WELDING Journal

JUNE 2021

AWS

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The American Welder

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

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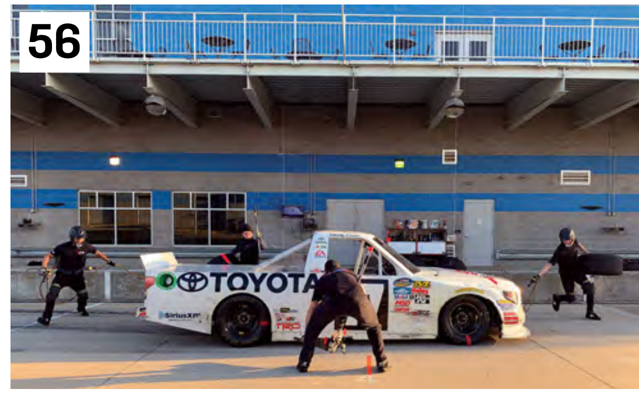
CONTENTS

FEATURES



THE AMERICAN WELDER

WELDING RESEARCH SUPPLEMENT

DEPARTMENTS

On the cover: 5 Off 5 On pit crew students practicing. (Courtesy of Pit Instruction & Training, Mooresville, N.C.)

WELDING JOURNAL

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AWS Promotes Diversity

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

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The Power of Resiliency

Carey Chen
AWS Treasurer

"When assessing how AWS did in an extremely tough year, with financial challenges aplenty, one has to credit the staff, the volunteers, the Board of Directors, and our loyal members with extraordinary resiliency."

2020 can be simply summarized in eight words:

- Global pandemic
- Economic recession
- Civil unrest
- Election circus

Resiliency is one of the most important qualities for an organization to possess in the face of financial adversity. The American Welding Society (AWS) demonstrated strong resiliency in 2020 as the COVID-19 pandemic disrupted lives and businesses throughout the world. Our resiliency was made possible through an unwavering commitment by staff to cut costs and keep our Society flourishing while our customers and dedicated volunteers strived to adapt to changing business conditions. It worked, and it kept us healthy.

In spite of the challenges of 2020, the financial results for AWS were fairly decent, all things considered. Despite a general softness in revenues, we continued to generate a healthy surplus and favorable cash flow. Also in our favor was the amazing resiliency of U.S. stock markets.

The decline in revenues for AWS showed no sign of slowing as the year ended — especially with the cancellation of FABTECH — but we still beat our late-term forecast for 2020 revenues. Similarly, our surplus for the year was higher than predicted, coming in at $7.36 million. The AWS reserve fund at the end of 2020 also surpassed that of the previous year. The two largest drivers of this increase included positive transfers from operations supplemented by positive market investment changes of $15.1 million. In addition, careful attention to cost savings by our operating staff and management yielded savings of $4.35 million.

The AWS Foundation's assets for the year increased to $98.7 million, up $15.1 million from the December 31, 2019 balance. Again, this result was achieved through positive investment changes and transfers from AWS operations.

One of my proudest moments came when the AWS qualified for a Paycheck Protection Program (PPP) loan last year. Qualifying and receiving the PPP loan was not what made me proud. The moment of pride came when we acknowledged there were many other companies and nonprofit organizations that needed the money far more than AWS did, and we returned the PPP money in full. Furthermore, we ended the year with a positive surplus, demonstrating that we survived the worst of 2020 on our own steam.

I cannot say enough to acknowledge the diligent efforts of AWS staff in managing costs proactively and protecting our surplus as the COVID-19 pandemic raged on. We were able to weather 2020's economic uncertainty partly through the healthy reserves that we built up over years of investment discipline and sound financial management.

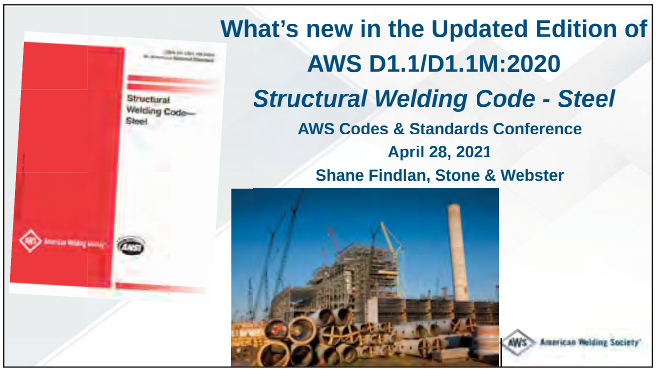
As you know, a significant portion of the AWS staff has been working remotely during the pandemic. While this creates some difficulties in staff interaction, it can be managed effectively. When the average percentage of people testing positive for COVID-19 reaches a low-enough level locally, we will begin moving a larger portion of staff back into our headquarters building.

In general, considering the uncertainty of 2020, the financial performance of AWS was better than expected. Revenues for the year closed at $33.97 million (down $7.0 million from 2019), and the surplus was $7.36 million (down $2.6 million from 2019). The full-year results aligned with a model predicting a decline in sales of 20% resulting from the FABTECH show cancellation and other factors. With the proactive analysis by the Finance and Business Development Committee, and support of the Executive Committee and AWS Board, we identified cost reductions of approximately $3.8 million that allowed us to maintain staffing levels without reducing wages or benefits. Operating staff helped us to realize even greater cost savings of $4.35 million for the year.

Some additional financial results are worth noting: Total cash and cash equivalents at year-end were $6.3 million and increased by $1.2 million over a one-year period. This enabled us to transfer a total of $2.5 million each to our reserves and Foundation investment portfolios. Overall, our investments had a year-end balance of $194.7 million, increasing by $36.9 million, or 23.4%. Total net assets as of December 31 were at $224.1 million, an increase of $35.6 million, or 18.9%, from the previous year.

When assessing how AWS did in an extremely tough year, with financial challenges aplenty, one has to credit the staff, the volunteers, the Board of Directors, and our loyal members with extraordinary resiliency. It is what kept us healthy through 2020 and will keep us recovering in the year ahead. WJ

Virtual Conference on Structural Codes & Standards Presented by AWS



Pictured is a slide from Shane Findlan's presentation on AWS D1.1/D1.1M:2020, Structural Welding Code — Steel, *during the conference.*

The American Welding Society (AWS), Miami, Fla., held the inaugural **Structural Codes & Standards Virtual Conference** on April 28. It was designed to give an overview of current versions of some of the most popular structural codes and standards, with an emphasis on significant changes in recent revisions. More than 90 attendees took part in the online event.

Conference Chair Tony Anderson, director of aluminum technology, ITW Welding North America, and Conference Co-Chair Shane Findlan, consultant welding engineer at Stone & Webster LLC, moderated the live discussions.

Six speakers gave presentations on various AWS D1 structural welding codes, with a final session offering an overview of the AWS D14 Committee standards for machinery and equipment. On behalf of all the conference speakers, Anderson and Findlan thanked all who attended and the following sponsors: Böhler Welding by voestalpine, Bug-O Systems, Euroweld Ltd., FinishLine, Hobart Filler Metals, The Lincoln Electric Co., Miller Electric Mfg. LLC, and Select Arc Inc.

The following details the technical presentations:

- Findlan gave an overview of the changes in the 2020 edition of **AWS D1.1/D1.1M, *Structural Welding Code — Steel***, compared to the previous 2015 edition;
- Anderson presented an overview of **AWS D1.2/D1.2M: 2014, *Structural Welding Code — Aluminum***, as well as an introduction to the recently published 2021 edition of **AWS A5.10/A5.10M (ISO 18273:2015 MOD), *Welding Consumables–Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum-Alloys — Classification***. This edition of A5.10 is the first aluminum welding consumable standard to include weld metal strength requirements;
- Nina Choy, supervising bridge engineer at Caltrans, delivered an overview of the changes in the 2020 edition of **AASHTO/AWS D1.5M/D1.5, *Bridge Welding Code***, compared to the previous 2015 edition;
- Richard D. Campbell, Bechtel Fellow and welding technical specialist, provided an introduction and overview of **AWS D1.6/D1.6M:2017, *Structural Welding Code — Stainless Steel***, with a focus on issues specific to welding of stainless steel compared to carbon steel; and
- The day wrapped up with an overview of the **AWS D14 Standards** given by Vermeer Corp. staff David Landon, manager of welding engineering, and Joseph Bailey, senior welding engineer. This presentation focused on the differences and similarities between codes for fabricated items that move compared to other codes that primarily focus on static constructions.

To learn more about this event, visit *awo.aws.org/conferences/conference-presentation-papers*, and if you're interested in purchasing the codes, go to *pubs.aws.org*.

— Andrew Davis, director, international activities, AWS

AWS Announces New CWI Pathway for IIW Diploma Holders and Launches AWS Certified

The American Welding Society (AWS), Miami, Fla., introduced a new pathway for certain International Institute of Welding (IIW) diploma holders to achieve the AWS Certified Welding Inspector (CWI) credential through the **CWI by IIW Waiver** program (*aws.org/cwi-by-iiw*).

The traditional route of earning the CWI credential is by passing a three-part exam: Part A (fundamentals) tests general welding knowledge; Part B (practical) has hands-on testing of welding inspection techniques; and Part C (open codebook) tests knowledge of a particular welding codebook.

IIW diploma holders have an opportunity to streamline the process of earning the CWI credential. By submitting evidence of one of the following IIW diplomas, they can apply for a waiver from taking Part A (fundamentals) and need only to pass the Part B (practical) and Part C (open codebook) exams to possess both IIW and AWS credentials: International Welding Engineer, International Welding Technologist, International Welding Specialist, and International Welding Inspection.

"In this competitive global environment, having dual credentials through both AWS and IIW can provide a competitive edge," said John Gayler, AWS senior vice president of welding and technology. "By offering the CWI by IIW Waiver program, AWS has paved the way for IIW diploma holders to possibly open career opportunities. And the price has been adjusted as IIW diploma holders only need to take two exams instead of three!"

In addition, because welding is among the most crucial and essential skilled trades that impact everyday life, yet the number of skilled welding technicians and professionals continues to decrease, AWS has launched a new initiative — **AWS Certified** (*aws.org/certified*) — targeting students and early career welders. It shines a light on the importance of obtaining AWS certifications. AWS is best known for the CWI credential, but the Society has ten more certifications on different specialties/career paths.

"Being AWS Certified shows you're proud to be in this industry, and it requires you to master the skills that uphold our industry standards. It gives you credibility and respect among your peers," said Nate Bowman, director of welding optimization and education at Central Welding Supply. "Welding education is the key to success in the industry." WJ

Jobs and Education Bills Reintroduced

Congressional sponsors of several bills that failed to progress in the prior Congress have reissued their proposed legislation. These include the following:

Building U.S. Infrastructure by Leveraging Demands for Skills Act. The purpose of this legislation is to promote, through government grants, so-called industry or sector partnerships that engage in collaborative planning, resource alignment, and training efforts across multiple businesses for a range of workers employed or potentially employed by infrastructure industries (i.e., transportation, construction, energy, water, information technology, and utilities).

