 and 10. DOE 1 and DOE 2 utilized room temperature preload applied immediately prior to starting to simulate artificial restraint. The low/high preload values were 0 and 90% of the tested material room temperature yield strength. Figure 8 shows a schematic of this preload procedure.

DOE 2 and DOE 3 utilized tensile straining at a constant rate within the DDC temperature range of 800° and 1050°C to reflect the strain ratcheting effect in highly restrained multipass welds found by McCracken and Tatman (Ref. 20). The amount of DDC temperature range strain applied per

thermal cycle is approximately 9% of the threshold strain to complete separation so ten thermal cycles would total to 90% of strain to complete separation. Strain was applied based on jaw displacement as a fraction of the gauge section in the free span between the jaws. For example, a jaw displacement of 2.5 mm with a free span of 25 mm results in 10% strain across the gauge section. The DDC strain was constant in DOE 2 and varied between 0 and 9% in DOE 3. Figure 9 provides a visual representation of one SSR cycle with applied DDC strain. To reiterate, all extrinsic straining occurs on heating and the remainder of testing is conducted under fixed displacement, where intrinsic strain accumulates due to thermal expansion or contraction.

Table 5 — SEM Parameters Used for Fractography

Accelerating Voltage	Beam Current	Working Distance	Stage Bias	Detector
9 kV	50 pA	5–15 mm	–4 kV	T2

Table 6 — Complete DOE Results for Each Material

Material	Sample	Energy, MJ	Cracking	P-Values	Coefficients, MJ	R-Squared, %
Nickel 201	1	2.1012	None	Cycles: < 0.001 Preload: 0.953 P*C: 0.039	Cycles: 1.660 Preload: –0.0009 P*C: –0.00695	98.13
	2	0.9093	None			
	3	18.4291	None			
	4	8.3648	None			
	5	2.1540	None			
	6	0.9918	None			
	7	14.6862	None			
	8	12.1653	None			
Alloy 52M	1	1.3890	None	Cycles: < 0.001 Preload: 0.107 P*C: 0.038	Cycles: 2.136 Preload: 0.0285 P*C: –0.00679	99.15
	2	3.9873	None			
	3	23.2733	Profuse			
	4	19.5568	Profuse			
	5	1.6822	None			
	6	4.1930	None			
	7	19.5719	Profuse			
	8	16.0772	Profuse			
310 SS	1	2.1554	None	Cycles: 0.012 Strain: 0.691 S*C: 0.038	Cycles: 1.542 Strain: –0.69 S*C: 0.772	94.62
	2	1.7501	None			
	3	15.9546	None			
	4	25.6883	Some			
	5	1.8297	None			
	6	1.7634	None			
	7	14.7967	None			
	8	43.7896	Some			
Alloy 52MSS	1	1.7940	None	Cycles: 0.003 Strain: 0.568 S*C: 0.053	Cycles: 1.757 Strain: –2.55 S*C: 1.748	95.76
	2	0.9609	None			
	3	18.0273	None			
	4	38.5063	Failure			
	5	1.8575	None			
	6	1.1144	None			
	7	17.075	None			
	8	23.5176	Failure			

Prior to running the DOEs, the threshold strain to complete separation was determined to ensure samples were not overloaded and fractured during the high-cycle tests. This procedure consisted of running a SSR test with 5% DDC temperature range strain added per cycle until the sample completely separated. For 310 SS, this complete separation strain was 30%, for Alloy 52M it was 15%, and for Alloy 52MSS it was 10%.

The response variable was imposed mechanical energy within the DDC temperature range, which was calculated by integrating the stress-strain curve generated from testing in the temperature range of 800°–1050°C. The heating and cooling portions were calculated separately and added together. Since GB sliding can occur during stress relaxation or stress accumulation, the absolute value of imposed mechanical energy was used for DOE calculations (Refs. 2, 18). Figure 10 shows an example of the integrated

stress/strain curve with the imposed mechanical energy result across the entirety of the curve. This was achieved using MATLAB's built-in trapezoidal area function. Imposed mechanical energy was selected to characterize the effect of strain ratcheting on GB movement/strain because it captures the stress/strain behavior throughout SSR's low-cycle, fatigue-type procedure. Furthermore, the absolute value was used because both stress/strain accumulation and relaxation could potentially cause GB sliding, but in opposite directions. Thus, the response variable needed to account for both directions of sliding.