Jumpstart Our Businesses by Supporting Students (JOBS) Act. This legislation would make shorter-term education and training programs eligible for federal Pell Grants. Pell Grants are needs-based grants for low-income and working students that can only be applied toward programs that are more than 600 h or at least 15 weeks in length. The JOBS Act would expand this eligibility to students enrolled in job training programs that are at least eight weeks in length, a minimum of 150 h, and providers of industry-recognized credentials and certificates. Eligible job training programs would include those offering career and technical education instruction at an institution of higher education, such as a community or technical college.

College Transparency Act. This legislation would establish a postsecondary data system for the National Center for Education Statistics that collects and reports on student outcomes — such as enrollment, completion, and post-college success — to help prospective students determine which programs of study efficiently support their career aspirations. It is anticipated that this would benefit community colleges in particular because more detailed data may reveal them to be the most cost-effective and productive option for many students to continue their education.

Manufacturing Provisions for Infrastructure Proposal Established

The U.S. president's $2.4 billion infrastructure proposal, commonly known as the American Jobs Plan, includes several components focused on manufacturing. Among them are the following: $50 billion to create a new office at the Department of Commerce dedicated to monitoring domestic industrial capacity and funding investments to support production of critical goods; $14 billion for the National Institute of Standards and Technology, including quadrupling financial support for the Manufacturing Extensions Partnership; $52 billion to increase access to capital for domestic manufacturers; and $31 billion for programs that give small businesses access to credit, venture capital, and R&D dollars.

National Safety Council Lists OSHA's Most-Cited Rules

The National Safety Council has released its annual list of the safety rules most cited by the U.S. Occupational Safety and Health Administration (OSHA) against employers. For the fiscal year of 2020, they are as follows (in order): fall protection (general), scaffolding, hazard communication, ladders, respiratory protection, lockout/tagout, powered industrial trucks, personal protective equipment (eye and face protection), fall protection (training), and machine guarding.

Visa Ban Expires

The temporary suspension on entry through certain visa classifications expired at the end of March. It had been in effect since June 2020. The visa classifications were as follows:

- H-1B specialty occupation professionals;
- L-1 intracompany executives, managers, and specialized knowledge workers;
- H-2B temporary nonagricultural workers; and
- J-1 intern, trainee, teacher, and summer work travel program beneficiaries.

Office of Manufacturing and Industrial Innovation Policy Act Created

The Office of Manufacturing and Industrial Innovation (OMII) Policy Act, recently introduced in both the House and the Senate, will be overseen by a chief manufacturing officer in the Executive Office of the President. Modeled on the Office of Science and Technology Policy, the OMII policy will provide manufacturing and industrial perspective and advice to the president, develop a national manufacturing strategy, and coordinate the siloed 58 federal manufacturing programs. This legislation will also establish a President's Committee on Manufacturing and Industrial Innovation, which will be composed of representatives from the business, consumer, defense, public interest, and labor sectors to analyze the landscape of manufacturing efforts and activities in the United States. The committee will report on the state of manufacturing and provide recommendations to strengthen the sector through federal policies and initiatives.

OSHA Proposes Update to Its Hazard Communication Rule

The U.S. Occupational Safety and Health Administration (OSHA) is working to update its *Hazard Communication Standard* to align with the seventh revision of the *Globally Harmonized System of Classification and Labelling of Chemicals*. The proposed changes include clarifying the purpose and scope of the standard, adding definitions, codifying the enforcement policies currently in OSHA's compliance directive, clarifying requirements related to the transport of hazardous chemicals, adding labeling provisions for small containers, and adopting new requirements related to the preparation of safety data sheets and new provisions linked to claiming concentration ranges as trade secrets. OSHA has preliminarily determined that the proposed modifications would enhance the effectiveness of the standard by improving dissemination of hazard information to employees. WJ

HUGH K. WEBSTER, AWS WASHINGTON GOVERNMENT AFFAIRS OFFICE — Contact the AWS Washington Government Affairs Office at 1747 Pennsylvania Ave. NW, Washington, DC 20006; email *hwebster@wc-b.com*; fax (202) 835-0243.

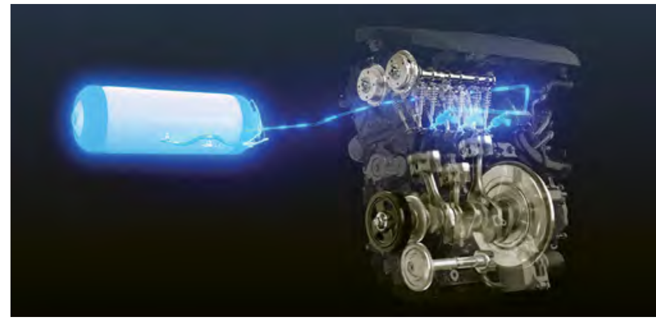
It's Life in the Fast Lane as Automotive News Speeds Ahead

In line with the automotive theme in this *Welding Journal*, here's a range of news from Toyota Motor Corp., Toyota City, Japan; Ford Motor Co., Detroit, Mich.; Alcoa Corp., Pittsburgh, Pa.; BMW Mfg., Spartanburg, S.C.; and General Motors (GM), Detroit, Mich.

• **Toyota** has revealed that, toward the achievement of a carbon-neutral mobility society, it's developing a hydrogen engine. The automaker has installed the engine on a racing vehicle based on the Corolla Sport, which it will enter in competition under the ORC ROOKIE Racing banner starting with the Super Taikyu Series 2021 Fuji Super TEC 24 Hours race in May.

Fuel cell electric vehicles use a fuel cell in which hydrogen chemically reacts with oxygen in the air to produce electricity that powers an electric motor. Hydrogen engines generate power through the combustion of hydrogen using fuel supply and injection systems that have been modified from those used with gasoline engines. Except for the combustion of minute amounts of engine oil during driving, which is also the case with gasoline engines, hydrogen engines emit zero carbon dioxide (CO_2) when in use.

The company plans to fuel its hydrogen-engine-powered vehicle during races using hydrogen produced at the Fukushima Hydrogen Energy Research Field in cooperation with the New Energy and Industrial Technology Development Organization and Japan's Ministry of Economy, Trade and Industry.



Toyota is working on a hydrogen engine. To watch a 3D video of this technology, visit youtube.com/watch?v=00yM5RlD7Zo. *(Credit: Toyota.)*

• As robots and autonomous systems are poised to become part of our everyday lives, the **University of Michigan** (U-M), Ann Arbor, Mich., and **Ford** are opening a facility where they'll develop robots and roboticists.

U-M's Ford Motor Co. Robotics Building is a four-story, $75 million, 134,000-sq-ft complex on the north campus. As the new hub of the U-M Robotics Institute, its first three floors hold custom U-M research labs for robots. The fourth floor houses the automaker's first robotics and mobility research lab on a university campus.

The facility brings together U-M researchers from 23

The 20-in. wheels for the Audi e-tron GT[2] are made of CO_2-reduced aluminum. (Credit: Audi AG.)

different buildings and ten programs. Additionally, the facility will allow Ford engineers to explore how their upright Digit robots can work in human spaces. At U-M's proving ground, they will also be able to perform on-road testing of autonomous vehicles taken from robotic computer simulations.

"Autonomous vehicles have the opportunity to change the future of transportation and the way we move," said Tony Lockwood, technical manager, autonomous vehicle research, Ford Motor Co. "As this new technology rolls out, having our Ford team working on campus collaborating with the academic world will help us shorten the time it takes to move research projects to automotive engineering, unlocking the potential of autonomous vehicles."

• **Alcoa** is supplying sustainable aluminum for the wheels on the **Audi** e-tron® GT[2], which is claimed to be the first vehicle to use metal from a technology that eliminates all direct CO_2 emissions from the traditional smelting process. The company is supplying aluminum to RONAL GROUP for the manufacture of these high-performance alloy wheels, which are produced with a combination of metal from the ELYSIS™ zero-carbon emissions smelting technology and EcoLum™, its low-carbon aluminum brand.

In addition, the wheels are weight optimized with RONAL GROUP's flowforming technology. They are produced using 100% green electricity in Landau, Germany, and used exclusively for Audi's first electric sports car.

• Officials of **BMW Mfg.**, along with South Carolina Secretary of Commerce Bobby Hitt, broke ground for a $20 million, 67,000-sq-ft training center on the BMW campus.

The investment is a continuation of the automaker's 2017 commitment to invest $200 million over five years into workforce training. When finished in the summer of 2022, the building will have classrooms for professional development and technical training, an outdoor amphitheater, and an outdoor meeting/workspace with wireless abilities.

"The rapid pace of digitalization, electrification, artificial intelligence, and autonomous driving is transforming the automotive industry," said Knudt Flor, president and CEO of BMW Mfg. "Advancing the skills of our workforce is a priority for BMW. This training center will offer a learning environment that promotes creativity, fosters innovation, and improves technical training skills."

• **GM** President Mark Reuss has announced Chevrolet will introduce a Silverado electric pickup truck that will be built at the company's Factory ZERO assembly plant in Detroit and Hamtramck, Mich. Reuss also confirmed the recently revealed GMC HUMMER electric vehicle (EV) SUV will be built at the factory.

The automaker plans to deliver more than 1 million EVs globally by 2025. With the company's Ultium Platform, virtual development tools, and technology, it has reduced vehicle development times by nearly 50% to 26 months.

"The vehicles coming from Factory ZERO will change the world and how the world views electric vehicles," Reuss concluded.

Project MFG's Reality-Based Competition Show Highlights Manufacturing

Project MFG, with partial funding from the U.S. Department of Defense, held a reality-based competition show, *Clash of Trades*™, that enabled students from all over the country to vie for $300,000 in prizes and awards as well as win scholarships and the title of national champion. The show highlighted the stories of individuals entering the field and the high-tech, future-focused work being done in the U.S. manufacturing industry. The pilot episode premiered on YouTube on April 20 at 7 p.m. CST.

Twenty-four teams, representing nine states, initially competed in the challenge. These were whittled down to four teams: Danville Community College (DCC), Calhoun Community College, Tennessee College of Applied Technology, and Southwestern Illinois College. The teams were selected based on rigorous judging of a complex advanced manufacturing project and concluded the 2020 competition series that was delayed due to COVID-19.

The competition reflected the advanced manufacturing workplace by requiring the production and documentation of a trophy. Each team had identical materials and cost constraints as well as 16 h on the clock. Up to 100 points were available, and the team with the highest point total won.

The trophy consisted of three parts, two of which the teams knew about going into the competition: a welded stand as the base, a machined and engraved neck in the middle, and a surprise piece, which was an engraved globe to top the finished trophy.

• The first round was called plan of attack. Each team developed a strategy, taking into account time, cost, and re-

Project MFG held the Clash of Trades *reality-based competition show to highlight the individuals entering the field and the high-tech, future-focused work being done in the U.S. manufacturing industry. The winners of the first Project MFG national challenge are Danville Community College students (from left) Koby Carter, Trent Oswald, and Chase Smith.*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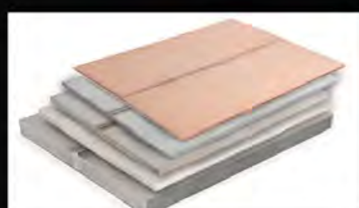

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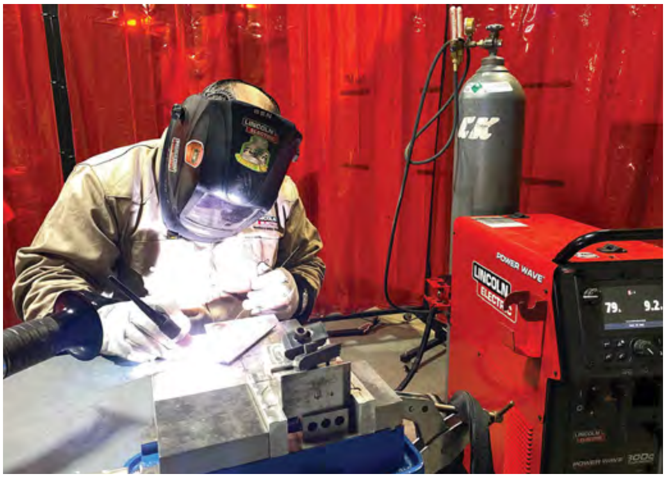


Ben Bradbury, customer training instructor at The Lincoln Electric Co., prepares the equipment for a student welder during Project MFG's national challenge.

sources. Key factors included the size of the team, the number of hours on the clock, and purchases, such as an additional laptop or replacement parts.

• The second round was called test your metal. Here, teams found the results of a destructive test sample weld sent to The Lincoln Electric Co. before the competition. For those who didn't pass, a detour was required on their race to the finish. As a penalty, each team who failed the test sample weld completed an additional weld on two pieces of pipe with only 15 min to do it. If the detour weld passed, they moved on to weld their base. If they failed, the welder sat out for 30 min. Ben Bradbury, customer training instructor, Lincoln Electric, tested the sample weld. Each team's welding performance was judged by a visual inspection and how it measured up against the provided specifications.

• For the final round of judging, the trophies traveled to Zeiss for precision measurement and metrology analysis. Using its Calypso system, the company's experts analyzed each trophy's neck and globe to determine if the measurements fell within the tolerances defined in the competition guidelines.

Koby Carter, Trent Oswald, and Chase Smith from DCC were the winners of *Clash of Trades* and the first Project MFG national champions. The school and team were awarded $35,000 — a $20,000 scholarship for the school and $5000 in prizes for each of the three students.

"The thing that I'm most proud of these guys for is their ability to think on their own. The guys out there stepped up to the challenge and performed and showed that they had the skills necessary to take it home," said Jeremiah Williams, integrated machining technology director, DCC.

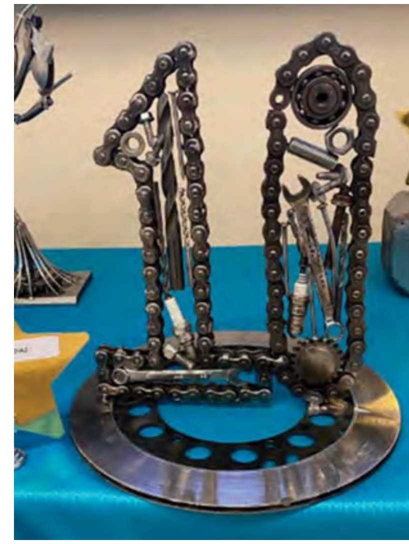
The 2021 season has begun and will culminate this fall in the next Project MFG National Championship. Future episodes of *Clash of Trades* will be created to share the action of the competitions and stories of the competitors with general audiences. To become a sponsor, bring Project MFG to your school, or apply to become a school-sponsored competitor, go to *projectmfg.com/educators*.

Viewers can watch the competition show on Project MFG's YouTube channel. — *Roline Pascal, education editor*

Florida Technical College-Kissimmee Campus Marks National Welding Month

April was a meaningful time for the Florida Technical College (FTC)-Kissimmee Campus. To start, the institution celebrated National Welding Month through encouraging both students and instructors to fabricate welded art. Their creations, including an R2-D2 from *Star Wars*, unique tabletop and stand-alone figurines, and various camp-type logs, were displayed under a star banner highlighting the movement. In addition, the institution turned ten on April 12, inspiring Instructor Jerry Diaz to form a "10" out of chains, nuts and bolts, wrenches, and other shop parts. The digit was assembled using gas tungsten arc welding.

Posing for a group shot are (from left) Florida Technical College-Kissimmee Campus Executive Director Martin Levert; Welding Program Coordinator Christian Aradillas; and Welding Instructors Jerry Diaz, Emmanuel Ortiz, and Nancie Ershen.


This welded "10" was made by Instructor Jerry Diaz to honor the ten-year anniversary of the college's Kissimmee Campus.

"We are so proud of our FTC welding team to be able to create this amazing welded art with our students as part of our March/April curriculum and to also celebrate our ten-year anniversary is so meaningful for the entire FTC family," said Executive Director Martin Levert.

To learn more about the college's 12-month welding diploma program, visit *ftccollege.edu/programs/construction-trades/welding-diploma*. — *Kristin Campbell, managing editor* WJ

Sarah Stork Spreads Her Wings

A desire to assist on farm repairs led to this metal sculptor soaring as a full-time artist

Life is full of unexpected turns. For Sarah Stork, moving to a farm in Georgetown, Tex., proved to be the catalyst that launched her career as a metal artist.

It all started with a pipe fence that needed to be built on 14 acres of land. Stork wanted to help with the fabrication of it and other repairs needed on the farm, so in 2012, she enrolled in Austin Community College's Structural Code Welding program and eventually earned her associates degree.

"I wanted to do something that would be useful for my husband and [learn] a trade that would benefit not only him but me as person," Stork recalled.

Little did she know that trade would take her far beyond fixing fences and into first place of a national art competition.

Taking the Bull by the Horns

Stork had only been welding for three semesters when an instructor invited her to participate in the 2015 SkillsUSA State Competition. He suggested she join the fabrication team, but Stork received less than a warm reception. When the instructor introduced her to the other men on the team, they laughed and continued on their work. The instructor countered their indifference with the suggestion that Stork build a sculpture, despite the fact that she had never made one from metal before.

Stork rose to the challenge, making a Longhorn bull that was oxyfuel gas and gas metal arc welded. She won first place in the state level and second in nationals. In 2016, she returned to the nationals final and won first place.

The inspiration for her bull statue came from an oil canvas of a Longhorn she had painted for her instructor. Although artistically inclined, Stork never had formal art training. When it comes to crafting her sculptures, she learns the necessary process and lets her intuition guide her from there. Even though the bull was her first metal sculpture, creating it came natural to her. It was the first spark of what would become her artistic career.

"I made the Longhorn bull and that kind of set the pace for the direction of my life of going with the art," Stork said. "I can do structural, but I'm really enjoying the art and freedom of that and the reactions I'm getting for things I'm making."

Sarah Stork poses with two stingrays she made for Chris Mapes, president and chief executive officer of The Lincoln Electric Co. (All photos courtesy of Stork [@sarah_stork_] /Instagram.)

Fig. 1 — Stork performs gas metal arc welding on a metal sea turtle.

Committing to the Craft

The majority of Stork's pieces are fauna, with sculptures including stingrays, a sea turtle (Fig. 1), a shark, an Indian runner duck, fish, a hen, and more. Among these one-of-a-kind metal animals, a butterfly woman stands out from the group — Fig. 2. The sculpture, named Angela, marked what Stork called a watershed moment in her career.

"I felt like I had symbolically made myself into a butterfly. So I'm going to soar; I'm going to make art," Stork imparted. "Because before then, I was only making like one to two sculptures a year since 2015, and it was in 2019 that I did the butterfly. I thought it was like a transformation that I'm going to be an artist. And she's just beautiful. The sunlight goes through her wings. It reflects on the ground, and she's gorgeous."

Now fully emerged from her metaphorical chrysalis, Stork spreads her wings with commissioned artwork and still finds time for the occasional fabrication job. And while creating sculptures of animals and repairing farm equipment might seem very different, Stork sees a crossover between the two.

"When you're looking at a pile of metal that is for [something] structural, being an artist, you can look at that and see this could be anything you want it to be. And then on the other hand, it could still be structural," Stork explained. "The whole fabrication and structural part of that is still artistic. It still creates beauty, especially in buildings and how they design them. Truly everybody who is a welder is an artist because it takes the skill, hand-eye coordination, and ability to see what you're doing and keep a steady hand like a surgeon. They're so similar in many ways, an artist and a fabricator."

Fig. 2 — The Angela sculpture marked a watershed moment in Stork's career.

Hard Work Pays Off

Every artist knows the trial and error that comes with their craft. The first sculpture is not always the final one, a lesson Stork learned with a metal pineapple — Fig. 3. There are two versions of the piece: The second one fits her vision while the original serves as a reminder that sometimes you have to step away from a project.

"It reminds me, don't just keep welding and think that it's going to change into what you want it to be. So [the pineapple] is like a doorstop at this point," Stork revealed. "It wasn't up to the quality that I was looking for. So I stopped and cried, and then I pulled myself up by my bootstraps and started making a different pineapple, and it turned out fine. So, you've got to stop and look at what you're doing and [be able to say], nope, this is not working."

The pineapples serve as a testament to Stork's drive to not just get the job done but to do it well. She believes that quality is what makes her a good welder.

"I'm not afraid of hard work. I'm not afraid of getting burned. Not afraid of setting myself on fire," she said. "I have that work ethic of putting in 150 to 200%, seven days a week."

Her work ethic and talent were noticed by Baileigh Industrial, who came across her Instagram page (*@sarah_stork_*) and offered to sponsor her. The company provided her with equipment, such as an English wheel, planishing hammer, shrinker stretcher, Beverly shear, and more.

Fig. 3 — Stork's revised pineapple sculpture.

"They thought that I could benefit from doing cold forming and using their equipment . . . They sent out a big pallet with equipment to help me grow as an artist, and I thought that was just amazing," Stork beamed.

Armed with an arsenal of new equipment, Stork's work ethic was put to the test on a recent sculpture: a 6-ft-long

Fig. 4 — This shark sculpture was Stork's most challenging project.

Fig. 5 — Stork recently made this cat, named Meatball, as a personal project between commissions.

shark made out of 16- and 18-gauge sheet metal over a frame of $\frac{1}{8}$-in. rod — Fig. 4. It was her first piece made from both cold forming and gas tungsten arc welding (GTAW). Stork came across challenges learning how to cold form it with the new machinery and remembering how to GTAW after a lapse of time without practicing the process.

"Over time, I got better and better. It takes practice. I thought this was the most challenging [project], but I got it done," she affirmed.

A Textbook Debut

In addition to working on commissions, Stork has also contributed to the 9th edition of the *Welding Principles and Applications* college textbook by Larry Jeffus.

"[Jeffus] wanted to know if I would be willing to write up a little story about my life and welding and how it changed my life," Stork said. It was a satisfying opportunity for the female welder who was once dismissed by her classmates.

"Now that college textbook is all over the world. It's kind of funny; it's back at Austin Community College. So, there's my face when they open up the book," she mused.

On the Horizon

At the time of the interview, Stork was working on a cat sculpture (Fig. 5) as a breather between sea-life projects and upcoming commissions. Beyond that, refining her skills is an ongoing pursuit. Stork plans to continue practicing GTAW and working with mild steel on the English wheel, both with the intention to incorporate more aluminum and stainless steel in her art. A shop expansion in the near future will also help her move in this direction.

"With the shop expansion, I can have a clean room and start doing stainless and other types of metals without having all that grinding dust and rusty steel that I've been working with as of late," she said.