With two factors and one replicate, the total number of runs was eight per DOE. Four center points were initially planned; however, statistical analysis showed the assumption of linearity remained valid for the first eight runs. The Nickel 201 tests followed the preload/number of thermo-mechanical cycles in DOE 1, the Alloy 52M tests followed

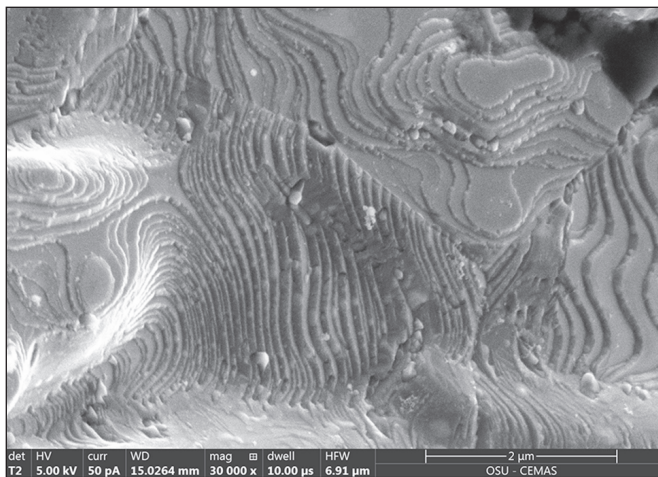


Fig. 12 — 310 SS DDC fracture surface showing thermal faceting.

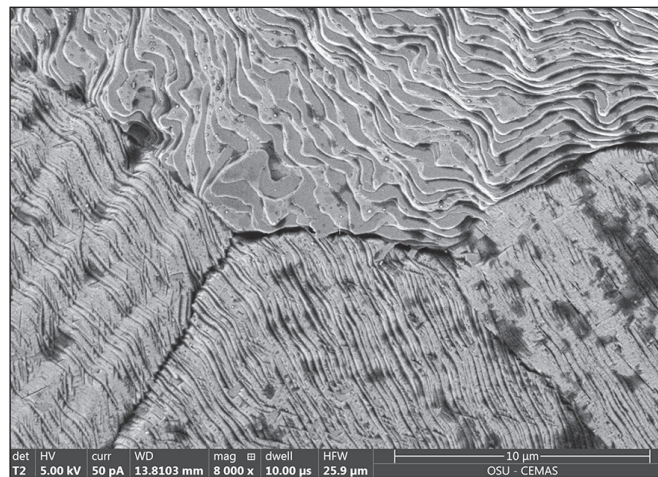


Fig. 13 — Alloy 52M DDC fracture surface showing thermal faceting.

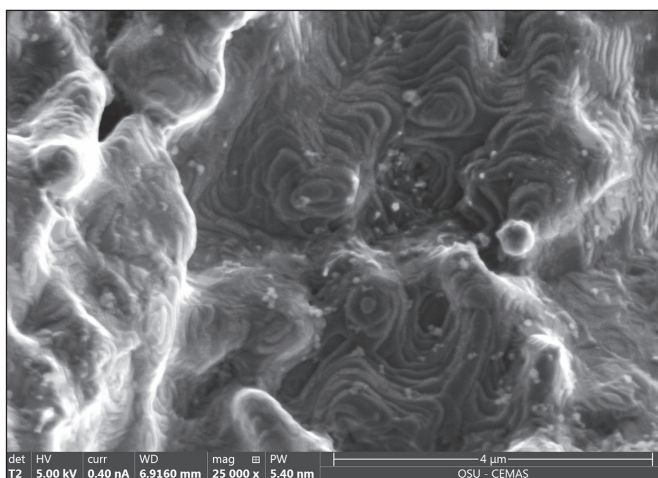


Fig. 14 — Alloy 52MSS DDC fracture surface showing thermal faceting.