Further fueling her headway is the positive response her work has garnered in the welding community. With her commitment to improving, natural talent, and hard work, this Stork is set to soar to great heights. WJ

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

Q: Are there any advantages associated with the use of pulsed gas metal arc welding (GMAW-P) over conventional GMAW spray transfer when welding aluminum?

A: You will often hear that you need high heat input to successfully weld aluminum alloys when compared to steel. This is because aluminum has five times more thermal conductivity than steel. If we need more heat input to weld aluminum, why would we consider a welding process like GMAW-P that was developed largely to reduce heat input when using the GMAW process?

In the case of thicker sections of aluminum, particularly those welded in the flat position, conventional spray transfer GMAW is very well suited. Because aluminum quickly transfers heat away from the weld area, establishing the weld pool does take more energy than with steel.

However, because aluminum has a relatively low melting point, thin sections of aluminum (which have less mass to transfer heat) are especially prone to burn-through and warping. In short, there's a fine line between providing sufficient energy to ensure good fusion and controlling the heat input to prevent problems.

In many aluminum applications, such as truck and trailer bodies, light boats, storage tanks, and sign fabrication, material thicknesses of ⅜ in. and thinner are commonly used. In general, when welding this material thickness range, the GMAW-P process can help to solve heat control issues. GMAW-P can work well with thin and thicker sections because it is a modified spray transfer process. GMAW-P alternates between a high peak current and a lower background current, lowering the overall average amperage. The welding machine switches between a high peak current and a low background current 30 to 400 times per second. The pulse of the peak current propels the molten droplet across the arc and provides the energy to produce good fusion associated with spray transfer, while the low background current allows the weld pool to cool and helps prevent excessive heat input — Fig. 1.

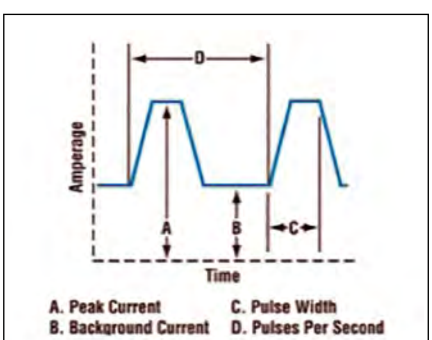


Fig. 1 — Pulsing between a high peak and low background current has the potential for creating many welding benefits.

GMAW-P of Sheet Metal

For the purposes of this article, the term sheet metal refers to a material thickness of ⅛ in. or less.

This is an area where GMAW-P has a distinct advantage over conventional spray transfer. The welding of aluminum sheet metal was customarily reserved for the gas tungsten arc welding (GTAW) process. The GTAW process better controls heat input and minimizes the risk of burn-through when used by a skilled welder. However, productivity is one issue with the GTAW process, as welding travel speeds with GTAW tend to be much slower when compared to GMAW.

The GMAW-P process, in contrast, has the potential to successfully weld aluminum sheet metal at high speeds with minimal risk of burn-through and improved distortion control.

Other Potential Advantages of GMAW-P

• GMAW-P can provide better control over the weld pool when welding out of position, which enables new operators to easily learn the process and experienced operators to better control bead appearance.

• Operators can run larger diameter wires at currents lower than what it would take to run a nonpulsed process. A larger wire diameter improves feeding performance because larger wires are stiffer and feed better. Larger diameter wires are often less expensive to purchase than smaller diameter wires.

• The process provides better control of the bead profile.

• Dialing in a wider arc cone helps tie in both sides of a joint.

• Dialing in a narrow arc cone helps focus the arc and provides good fusion at the root of a joint.

• Adjusting arc length (voltage) and wire feed speed for optimum performance helps eliminate excess heat input, over welding, and postweld grinding.

• The process allows for a clean arc transfer over the full wire speed range of each program, avoiding globular transfer mode and allowing a wider range of material thicknesses to be successfully welded.

Many GMAW-P systems for aluminum today feature built-in pulsing programs for 4xxx series silicon filler metals (e.g., 4043, 4943, and 4047) and 5xxx series magnesium filler metals (e.g., 5356, 5183, and 5556) in a variety of diameters. Most importantly, the systems are operator friendly. In many cases, all the operator must do is set the wire feed speed to match the application. Use faster wire feed speeds for thicker material and slower wire feed speeds for thinner material. The systems adjust all other voltage and pulsing variables automatically. In this respect, GMAW-P systems where operators only need to adjust wire feed speed are typically easier to use than conventional GMAW systems, which require operators to fine-tune both wire feed speed and voltage. WJ

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

BY DAN KAY

Q: For this month's column, readers are challenged to have some fun testing their brazing knowledge with this quiz.

All respondents with the correct answers will be entered in a drawing where nine prize winners will be selected. The deadline for receiving answers and entering the drawing is June 30.

Anyone interested in entering the prize drawing should email their responses to *quiz@aws.org*. Please only list numbers 1–20 with your letter choice(s) next to it.

The answers to these questions will be published in the October Brazing Q&A column along with the names of the winners.

Winners will be chosen based off chronological order. The first three all-correct submissions received get a prize choice of either the *Brazing Handbook* or a digital PDF of American Welding Society A5.8, *Specification for Filler Metals for Brazing and Braze Welding*. The following six all-correct submissions get their choice of the A5.8 or a *Jefferson's Welding Encyclopedia* compact disc, based on availability.

1. Brazing depends on capillary action for the success of most brazing applications. Who was the first person to "discover" the capillary action of liquids?

a) Thomas Edison
b) Leonardo da Vinci
c) Benjamin Franklin
d) Evangelista Torricelli
e) Sir Isaac Newton

2. Why is a vacuum furnace designed to operate with minimal atmospheric pressure inside its chamber? (Choose only one.)

a) It is well known that capillary action is stronger in a vacuum than in a gaseous atmosphere.
b) The amount of oxygen getting into the furnace is kept low, which then minimizes any oxidation that can occur.
c) It is cheaper to run a furnace without any atmosphere rather than having to add in the cost of any gaseous atmosphere to each brazing run.

3. Which of the following applies to the weight of any fixturing placed into a furnace load to help keep parts aligned and flat during the brazing operation? (Select only one.)

a) It does not matter, because all parts of the load are inside the furnace; therefore, they all come up to brazing temperature together.
b) Keep the weight of fixtures down to 50% (or less) of the weight of the parts being brazed, because every pound put into a furnace costs money to heat up to brazing temperature.
c) Weight does not matter in a vacuum furnace, because both atmosphere and gravity are removed inside a good vacuum furnace.

4. When torch brazing, what is the preferred type of torch body/tip to use?

a) A multiflame ("rosebud") type of torch tip, because the many tiny flames comprising the overall large flame help to spread the heat over a larger area of the part being brazed.
b) A single-hole torch tip, because it is reliable and readily available in most shops where it can be used by both welders and brazing personnel.

5. At cryogenic temperatures, what unique brazing filler metal (BFM) can offer not only superior superconducting electrical properties but also excellent physical properties compatible with the base metals being used in the instrumentation or equipment for these cryo applications? (Hint: Check the February 2021 Brazing Q&A column.)

a) BAg-1
b) BNi-19
c) TiBraze620
d) ZrCdMn32-3
e) SuperBraze41

6. When torch brazing, a person might actually be braze welding instead of regular brazing when which one of the following is happening?

a) The torch flame is kept focused on top of the joint to help melt the BFM wire (or paste, etc.) that is placed at the edge (or top) of the joint so as to form a fillet at that edge (or top) of the joint, and then, when the fillet has been nicely formed, the flame is removed.
b) The torch flame is held long enough at the edge of the joint to not only melt and flow the BFM but also to soften and partially melt the edges of the base metal so as to supplement the BFM flow into the joint.
c) The torch flame is adjusted to an oxygen-rich flame to make it hotter, which melts and flows the BFM faster, thus improving production rates.

7. U.S. nuclear submarines use brazing as an important joining method for a number of critical systems, such as the water piping/plumbing connections throughout the sub as well as the nuclear reactor's control-rod grids. Is this statement true or false?

a) True
b) True only for the water plumbing systems, because brazing is not allowed for joining any components in any part of a nuclear-reactor system.
c) False

8. When comparing distortion of metals by welding or brazing, which of the following is correct? (List all that apply.)

a) Welding can cause more distortion due to its intense localized heating of the base metal, whereas the broad/wide heating of base metals by torch brazing or furnace brazing is

such that distortion can never occur.
b) Localized overheating and distortion of a metal can occur by welding but can also happen with a brazing torch that is held too close to the joint and/or not moved over the total joint area sufficiently during the brazing operation.
c) When furnace brazing, distortion can occur when a massive part is heated too rapidly, causing the thinner section to expand much more rapidly than the heavier, more massive section of that same part.

9. BFM paste should not be placed on the inside of an assembly for joining some internal components of that assembly because of the following reasons (pick all those that apply):

a) Pastes are messy and difficult to keep in place when assembling parts together, thus preventing proper fitup of parts for brazing. Therefore, only use pastes on the outside of parts.
b) Because BFM pastes consist of BFM powder mixed with a gel binder, the gel will volatilize during brazing and form large amounts of gas that must be able to be vented to the outside of the assembly being brazed.
c) Due to the gel nature of BFM pastes, the paste will become liquid too soon when heated, thus running away from internal joint areas prior to reaching brazing temperature, resulting in too much contamination of interior surfaces of the assembly being brazed.
d) Because BFM pastes have so much gel in their mixtures, there will not be enough actual BFM powder available in that paste to be able to make a proper brazed joint.

10. In the famous "broken arrow" welding symbol used on drawings for weldments, there is a small circle placed at the junction where the arrow bends, indicating the joint is to be "welded all around." Why is there no similar "all-around" circular symbol used on such bent arrows when it is on drawings for brazing?

a) Designer forgetfulness
b) Only welds need to go all the way around a joint.
c) Because of the way a brazing torch is held, it is often too difficult to move it completely around a joint being brazed.
d) When a joint is properly heated, capillary action will bring the molten BFM all around the joint.

11. To properly control the flow of BFM at the edge of a joint, it is important to place dimensional limits on the maximum size of any external fillets resulting from a brazing operation, the minimum/maximum radii allowed for that fillet, the minimum distance the fillet can be to any critical surfaces nearby, or any combination of these variables. Is this true?

a) Yes, always true
b) Sometimes true
c) Only true if dimensions of fillets are controlled to +/– 0.001 in. (0.0254 mm)
d) No, never true. Do not place dimensions on fillets or on BFM flow on surfaces.

12. Induction brazing of two mild-steel tubes together in air using a silver-based BFM (BAg-5) and an Aerospace Material Specification (AMS) 3410 white brazing flux can work well, and the flux can be easily removed using hot water. But, if someone switched instead to a bronze BFM to save money, will the same flux be adequate? Can the flux be easily removed after brazing? (Pick all those that apply. Hint: See the December 2017 Brazing Q&A column.)

a) Yes, the AMS 3410 white flux is good for induction brazing with bronze BFMs and can be easily removed with water after brazing.
b) No, the white flux will probably not protect well enough at the high temperatures needed for bronze brazing and could result in hard-to-remove flux residues on the surface.
c) If you switch to bronze brazing, then you should probably switch to a higher-temperature flux, such as AMS 3411 (black flux).

13. Can BFMs be used to join metals to ceramics in furnace brazing? (Choose all that correctly apply.)

a) No. Ceramics are made of oxided materials, and BFMs cannot wet oxides.
b) No. Because ceramics are filled with oxides, brazing fluxes would be required to handle those oxides, and fluxes will break down the ceramic, significantly weakening its structure.
c) Perhaps, but only if the effect of the oxides is neutralized by putting magnesium (Mg) chips or powder in the furnace, because Mg will readily absorb oxygen, thus allowing most BFMs to nicely wet a ceramic surface.
d) Yes, if the ceramic is first metallized using a process such as the Mo/Mn coating process that finishes up with a nickel plating on top.
e) Yes, if the ceramic is brazed in a high-quality vacuum brazing atmosphere using an "active BFM," meaning a BFM that has a special "oxygen getter" added to it, such as titanium (Ti).

14. When furnace brazing, it is not necessary to do a thorough cleaning of the base metals being joined because the high temperature of the furnace (atmosphere or vacuum) will be sufficient to clean up the parts for effective brazing.

a) True
b) False

15. Radiography is a good method for detecting the presence of BFM or voids in a brazed joint, irrespective of the thickness of the base metals through which the x-rays are being sent.

a) True
b) False

16. When vacuum brazing, the harder (stronger) the vacuum (such as 10^{-8} Torr vs. 10^{-4} Torr), the better it will be for brazing.

a) True
b) False

17. The diffusion pump used on many vacuum brazing furnaces contains an oil that volatilizes into a gas that is used to trap any air molecules so that a stronger (harder) vacuum can be achieved. This liquid will darken and thicken over time as it becomes progressively contaminated. What should be done with this contaminated oil?

a) Discard it by any convenient method, such as giving it to your local trash hauler.
b) Same as "a" but only use haulers who guarantee compliance with all local disposal and environmental issues.
c) This diffusion pump liquid is actually NOT an oil but a very expensive, highly volatilizing synthetic fluid that should never be discarded with other waste shop-oils. Instead, it should be recycled back to your diffusion-pump-fluid supplier for significant credit.

18. A "hump-back" continuous belt furnace for brazing has its center hot zone section higher off the ground than either its entrance or exit chamber. Based on such a design, what is the ideal atmosphere to use in a hump-back furnace?

a) Argon
b) Hydrogen
c) Nitrogen
d) Endothermic gas
e) A special blend of helium with stratified methane

19. During furnace cooling with an inert gas, the gases with the best heat-extraction capability, in proper order from best heat-extraction capability to worst, are which of the following (pick one answer):

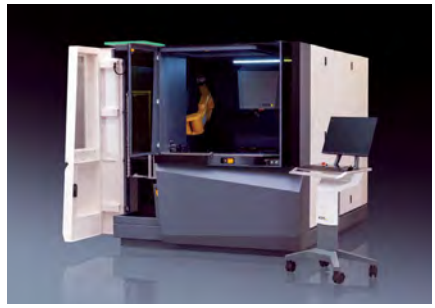
a) Hydrogen, helium, nitrogen, and argon
b) Helium, hydrogen, argon, and nitrogen
c) Hydrogen, nitrogen, xenon, and argon
d) Argon, hydrogen, helium, and nitrogen

20. If the quantity of voids in a brazed joint exceeds 20%, then that part should be rejected, because such a brazement will probably either be a weak joint or a joint with a high probability of being a "leaker."

a) True
b) False

DAN KAY (dan.kay@kaybrazing.com), *with 45 years of experience in the industry, operates his own brazing training and consulting business. This column is written sequentially by ALEXANDER E. SHAPIRO, TIM P. HIRTHE, and DAN KAY. Shapiro and Hirthe are members of and Kay is an advisor to the C3 Committee on Brazing and Soldering. All three have contributed to the 5th edition of the AWS* Brazing Handbook. *Readers are requested to email their questions for use in this column to the authors,* aquinones@aws.org, *or send to the authors' attention at* Welding Journal, *8669 NW 36 St., #130, Miami, FL 33166.*

Laser System Aimed for Advanced Applications



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changing the world for the better. From food to healthcare and education to transport, each episode explores a different topic, reveals how automation is changing what's possible, and dissects the opportunities robots are creating. The free podcast can be accessed at *global.abb/group/en/media/podcasts/the-robot-podcast*.

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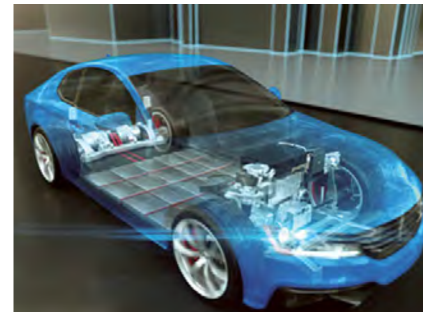
Playlist Includes 19 Videos on the Automotive Industry



The *Laser Solutions for Automotive* YouTube playlist presents 19 videos that highlight advanced laser technology. The short videos show how these technologies enable materials-processing tasks in automotive production, energy storage (batteries), and e-mobility manufacturing that were difficult or impossible to perform with lasers in the past. Some of the diverse and challenging applications featured in the playlist include welding copper, foil, and dissimilar materials. The playlist can be accessed at *youtube.com/playlist?list=PLf0ArP89rBAT5TkgWtMjlkjO0flNstnm8*.

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Report Evaluates the 2021–2025 Global Welding Power Supply Market

Global Welding Power Supply Market 2021–2025 forecasts this market will experience a growth of $2.26 billion at a compound annual growth rate of 6%. It identifies the following as major contributors to the market's growth: energy efficiency due to inverter-based welding power supplies, rising demand from the construction industry, increasing import of steel in the United

— *continued on page 90*

Fiscal 2020 year in review

By Gesana Villegas, AWS Chief Financial Officer/ Chief Administrative Officer

When the pandemic hit back in March of 2020 and we were all uncertain as to what would happen, this narrative did come to mind: How comforting it will be to report we weathered the storm relatively well because AWS and the AWS Foundation are financially strong. In 2020, we put into practice what we do best, which is prudent financial rigor and staying focused even in challenging times. Overall, we had a relatively good year considering the impact of COVID-19 worldwide. The power of resiliency, as our Treasurer points out, allowed us to get through, while learning a few lessons along the way.

Every year, I allude to our ability to add significantly to our financial position and at the same time move the needle forward by executing on our strategic goals; this year we were able to do both. The pandemic hit us at an opportune time considering that the release of one of our main flagship codes (D1.1) runs on a five-year cycle, 2020 being that year. Our standards sales, renewals, as well as new and existing virtual content helped offset the decline associated with the cancellation of live events. Cost containment based on carefully planned scenario analyses played a key role in how we ended the year.

Our operating revenues came in at $34.0 million, a decline of $7.0 million or 17.1% from 2019. Our operating surplus came in at $7.4 million, decreasing by 26.4% from the prior year. Given the unprecedented times, our financials generated a nice bottom line. We are pleased to report we operated in the green for most of the year. Of course, we experienced disappointing moments when we had to cancel event after event and the volume of activities declined significantly, but we remained calm while navigating through uncharted waters. We found ourselves applying our creative business mindset with the goal of keeping our constituents engaged and servicing them to the extent possible, which at times meant running events at a loss. The discipline of adhering to our cost measures and spending according to the models developed was coupled with making every effort to drive activities via sales calls, recruitment and retention campaigns, bundles, discounts, waving certain fees and extending grace periods, as well as complimentary trials, podcasts, videos and more. These actions truly paid off.

As our Treasurer mentioned in his editorial, we received PPP funding, and the proud moment came when we returned the funds within the same day of receipt after determining we could run on our own steam, allowing other organizations in more need to tap into the governmental financial assistance. The second proud moment for us came when we determined we did not need to furlough or make changes related to our employees. It validated our stability, which took years to build. It is worth noting we were able to keep our engine running because of the industry we serve; AWS supports essential businesses, and we are proud of our mission.

Our annual expositions in Mexico, Canada and the U.S. did not materialize. We forfeited about $4.7 million of potential revenues generated through our trade shows. Fortunately, we were able to recover in Mexico through insurance proceeds received, which made up for the costs incurred to date. Revenues generated through our Standards sales increased by 17.5%. The Education and Training main revenue stream, which is our live

CWI training, was down 46.2%; however, we were able to offset the decline through virtual educational offerings including the 8-week and 2-week CWI training courses, our new professional development series, and our Welding Curriculum. The Certification main revenue stream, which is our CWI exam, was down 30.7%; however, increases in renewals and recertification helped offset the decline. It was good to see improvement in our international business during the last quarter, mainly in China. They seemed to have bounced back, giving us a feel of possible recovery on the horizon, though the timing is still uncertain. Member dues were down by 11.2%, but retention remained reasonably steady, which speaks to the value we bring to the members. We aim to serve our member needs and deliver the ultimate experience, though we know much work still needs to be done. Advertising declined by 31.9%, a continued trend over the past couple of years, making it a significant focal point for us.

Many highlights are worthy of special mention during an unprecedented and unimaginable year:

(1) We welcomed our new CEO and Executive Director, Gary Konarska, shortly after going remote.

(2) Gary stayed engaged with staff via CEO weekly videos and quarterly town halls to keep everyone apprised of our current state; it was an effective way for staff to stay connected and updated as they got to know the CEO.

(3) Our Executive Committee met monthly (February-August vs. twice a year) to discuss the financials, status of strategic goals as well as other pertinent topics; our Board of Directors met five times vs. twice a year.

(4) Human Resources played a critical role during the pandemic, from staff interaction (including staff surveys to gauge sentiment) to ensuring we follow CDC guidelines. Our 3:05 p.m. Coffee Channel became a popular forum for staff to chat and exchange thoughts.

(5) Safety and health, both physical and mental, became our #1 priority.

(6) Staff and volunteers showed resilience by learning to adapt, including on the technical front. They chose to stay positive and highly engaged throughout the year; virtual meetings became the mode of operation and we got better over time.

(7) Going remote went as successfully as it could. Thanks to our IS department, we were equipped to do so prior to COVID-19.

(8) It was a productive year, nonetheless. Volunteer participation was phenomenal; we made great progress on multiple documents; District Conferences were held virtually; and Section Meetings were conducted on virtual platforms, a new way forward as a method to increase participation.

(9) Collaboration and communication heightened, and results improved accordingly.

(10) Downtime or no downtime, we focused on continuous learning with the launch of our "12 Minutes Per Day" personal growth initiative. LinkedIn learning is our main platform.

(11) Developed an internal training course for our staff to navigate through our own CRM platform.

(12) Curated Welding Fundamentals Training for in-house use. The "Introduction to Welding" training course that will expose staff to welding concepts. All staff will complete it by Q1 of 2021.

(13) Established the framework for the AWS Learning Academy to focus on the professional development of our staff. We rolled out two groups – the organization leadership cohort and the strategic leadership cohort.

(14) Reached out to sister organizations to get a pulse on the impact of COVID-19. We gathered great insights — from financial trends to remote work policy, virtual offerings, and communication platforms.

(15) Enhanced our marketing/communications internally as well as externally via digital and social media.

(16) Completed our data governance project and fine-tuned our access rights.