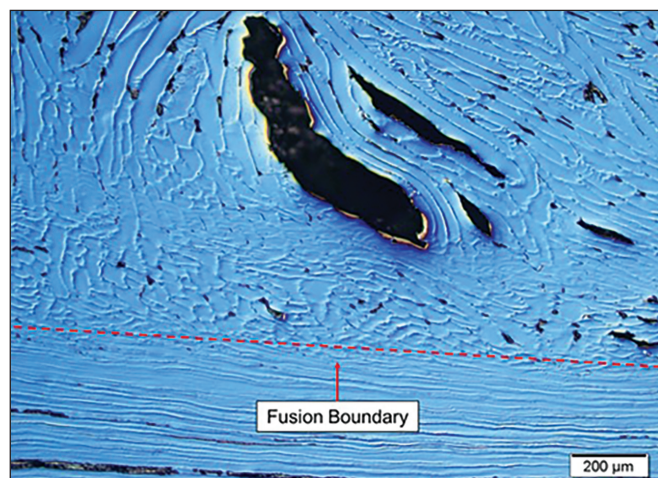


Fig. 15 — 310 SS metallography cross section showing large overloading cracks alongside smaller DDC cracking. The dark spots at interdendritic regions are etching artifacts. The base metal is shown at the bottom of the image.

DOE 2 with preload/number of thermomechanical cycles and a constant DDC strain applied each cycle, and the 310 SS and Alloy 52MSS tests followed DOE 3 with DDC strain/number of thermomechanical cycles and no preload. DOE calculations were performed using Minitab® 18.

Characterization

As-welded sections from each material were examined using destructive metallography to ensure no cracks were present prior to testing. 310 SS was etched using the electrolytic technique in 10% oxalic acid with 6 V and 1 A for 3 s. The nickel-based filler metals were etched using electrolytic technique in 10% chromic trioxide solution with 6 V and 1 A for 3 s. The Nickel 201 base metal was unetched. Little or no etching was intentionally used to avoid confusion between etching artifacts and cracking. An Olympus GX51 optical microscope was used for this task. Also, samples were imaged using differential interference contrast to further enhance surface topography

and hence improve crack identification. Tested samples were prepared and examined following the same metallography procedure. Fractured samples were imaged using a Thermo Fisher Apreo low-vacuum field emission scanning electron microscope (SEM) operated in optiplan mode with the parameters shown in Table 5. Sample preparation consisted of ultrasonic cleaning, ethanol rinse, and bake-out in a light furnace for 20 min.

Results

SSR Test Outputs

There were 32 samples tested across the three DOEs and four materials presented here, and six graphs were generated for each sample using the acquired thermomechanical data. One representative set of graphs is shown in Fig. 11 from 310 SS sample 4, which was subject to high strain and a high number of thermomechanical cycles. In order, the

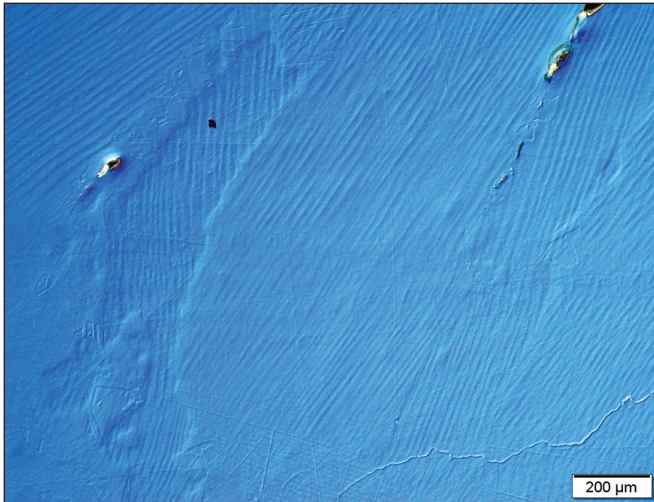


Fig. 16 — Alloy 52M metallography showing DDC.

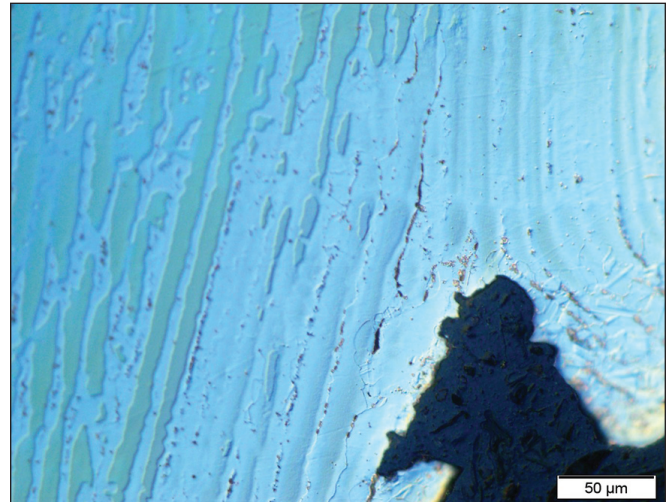


Fig. 17 — Alloy 52MSS metallography cross section showing DDC and primary fracture.

graphs show stress and temperature vs. time, strain and temperature vs. time, stress and strain vs. time, stress and strain vs. temperature, stress vs. strain, and stroke vs. time.

DOE Results

The results for each DOE are compiled and summarized in Table 6. Recall the factors for 310 SS and Alloy 52MSS are DDC strain and number of thermomechanical cycles, and the factors for Nickel 201 and Alloy 52M are preload and number of thermomechanical cycles. The critical P-value in this design is 0.05. The P*C or S*C values show the interaction between preload and cycles or DDC strain and cycles. The coefficients shown in Table 6 can be combined to form predictive equations for the imposed mechanical energy (E) in each material's DOE. Equation 1 is for Nickel 201, Equation 2 is for Alloy 52M, Equation 3 is for 310 SS, and Equation 4 is for Alloy 52MSS, where E is the imposed mechanical energy, C is the number of thermomechanical cycles, P is preload, and S is the DDC strain.

- (1) $E = 1.660C - 0.0009P - 0.00695P*C$
- (2) $E = 2.136C + 0.0285P - 0.00679P*C$
- (3) $E = 1.542C - 0.69S + 0.772S*C$
- (4) $E = 1.757C - 2.55S + 1.748S*C$

Optical and Electron Microscopy Observations

Samples with full separation failures from 310 SS, Alloy 52M, and Alloy 52MSS were examined with SEM fractography. These full separation failures came from the stress tests conducted prior to the DOEs, which were used to determine the complete separation strain. All showed the presence of thermal faceting. SEM results for 310 SS, Alloy 52M, and Alloy 52MSS are shown in Figs. 12–14, correspondingly. Sample 4 from each material DOE was selected for destructive metallography since these samples typically showed signs of cracking when viewed macroscopically. Light optical micrographs of 310 SS, Alloy 52M, and Alloy 52MSS are shown in Figs. 15–17, correspondingly. All cracks were intergranular and often oc-

curred along straight, migrated grain boundaries with one or more crack tips located at triple points. Some cracks were found in the process of formation and gave the grain boundary a perforated appearance as though many voids formed along the boundary and would eventually connect to form DDC. An example of this is shown in Fig. 18.