(17) Reviewed and revised existing practices – from procurement to retention policy, and rolling out new performance evaluation practice.

(18) Conducted a CWI Survey (entire population) to gather insights to help improve the program; continuous improvement is always on our minds.

(19) Implemented metrics to measure customer service levels, application processing flow, event/exam attendance, and more.

(20) Developed a two-year business plan for each unit (including support units) aligned with the organizational strategic plan. The roadmaps give us visibility into the overall resource needs and direction, and the exercise challenged us to be forward thinkers.

As it relates to our strategic goals, we are happy to report we were able to accomplish most of the goals we set out for 2020. Of special mention are the following:

(1) Digital Transformation (DT):

a. The message is loud and clear: We continue to emphasize DT is not only about technology. To be successful, we need to change the mindset of those involved to foster innovation and embrace changes in culture and processes.

b. We developed a comprehensive 3-year Digital Transformation Roadmap and executed many projects throughout the year as follows:

1. We rolled out our Certified Welder Portal to submit new CW applications electronically, and we are working on transitioning ATF's from paper-based audit application and documentation to fully online.

2. Launched SpecBuilder, our online committee management and balloting system.

3. Implemented a new LMS to deliver online courses. This more intuitive platform improves the customer experience.

4. Developed the purchase order process online platform and automated our accounts payable approval process, necessary in a remote environment.

5. Substantially completed our CRM upgrade.

6. Completed our digital assessment, content audit and delivery, and vetted and selected our ECMS (enterprise content management system).

7. Publically launched our text/web chat feature.

8. Implemented IVR (Interactive Voice Response) to allow the check of certification and membership application status via phone menu.

9. Evaluated and selected a virtual video conference platform of choice to use across the organization.

(2) Other goals of special mention include:

a. Utilized the findings of the Welding Inspection Market Study to act on international opportunities identified, starting with the Indian Market.

b. Developed free content offerings including "how-to" videos. The AWS certified video series shows the value of certification, as well as other informational webinars and podcasts.

c. Developed paid content such as the Instructional Strategies for Welding Educators video training course, the online 2-week CWI Seminar, online professional development webinars, and the Education 2020 Virtual Summit.

d. Launched the Member Benefit Webinar series.

e. Launched the Welder Qualifier Endorsement Training/Exam online.

f. Updated the Piping Exam/Endorsement, the Certified Welding Engineer exam, the Welding Procedure Qualification Endorsement, and the D1.1 2020 CWI exam.

g. Published 26 revised and 5 new ANSI standards.

h. Engaged in a Process Improvement Initiative, starting with Certification followed by Membership; both great opportunities identified to help us serve the membership at a more efficient and effective level.

On the balance sheet side, our total assets at year-end 2020 were $231.2 million, an increase of $34.2 million or 17.3% over 2019. Approximately 84% of our total assets are invested in the marketplace. Total net assets (net worth) including the AWS Foundation came in at $224.1 million, an increase of $35.6 million or 18.9% over 2019. The market played a big factor in the overall increase of our assets.

Highlighting our reserves, we ended the year with $74.9 million, an increase of $19.5 million or 26.1% over 2019. Our financial results from operations allowed us to transfer $2.5 million to our reserves, which is truly remarkable given the environment. Positive market change of $15.1 million contributed to the overall growth of our reserves, a fascinating phenomenon beyond what we could have possibly imagined back when the pandemic hit.

Our financial discipline and fiscal responsibility have allowed us to build our reserves over the years, giving us the ability to continue to focus on our mission even in periods during downturns. We definitely put this to the test in 2020. Reserves give us the flexibility to provide, invest, and participate in initiatives that help us strengthen our position in the marketplace. We have taken a proactive approach to look at opportunities to meaningfully deploy our reserves. This is a topic of heavy discussion.

Fiscal year 2020 was like no other. We are thankful to be able to continue moving ahead and accomplishing many goals even in a period of heavy turmoil. As I always say, the impetus behind how we propelled our business forward is our capable staff and the thousands of incredibly devoted volunteers, all of whom are very passionate about the welding industry. We sincerely thank them for weathering the storm alongside us, as well as all of our constituents who believe in us and recognize the impact we have on the industry. It is a great feeling to know we are essential to many of our constituents.

AWS Foundation Highlights for 2020

The AWS Foundation focuses on developing the welding workforce by supporting programs that attract students and young professionals to the industry. We are pleased to report that despite challenging times in 2020, the Society was able to transfer $2.5 million to the AWS Foundation. Over the years, numerous awards have been added via transfers from the Society and its reserves. The funding helps support the mission of the AWS Foundation, which is to financially support programs that ensure the growth and development of the welding industry through research and educational opportunities.

As mentioned by the Chairman of the AWS Foundation in the 2020-2021 AWS Foundation Annual Report, the pandemic did not slow us down. We continued to work hard to attract and inspire young people and career changers to consider welding as a profession. We engaged via articles, monthly newsletters and videos in various platforms and social media channels. Please check out our DYI videos and the Arc2Art project, as well as the Arc Junkies WELD podcasts.

We are pleased to report the AWS Foundation continues to exhibit nice growth over the years in terms of asset size and programs. The positive momentum in the marketplace contributed to the growth in 2020, adding $15.1 million in market gains.

Net assets (which are 99% invested in the marketplace) increased to $98.4 million on December 31, 2020, increasing by $15.4 million or 18.6%. The Society continues to be the main supporter of the AWS Foundation. Over the years, the Society has transferred more than $50 million to the AWS Foundation. Recent funding allowed for programs such as workforce development grants and welder training and competition scholarships. Grants to secondary and technical/vocational schools, with the goal of increasing attendance and graduation rates, have been a great success.

Our Scholarship Matching Program is back in effect — be sure to take advantage of the program. We continue to match contributions toward scholarships at 100%. The total matching dollars since the program's inception in 2012 stands at $8.5 million. In 2020, we awarded 1,136 Scholarships worth more than $1.6 million, 19 Grant Awards totaling $371,500, and four Fellowships totaling $120,000. Since 1991, when the AWS Foundation began offering scholarships, almost $13 million has been awarded.

Find out how you can help in the mission of alleviating the welder workforce shortage. You, too, can make an impact by helping us increase awards via your generous contributions. Please contact Monica Pfarr at *mpfarr@aws.org*.

AWS Highlights for 2020

Expositions

All expositions were canceled in 2020 because of COVID-19. Insurance proceeds helped us offset the revenues not generated due to cancellations.

Educational Services

Revenues excluding conferences were $4.3 million. Overall revenues decreased by 20.4% from 2019. CWI public seminars, when combined with custom seminars, decreased by 46.2% in comparison to 2019. Online educational courses including our 8-week and most recent 2-week CWI training course had an increase of 19.4% over 2019. Conference and other event revenues had a decline of 26.4%.

Membership

Member dues revenues decreased by 11.2% from 2019. Member value remains a key focus for us. Our overall membership count was 65,233. International Members were 5,501 or 8.4% of total membership, and Student Members were 9,675 or 14.8% of total membership.

Certification and Accreditation

Our top revenue-producing business generated $12.0 million, a decrease of 12.3% when compared to 2019. CWI Examination, our key product, had a decrease of 30.7% in comparison to 2019. International certification activities decreased by 8.3% from 2019, while China showed an increase of 6.9%. CWI Renewals and Recertification were up 4.2% and 5.3%, respectively. Our Welder Certification had a decrease of 19.9% over 2019. Total international activities organization-wide came in at $6.4 million, in line with 2019.

Standards Sales

The 2020 D1.1 *Structural Welding Code — Steel* edition, our flagship code, was a key driver for us. It is the top source of revenues to support Standards Development. We also released the 2020 D1.5 *Bridge Welding Code*, which added to our revenues, helping offset the overall decline in revenues in other areas. Revenues from these editions and other standards, which include royalties received from third parties, helped generate $9.9 million in total hard copy and electronic book sales, an increase of 9.1% from 2019.

In Summary

Looking back at 2020, we never imagined facing such a disruptor as COVID-19, which impacted so many lives and businesses. We were fortunate that the impact was minimized by the resiliency everyone showed, from our staff to our volunteers. It is uplifting to see what a critical role welding plays in the economy, including infrastructure, transportation and equipment, all relevant during a pandemic. We determined early on that COVID-19 would not get the best out of us. We exist to protect and improve lives. We knew we had a mission to serve and that is what drove us. Our conversation became how to get the training, certification, and body of knowledge (standards) to the people in order to get through this crisis, even if it meant operating at a loss.

We feel accomplished being able to operate in the black and add to our financial strength even in a period of worldwide upheaval. Our financial discipline, business drive and determination to carry our mission and serve our constituency allowed us to have a relatively good year. We were able to generate good financial results and accomplish the goals we set out to meet in 2020, including projects within DT, a critical strategic thrust for us. We were also pleased to see the market play its role when it came to our investment portfolio.

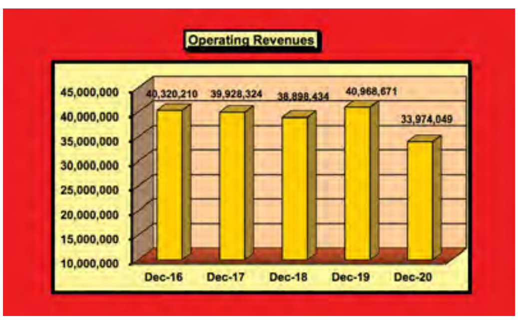
A few takeaways from 2020: Safety and health have always been top-of-mind for us. However, after going through this pandemic, it has taken precedence. We consider safety and health first in everything we do. Some lessons learned along the way are the importance of staying connected and engaged, and the importance of collaboration and communication, which helped elevate our productivity. We broke silos and promoted teamwork. Sentiment and empathy for what goes on in people's personal lives make us better leaders, something we emphasize to a greater extent because of the pandemic. As with many organizations, working arrangements — whether it is time at the office, remote work, or a hybrid model — is a topic we are discussing as a way forward to reach what will work best for us. We also learned the importance of adaptability, particularly embracing technology. Not only did we focus on the business, we also took the opportunity to focus on professional growth through learning and took the time to improve existing practices.

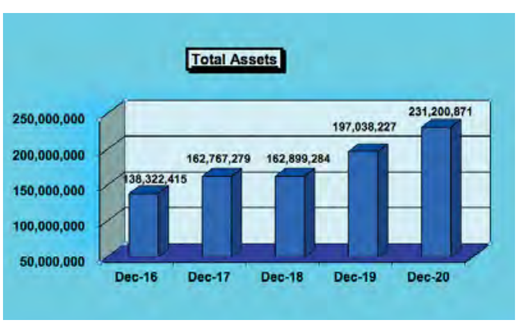
I knew back when the pandemic started that we would get through it relatively well. Coming from financial strength affords you that kind of thought and optimism. Not only did we get out, we got out stronger than ever.

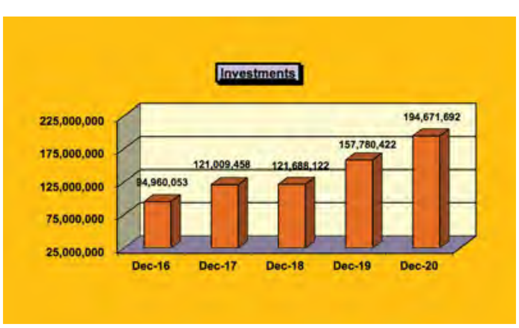
As always, the AWS Board of Directors and AWS Foundation Trustees would like to express their appreciation to all of our members, volunteers, industry leaders, and cooperating organizations that share our goals in helping us make this another good year. We also appreciate our capable staff, who helped achieve our 2020 results.

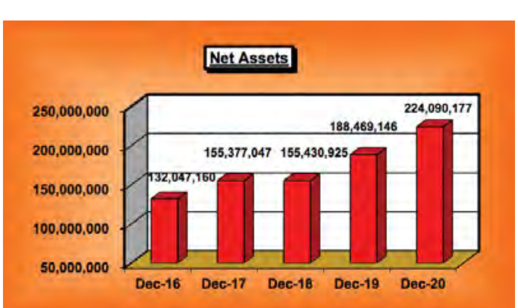
Five-year comparisons

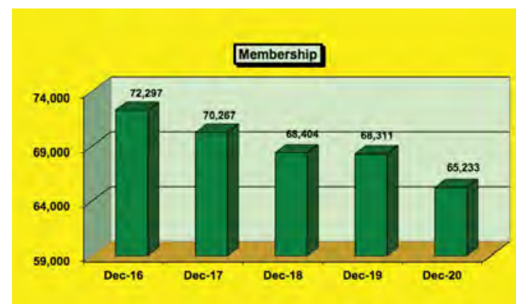
	Dec-16	Dec-17	Dec-18	Dec-19	Dec-20
Operating Revenue	40,320,210	39,928,324	38,898,434	40,968,671	33,974,049
Total Assets	138,322,415	162,767,279	162,899,284	197,038,227	231,200,871
Investments	94,960,053	121,009,458	121,688,122	157,780,422	194,671,692
Net Assets	132,047,160	155,377,047	155,430,925	188,469,146	224,090,177
Membership	72,297	70,267	68,404	68,311	65,233
Certification	12,873,622	13,070,779	12,651,370	11,975,240	10,747,284
International	4,008,800	4,434,700	3,137,800	3,595,700	3,501,261

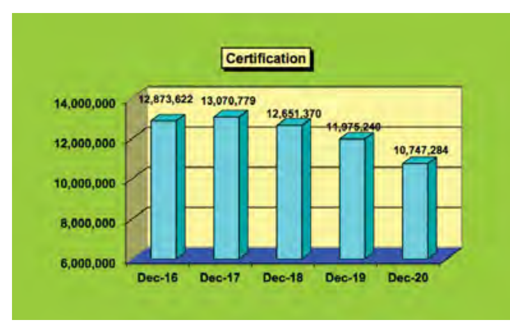


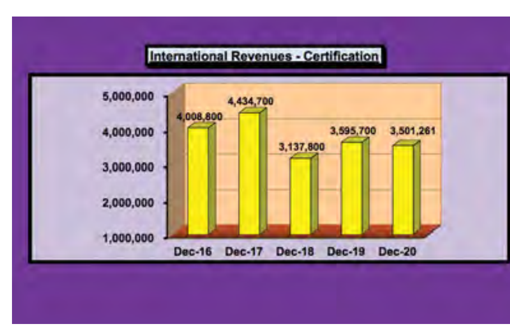












INDEPENDENT AUDITOR'S REPORT

American Welding Society, Inc. and AWS Foundation
Miami, Florida

Report on the Combined Financial Statements

We have audited the accompanying combined financial statements of American Welding Society, Inc. and AWS Foundation, which comprise the combined statement of financial position as of December 31, 2020, and the related combined statement of activities, functional expenses, and cash flows for the year then ended and the related notes to the combined financial statements.

Management's Responsibility for the Combined Financial Statements

Management is responsible for the preparation and fair presentation of these combined financial statements in accordance with accounting principles generally accepted in the United States of America; this includes the design, implementation, and maintenance of internal control relevant to the preparation and fair presentation of combined financial statements that are free from material misstatement, whether due to fraud or error.

Auditor's Responsibility

Our responsibility is to express an opinion on these combined financial statements based on our audit. We conducted our audit in accordance with auditing standards generally accepted in the United States of America. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the combined financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the combined financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the combined financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the entity's preparation and fair presentation of the combined financial statements in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the entity's internal control. Accordingly, we express no such opinion. An audit also includes evaluating the appropriateness of accounting policies used and the reasonableness of significant accounting estimates made by management, as well as evaluating the overall presentation of the combined financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

Opinion

In our opinion, the combined financial statements referred to above present fairly, in all material respects, the combined financial position of American Welding Society, Inc. and AWS Foundation as of December 31, 2020, and the changes in their net assets and their cash flows for the year then ended in accordance with accounting principles generally accepted in the United States of America.

Other Matter — Prior Year Combined Financial Statements

The combined financial statements of American Welding Society, Inc. and AWS Foundation as of and for the year ended December 31, 2019 were audited by Morrison, Brown, Argiz & Farra, LLC ("MBAF"), whose partners and professional staff joined BDO USA, LLP as of January 16, 2021, and has subsequently ceased operations. MBAF expressed an unmodified opinion on those statements in their report dated April 2, 2020.

BDO USA, LLP

Certified Public Accountants
April 9, 2021

American Welding Society®

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AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINED STATEMENT OF FINANCIAL POSITION DECEMBER 31, 2020

(WITH COMPARATIVE TOTALS AS OF DECEMBER 31, 2019)

ASSETS	2020	2019
Cash and cash equivalents	$ 6,285,569	$ 5,107,464
Accounts and other receivables, net of allowance for doubtful accounts of approximately $399,000 and $303,000 for 2020 and 2019, respectively	2,062,418	3,387,045
Prepaid expenses	202,176	447,846
Investments	194,671,692	157,780,422
Deposits	2,372,824	2,224,542
Other assets	1,327,340	2,527,340
Inventory	322,175	331,828
Goodwill	1,625,186	1,625,186
Property and equipment, net	22,331,491	23,606,554
TOTAL ASSETS	**$ 231,200,871**	**$ 197,038,227**

LIABILITIES AND NET ASSETS		
LIABILITIES		
Accounts payable, accrued expenses and other liabilities	$ 2,184,235	$ 3,871,129
Deferred membership, subscription and seminar income	4,926,459	4,697,952
TOTAL LIABILITIES	7,110,694	8,569,081
COMMITMENTS AND CONTINGENCIES (NOTE 15)		
NET ASSETS		
Without donor restrictions	179,947,966	150,147,559
With donor restrictions	44,142,211	38,321,587
TOTAL NET ASSETS	224,090,177	188,469,146
TOTAL LIABILITIES AND NET ASSETS	**$ 231,200,871**	**$ 197,038,227**

The accompanying notes are an integral part of these combined financial statements.

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINED STATEMENT OF ACTIVITIES FOR THE YEAR ENDED DECEMBER 31, 2020

(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2019)

	Net Assets Without Donor Restrictions			Net Assets		
	Revenues	Expenses	Change in Net Assets	With Donor Restrictions	Total 2020	Total 2019
OPERATING:						
Certification	$ 11,971,471	$ 3,688,584	$ 8,282,887	$ -	$ 8,282,887	$ 8,941,194
Standards development	10,095,137	2,784,750	7,310,387	-	7,310,387	5,823,580
Exposition (including insurance proceeds of $1,406,892 in 2020)	1,406,892	1,010,887	396,005	-	396,005	4,078,674
Membership	3,758,788	1,514,008	2,244,780	-	2,244,780	2,477,461
Educational services	4,601,268	3,945,093	656,175	-	656,175	909,904
Publishing and editorial	1,881,166	2,048,307	(167,141)	-	(167,141)	404,034
WEMCO	96,539	113,652	(17,113)	-	(17,113)	(95,524)
RWMA	98,692	135,314	(36,622)	-	(36,622)	(37,969)
ITSA	64,092	78,072	(13,980)	-	(13,980)	77,205
International activities	-	101,317	(101,317)	-	(101,317)	(345,142)
Marketing and corporate communications	-	990,348	(990,348)	-	(990,348)	(1,006,506)
Administration	-	8,243,011	(8,243,011)	-	(8,243,011)	(10,042,980)
Building operations	-	759,465	(759,465)	-	(759,465)	(812,365)
Board approved programs	-	-	-	-	-	(118,298)
TOTAL CHANGE IN OPERATING FUND BEFORE LOSS & TRANSFERS	33,974,045	25,412,808	8,561,237	-	8,561,237	10,253,268
INTANGIBLE ASSET IMPAIRMENT LOSS (NOTE 5)	-	1,200,000	(1,200,000)	-	(1,200,000)	-
WRITE OFF OF GOODWILL (NOTE 6)	-	-	-	-	-	(250,000)
INTER-FUND TRANSFERS	670,000	9,276,486	(8,606,486)	-	(8,606,486)	(12,145,199)
TOTAL CHANGE IN OPERATING FUND AFTER LOSS & TRANSFERS	34,644,045	35,889,294	(1,245,249)	-	(1,245,249)	(2,141,931)
RESERVE:						
Interest and dividends	2,388,440	-	2,388,440	-	2,388,440	2,717,057
Gain on investments, net	12,713,119	-	12,713,119	-	12,713,119	9,392,921
TOTAL CHANGE IN RESERVE FUND BEFORE TRANSFERS	15,101,559	-	15,101,559	-	15,101,559	12,109,978
INTER-FUND TRANSFERS	6,684,468	-	6,684,468	-	6,684,468	8,552,223
TOTAL CHANGE IN RESERVE FUND AFTER TRANSFERS	**$ 21,786,027**	**$ -**	**$ 21,786,027**	**$ -**	**$ 21,786,027**	**$ 20,662,201**

The accompanying notes are an integral part of these combined financial statements.

(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2019)

	Net Assets Without Donor Restrictions			Net Assets		
	Revenues	Expenses	Change in Net Assets	With Donor Restrictions	Total 2020	Total 2019
AWS FOUNDATION:						
Donations	$ 66,703	$ -	$ 66,703	$ 307,391	$ 374,094	$ 932,766
Interest and dividends	2,435,943	-	2,435,943	70,014	2,505,957	3,039,008
Gain on investments, net	12,312,367	-	12,312,367	419,342	12,731,709	10,466,936
Net assets released from restrictions	938,611	-	938,611	(938,611)	-	-
Operating expenses	-	966,056	(966,056)	-	(966,056)	(1,383,874)
Scholarships, grants, and other programs	-	1,663,793	(1,663,793)	-	(1,663,793)	(1,786,937)
Fellowships	-	90,289	(90,289)	-	(90,289)	(120,000)
TOTAL CHANGE IN AWS FOUNDATION FUND BEFORE TRANSFERS	15,753,624	2,720,138	13,033,486	(141,864)	12,891,622	11,147,899
INTER-FUND TRANSFERS	2,500,000	5,919,488	(3,419,488)	5,962,488	2,543,000	5,043,000
TOTAL CHANGE IN AWS FOUNDATION FUND AFTER TRANSFERS	18,253,624	8,639,626	9,613,998	5,820,624	15,434,622	16,190,899
PROPERTY FUND:						
Building operations	713,195	446,582	266,613	-	266,613	166,096
Insurance claim expense	-	-	-	-	-	(389,020)
TOTAL CHANGE IN PROPERTY FUND BEFORE TRANSFERS	713,195	446,582	266,613	-	266,613	(222,924)
INTER-FUND TRANSFERS	49,018	670,000	(620,982)	-	(620,982)	(1,450,024)
TOTAL CHANGE IN PROPERTY FUND AFTER TRANSFERS	762,213	1,116,582	(354,369)	-	(354,369)	(1,672,948)
CHANGE IN NET ASSETS			29,800,407	5,820,624	35,621,031	33,038,221
NET ASSETS, BEGINNING			150,147,559	38,321,587	188,469,146	155,430,925
NET ASSETS, ENDING			**$ 179,947,966**	**$ 44,142,211**	**$ 224,090,177**	**$ 188,469,146**

The accompanying notes are an integral part of these combined financial statements.