Discussion

Main Points

In general, Table 6 and Equations 1–4 show the number of thermomechanical cycles significantly impacts the imposed mechanical energy and preloading/straining does not. Throughout testing, several important aspects of the procedure were deliberately altered to improve the effectiveness of SSR, such as elevated temperature straining, spot welding where needed, elimination of preloading, and reduction of the gauge cross section. Here, “effectiveness” is the ability for SSR to recreate severe welding conditions to the extent of causing DDC in these materials. It would be of little value if the procedure were unable to do so. Despite the changes during testing and minor differences in material properties, the number of thermomechanical cycles has a similar trendline coefficient, about 1.5–2.1 MJ per cycle, across the four materials in Table 6 and Equations 1–4. The R^2 values in excess of 94%, the imposed energy equations (Equations 1, 2, 3, and 4), and the consistency of number of thermomechanical cycles coefficients indicate strong reproducibility. However, larger variations were found between Samples 3 and 7 as well as Samples 4 and 8 of each material, which were tested at equal conditions as shown in Table 6. This is likely because longer tests (i.e., tests with ten cycles instead of one) have greater opportunity for deformation and hence changes in stress-strain behavior over the course of the test. Figure 11C is an example exhibiting this change over time.

Assessment of SSR Testing

Referring to the SSR output graphs shown in Fig. 11

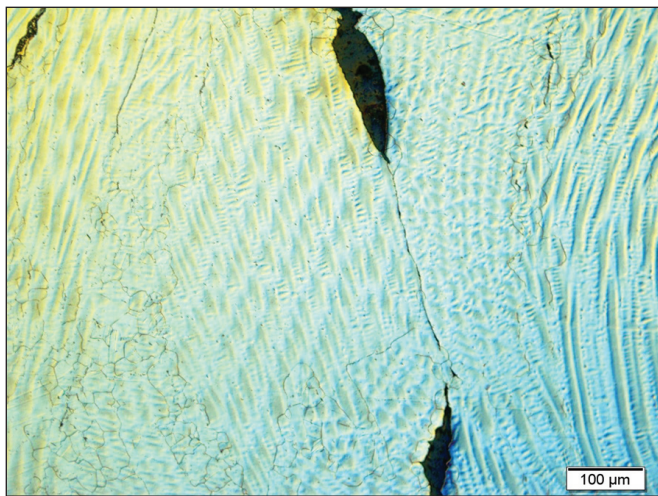


Fig. 18 — Alloy 52M DDC along the “perforated” grain boundary. Taken from a complete separation failure sample.

(310 SS Sample 4 with ten cycles and 2.7% strain per cycle), these results can be informative about sample behavior during testing in many ways. First, on the stress and temperature vs. time graph (A), initial hardening was evident after the first few cycles, then the sample began to weaken toward the end as peak stress dropped. Due to the fixed displacement, as the temperature rose, stress tended to drop or even become compressive as the sample thermally expanded and was subsequently resisted by the jaws. The opposite occurred on cooling. The test sample was subjected to fatigue loading with dominating tensile cycles since the sample spent a relatively longer time cooling and contracting than heating and expanding. On the strain and temperature vs. time graph (B), strain accumulated each cycle up to a maximum of about 40%. It must be noted this was a measurement of total strain on the sample, not just the strain added during heating, and hence there was an initial drop each cycle due to thermal expansion.

Looking at stress and strain vs. time graph (C) now, it becomes apparent strain begins to accumulate more slowly as the test progresses and peak stress begins to drop. The stress and strain vs. temperature graph (D) is more difficult to interpret. The test cycle begins at the bottom left of the graph where stress was near zero. On the first heating cycle, the stress grew to about 60 MPa in compression, increased to 70 MPa in tension while the extrinsic strain was applied in the DDC temperature range, and then decreased to about 25 MPa during the subsequent heating to 1200°C. On cooling to room temperature, the stress gradually increased to about 150 MPa. In the subsequent SSR cycles, the stress applied to the test sample remained tensile, varying between about 20 and 220 MPa, and followed similar trends of decreasing on heating, except during extrinsic straining, and increasing on cooling. The strain growth accumulated steadily, with local drops due to thermal expansion within the heating cycles, then gradually increased to about 40% at the final cycle.

The stress vs. strain graph (E) shows what would eventually be used to calculate imposed mechanical energy. The graph begins at zero strain and progresses briefly to the left as compressive strain was experienced during the very first cycle, then to the right as the sample was strained in a combination

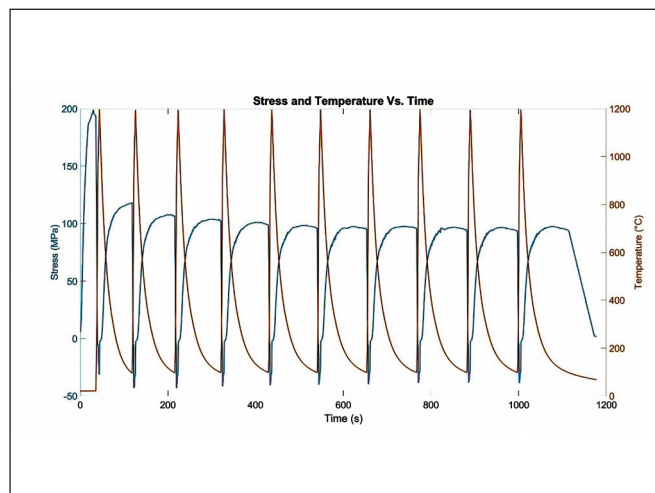


Fig. 19 — Nickel 201 Sample 4 stress and temperature vs. time plot showing effect of preload on stress over many cycles.

of on-heating extrinsically applied strain and on-cooling intrinsic strain ratcheting.

Finally, the stroke vs. time graph (F) shows the displacement of the Gleeble jaws as the test is underway. The sample was held fixed during most of the heating and all of cooling, and the steps corresponded to the extrinsic strain applied on heating. The information shown on these graphs for each material is helpful in monitoring the sample's behavior during testing and will aid in future work aimed at determining how these behaviors are related to DDC. In addition, the graphs help to visualize how the weld metal service behavior is artificially recreated within the SSR test.

It was initially difficult to produce DDC in samples that were primarily composed of base metal with welds partially penetrating the gauge section. Weld metal is more susceptible to DDC due to the presence of migrated grain boundaries, so if strain does not accumulate in it, there will be no DDC (Ref. 2). After the removal of preload and replacement with straining, DDC formed more readily and consistently, so future work will continue to include SSR to artificially produce DDC where needed.

DOE

The consistent high significance of number of thermomechanical cycles shown in Table 6 and Equations 1–4 across all materials indicates it is the factor that most strongly affects imposed mechanical energy. This is indicated by the coefficients for number of cycles having the largest numerical magnitude in the equations and the P-values, which are all less than 0.05 in Table 6. This is an unsurprising result, though it is interesting how consistent the numerical effect of cycling is across multiple materials and loading conditions. Perhaps this is due to similar thermomechanical properties among the materials involved.

Preload was initially added to act as an artificial restraint, but graphs of the data show the preload usually only affects the first one or two cycles and each subsequent cycle is more like nonpreloaded behavior. Figure 19 is an example graph showing this behavior taken from a high-cycle, high-preload Nickel 201 sample. Preload then turned out to be statistical-

ly insignificant after running the DOE calculations, so it was eliminated. This was determined by examining the coefficients for preload in Equations 1–4, which are small compared to number of cycles, and by examining the P-values for preload in Table 6, which are all in excess of 0.05.

With the P-value larger than 0.05, the extrinsically applied strain within the DDC temperature range does not show up as a statistically significant factor. However, its combined effect with number of thermomechanical cycles is significant and its coefficients in the imposed energy equations are comparative with those of the number of thermomechanical cycles. The DOE results in Table 6 show that DDC strain, used to simulate strain ratcheting in highly restrained multipass welds, greatly increases the likelihood of DDC forming during testing. The mechanical energy imposed within the DDC temperature range accounts for both the applied extrinsic strain on heating and the intrinsic strain accumulated as a result of fixed displacement on cooling. Samples that contained more DDC did experience higher imposed mechanical energy, thus there is a correlation between cracking probability and imposed mechanical energy. As a result, the imposed mechanical energy can be used to quantify the thermomechanical effect of the SSR procedure on the DDC response in tested materials.

The DOE results in Table 6 could not be used to rank DDC susceptibility due to variation in procedure and sample preparation. However, some of the qualitative results combined with the DOE do reflect trends observed in past research. The established ranking of susceptibility from lowest to highest is Alloy 52MSS < 310 SS < Alloy 52M < Nickel 201 (Refs. 11, 21). 310 SS, despite experiencing greater total strain in Samples 4 and 8, showed less cracking and more signs of ductility, such as necking and surface deformation, than similar samples of Alloy 52M. Nickel 201 and Alloy 52MSS had somewhat anomalous behavior here because no DDC was observed in Nickel 201, and Alloy 52MSS experienced complete separation failures on the final cycle of Samples 4 and 8. However, the Nickel 201 DOE was conducted without any DDC strain, and Alloy 52MSS had the greatest difference in sample geometry compared to the others, so making a comparison with the rest of the materials may be inappropriate.

Procedure Refinement

During the Nickel 201 DOE, it became clear changes would need to be made to the procedure/sample preparation to produce DDC. No cracking was observed in Nickel 201 even though past research suggests it was the most susceptible material tested in the current study (Ref. 21). This is likely due to the gauge section containing base metal, which was able to bear more of the plastic deformation where the weld metal was unable to do so. McCracken and Tatman's computational model was closely examined to find other factors that may impact DDC susceptibility (Ref. 16). It predicted elevated-temperature strain accumulation, so this was added to the SSR procedure. Furthermore, past research on STF involved preparing samples with gauge sections composed entirely of groove welds with surface spot welds on both sides of the sample to produce favorable grain orientations for cracking (Ref. 11). Likewise, spot welds were

added to both sides of all 310 SS samples to melt through any unmelted base metal, since they were not entirely composed of weld metal prior to this change. Figure 15 shows mainly cracking from overloading in 310 SS after testing with some small DDC cracks. The absence of abundant secondary DDC cracking besides the final failure indicates a low susceptibility to DDC. The increase in gauge section length, as the sample is strained, is accommodated by plastic deformation without significant grain boundary sliding, leading to DDC.

In contrast, the Alloy 52M showed extensive secondary cracking after a high number of thermomechanical cycles, as shown in Figs. 16 and 18. This is because the samples were composed entirely of weld metal. There was no irregularity in microstructure in the gauge section (i.e., no transition from base metal to weld metal), and it is suspected this factor was the most impactful in causing a distinct absence of DDC in Nickel 201 in addition to the lack of elevated-temperature straining. This base/weld metal transition can be problematic in mechanical testing because the base metal and weld metal have different strength and ductility, which means differing behavior during testing (Ref. 3).

After making these significant changes to the procedure and observing the DDC generated in this testing, it is clear this will be a viable method for studying the DDC cracking mechanism in future work. The DDC observed in Alloy 52M along with the fracture surfaces from Alloy 52M, Alloy 52MSS, and 310 SS all match the expected morphology and size scale of cracking, which has been observed in past research from both the authors and other researchers (Refs. 1, 18, 22). Also, the recorded thermomechanical behavior from testing closely corresponds to a past study that modeled thermomechanical behavior in a multipass weld (Ref. 20). These past studies represent both laboratory testing, such as STF and large-scale multipass welds. The strengths of performing a mechanistic investigation with this method are that it closely mimics actual production conditions while providing a carefully controlled environment for cracking to nucleate and propagate without the influence of confounding variables, which may be encountered in a large-scale testing, such as oxygen/hydrogen contamination and fusion-related defects.

Cracking Morphology and Fractography

The secondary cracking observed in the 310 SS (Fig. 15), Alloy 52M (Figs. 16 and 18), and Alloy 52MSS (Fig. 17) matches the expected DDC size, shape, and location as documented in past research (Refs. 3, 6, 18, 22). The thermal faceting observed on the DDC fracture surface of 310 SS (Fig. 12), Alloy 52M (Fig. 13), and Alloy 52MSS (Fig. 14) has been a consistent finding in these alloys in past research from the authors and others (Refs. 1, 22). Thus, SSR recreates DDC in terms of morphology and location in the microstructure. Also, this is not the first time thermal faceting has been observed on DDC fracture surfaces, though it is perhaps the first time it has been mentioned by name alongside DDC in decades of published literature (Refs. 1, 22). Collins et al. observed thermal faceting on artificially generated DDC fracture surfaces, and Hemsworth et al. observed it on a fracture surface extracted from a multipass weld (Refs. 1, 22). Very few researchers ob-

serve thermal faceting to begin with, likely because it is difficult to image due to its small size and is likewise easily obscured by thin oxide layers. Furthermore, sometimes it is found and referred to as slip lines or plastic deformation artifacts in error (Refs. 11, 22). At present, it is not yet clear how thermal faceting influences DDC, if at all, but future work will consider and investigate the potential implications it may have.

Conclusion

Optimized Procedure

The SSR procedure diagram shown in Fig. 9 remains accurate with the following stipulations:

- 1) The gauge section contained in the free span of the SSR samples should be made entirely of weld metal for microstructural consistency;
- 2) In the event it is somehow impossible to meet the previous requirement, spot welds should be added to the front and back of the sample;
- 3) No preloading is necessary; and
- 4) Gauge section should be of uniform geometry (i.e., no notches, reduced thickness, etc.) for even stress and strain distribution.

The number of cycles used in testing can be varied at will based on the desired level of welding restraint and thermal cycles. Elevated-temperature strain ratcheting should be added in the DDC temperature range to encourage crack formation. Based on results shown here, cracking appears near 90% of the complete separation strain. The outputs of the test are quantitative in the form of data acquired during the test, such as dilatometer, jaw displacement, stress, and temperature. These outputs can be processed and analyzed to calculate the imposed mechanical energy on the sample, which has been correlated with DDC occurrence here. The qualitative outputs are metallographic imaging and extent of cracking.

Summary

The SSR procedure has been adequately optimized to reliably produce DDC in a variety of materials and sample geometries with several different levels of susceptibility. Multiple thermomechanical cycles have a greater effect on imposed mechanical energy on samples than preloading. Overall strain accumulation is required for DDC to form. A significant interaction was found between the strain ratcheting, simulated through straining in the DDC temperature range, and the number of thermomechanical cycles. The mechanical energy imposed within the DDC temperature range can be used for quantification of the effect of thermomechanical cycling on the DDC response in tested materials. SSR will be used in future research to study the effects of impurities and grain boundary evolution during simulated welding thermal cycles.

The cracking generated by the SSR procedure has both similar fracture surface topography and cross-sectional cracking morphology as previous documented cases of DDC, both from laboratory tests and service failures. SSR can be used to simulate welding conditions, in particular multipass welding conditions, which often lead to DDC in high-chromium nickel-based

alloys. This represents an improvement over past laboratory tests because the thermomechanical conditions are more similar to production conditions without sacrificing the control over variables introduced by multipass weld tests, such as contamination and weld defects.

Acknowledgment

The authors would like to thank, first and foremost, the American Welding Society Foundation for funding this research through the Glenn Gibson Graduate Fellowship Grant. Additional funding was provided by voestalpine Böhler and The Ohio State University's (OSU's) College of Engineering and Institute for Materials Research. Companies supporting this research through material donations and services include Special Metals, Electric Power Research Institute, Framatome, Knolls Atomic Power Laboratory, AZZ Specialty Welding, and voestalpine Böhler. Electron microscopy was performed at the Center for Electron Microscopy and Analysis at OSU.

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