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINED STATEMENT OF FUNCTIONAL EXPENSES FOR THE YEAR ENDED DECEMBER 31, 2020

(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2019)

	Program Services	Management and General	Total 2020	Total 2019
Salaries	$ 7,512,089	$ 2,923,964	$ 10,436,053	$ 11,662,623
Retirement plan	536,890	213,045	749,935	802,473
Other benefits	1,459,244	261,202	1,720,446	2,079,732
Payroll taxes	392,201	339,726	731,927	808,091
Professional services	968,720	638,306	1,607,026	1,962,796
Promotion	336,248	14,169	350,417	464,338
Information services	201,445	728,372	929,817	878,165
Occupancy and office expenses	274,462	321,421	595,883	865,693
Travel	80,411	18,339	98,750	653,183
Shows and other events	724,849	39,425	764,274	647,767
Depreciation and amortization	593,938	1,333,825	1,927,763	2,071,509
Insurance	-	251,798	251,798	273,839
Postage and shipping	487,874	39,631	527,505	717,396
Publications	903,007	-	903,007	1,278,644
Education/Certification	2,390,302	-	2,390,302	3,200,891
Section rebates	402,011	-	402,011	432,000
AWS Asia	14,530	-	14,530	186,928
Technical standards cost of sales	446,415	-	446,415	571,370
Provision for bad debts	-	100,000	100,000	100,000
Board activities	-	86,864	86,864	694,147
Foundation-Mobile trailer and other program expenses	468,463	-	468,463	663,529
Foundation-Grants and other assistance	1,404,144	-	1,404,144	1,636,038
Other expenses	456,230	621,477	1,077,707	1,294,122
Credit card processing fees	594,491	-	594,491	555,833
Other expenses-Doral property	-	-	-	16,479
Insurance claim expense	-	-	-	389,020
TOTAL EXPENSES	**$ 20,647,964**	**$ 7,931,564**	**$ 28,579,528**	**$ 34,906,606**

The accompanying notes are an integral part of these combined financial statements.

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINED STATEMENTS OF CASH FLOWS FOR THE YEAR ENDED DECEMBER 31, 2020

(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2019)

	2020	2019
CASH FLOWS FROM OPERATING ACTIVITIES:		
Change in net assets	$ 35,621,031	$ 33,038,221
Adjustments to reconcile change in net assets to net cash provided by operating activities:		
Depreciation and amortization	1,927,763	2,071,509
Intangible asset impairment loss	1,200,000	-
Write off of goodwill	-	250,000
Gain on investments, net	(25,444,825)	(19,859,857)
Provision for bad debts	100,000	100,000
Decrease (increase) in assets:		
Accounts and other receivables	1,224,627	743,366
Prepaid expenses	245,670	(88,386)
Deposits	(148,282)	305,975
Inventory	9,653	(70,606)
(Decrease) increase in liabilities:		
Accounts payable, accrued expenses and other liabilities	(1,686,894)	1,145,954
Deferred membership, subscription and seminar income	228,507	(45,232)
NET CASH PROVIDED BY OPERATING ACTIVITIES	13,277,250	17,590,944
CASH FLOWS FROM INVESTING ACTIVITIES:		
Insurance proceeds received for damaged property	-	1,434,492
Purchases of property and equipment	(652,700)	(1,258,011)
Purchases of investments	(27,705,160)	(25,268,485)
Sales of investments	16,258,715	9,036,042
NET CASH USED IN INVESTING ACTIVITIES	(12,099,145)	(16,055,962)
CASH FLOWS FROM FINANCING ACTIVITIES:		
Proceeds from Paycheck Protection Program loan (NOTE 1)	2,627,200	-
Repayment of Paycheck Protection Program loan (NOTE 1)	(2,627,200)	-
NET CASH USED IN FINANCING ACTIVITIES	-	-
NET INCREASE IN CASH AND CASH EQUIVALENTS	1,178,105	1,534,982
CASH AND CASH EQUIVALENTS, BEGINNING OF YEAR	5,107,464	3,572,482
CASH AND CASH EQUIVALENTS, END OF YEAR	**$ 6,285,569**	**$ 5,107,464**

The accompanying notes are an integral part of these combined financial statements.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES

Organizations and Purpose

American Welding Society, Inc. ("AWS") and AWS Foundation ("Foundation") (collectively, the "Organizations") are not-for-profit entities, exempt from income tax under Section 501(c)(3) of the Internal Revenue Code ("IRC") and are primarily engaged in welding technology, education and research activities.

The financial statements of AWS include the accounts of Weldmex, LLC, 8669 Doral, LLC, and World Engineering Xchange, LLC ("WEX LLC") (the "Affiliates"). On October 16, 2012, AWS acquired a 100% interest in Weldmex, LLC (NOTE 5). On September 13, 2013, in connection with the purchase of the Organizations' new headquarters, AWS created 8669 Doral, LLC. On July 16, 2015, AWS acquired the operations of WEX, LLC (NOTE 6). On April 7, 2014, AWS established Weldmex – AWS, S. De R.L. De C.V. ("Weldmex – Mexico"), a limited liability company in Mexico for bank purposes through Weldmex, LLC.

Basis of Accounting

The combined financial statements have been prepared on the accrual basis of accounting in conformity with accounting principles generally accepted in the United States of America ("U.S. GAAP"). The accounts of the Organizations are maintained for internal reporting purposes in accordance with the principles of fund accounting.

Principles of Combination

The accompanying combined financial statements include the accounts of American Welding Society, Inc. and AWS Foundation. Combined financial statements are presented as the entities are under common control. All material inter-organization accounts and transactions have been eliminated in the combination.

Basis of Presentation

Net assets and revenues, gains and losses are classified into two classes of net assets based on the existence or absence of donor-imposed restrictions. The two classes of net asset categories are as follows:

> **Net assets without donor restrictions:** Net assets that are not subject to donor-imposed restrictions and may be expended for any purpose in performing the primary objectives of the Organizations. These net assets may be used at the discretion of the Organizations' management and the Board of Directors (the "Board").
>
> **Net assets with donor restrictions:** Net assets subject to stipulations imposed by donors and grantors. Some donor restrictions are temporary in nature; those restrictions will be met by actions of the Organizations or by the passage of time. Other donor restrictions are perpetual in nature, where the donor has stipulated the funds be maintained in perpetuity. Donor restricted contributions are reported as increases in net assets with donor restrictions. When a restriction expires, net assets are reclassified from net assets with donor restrictions to net assets without donor restrictions in the Combined Statement of Activities.

The transactions of the Organizations are categorized into separate funds. The purpose and net asset classification are as follows:

- **Operating** — This fund is used to account for all net assets without donor restrictions of AWS, except for those accounted for in the Reserve and Property funds. The operating fund also provides administrative support to the Foundation.
- **Reserve** — This fund is used to account for Board designated reserve funds which are to be used to supplement the cash needs of AWS.
- **AWS Foundation** — The Foundation's net assets with donor restrictions consist of donor-restricted contributions to be used for awards, scholarships, and an endowment fund. AWS Foundation also has net assets without donor restrictions that have been Board designated for a variety of purposes.
- **Property Fund** — This fund is used to account for AWS net assets without donor restrictions associated with its headquarters located in Doral, Florida.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Management Estimates

The preparation of combined financial statements in conformity with U.S. GAAP requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the combined financial statements and the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Risks and Uncertainties

Financial instruments that potentially subject the Organizations to a concentration of credit risk are cash, investments and accounts receivable. The Organizations place their temporary cash and cash equivalents with high quality financial institutions. At times, cash deposits may be in excess of the Federal Deposit Insurance Corporation's insured limits. The Organizations' customer base is relatively stable. Management closely monitors outstanding balances and relationships with customers, and collection losses have historically been immaterial. As of December 31, 2020, two customers represent 58% of the accounts and other receivables balance.

The Organizations have investments in mutual funds that are exposed to various risks, such as interest rate, market and credit risk. Due to the level of risk associated with certain investment securities and the level of uncertainty related to changes in the value of investment securities, it is at least reasonably possible that changes in risks in the near term could materially affect the Combined Statement of Activities. To minimize risks, the Organizations, through their investment advisor and investment committee, monitor these investments and the associated risks on a regular basis.

COVID-19 and CARES Act

On January 30, 2020, the World Health Organization ("WHO") announced a global health emergency because of a new strain of coronavirus originating in Wuhan, China (the "COVID-19 outbreak") and the risks to the international community as the virus spreads globally beyond its point of origin. In March 2020, the WHO classified the COVID-19 outbreak as a pandemic, based on the rapid increase in exposure globally.

The full impact of the COVID-19 outbreak continues to evolve as of the date of this report. The Organizations' major revenue sources are from certifications, standards development, expositions, memberships and investment income. Several events that were scheduled to take place in 2020 were cancelled due to the pandemic. AWS filed an insurance claim and was able to offset the lost revenue from the cancelled events with the insurance proceeds. The Organizations experienced a reduction in revenues during 2020 due to reduced operations and demand. Further, the Organizations have taken steps to reduce expenses by delaying staff hires and lowering budget spend as a result of the decreasing revenue trend experienced in 2020. As of the date of this report, investment values were not adversely impacted. Management is actively monitoring the impact of the global situation on its financial condition, liquidity, operations, and workforce. Given the daily evolution of the COVID-19 outbreak and the global responses to curb its spread, the Organizations are not able to estimate the effects of the COVID-19 outbreak on its results of operations, financial condition, or liquidity for future years. However, the outbreak may have a continued material adverse impact on economic and market conditions, triggering a period of national economic slowdown. As such, the Organizations' financial condition and liquidity may be negatively impacted for the year ended December 31, 2021.

On March 27, 2020, the "Coronavirus Aid, Relief, and Economic Security ("CARES") Act" was signed into law. The CARES Act, among other things, includes provisions relating to refundable payroll tax credits and deferment of employer side social security payments. It also appropriated funds for the SBA Paycheck Protection Program loans that are forgivable in certain situations to promote continued employment, as well as Economic Injury Disaster Loans to provide liquidity to small businesses harmed by COVID-19. In April 2020, AWS received funding for a Paycheck Protection Program loan in the amount of $2,627,200 and returned the funds to the financial institution on the same day of receipt. Management determined that they did not need to rely on such funding to support the Organizations. The Organizations noted no material impact from the other tax provisions of the CARES Act.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Cash Equivalents

The Organizations consider all highly liquid investments with a purchase date maturity of three months or less to be cash equivalents.

Accounts and Other Receivables, Net

Accounts and other receivables consist of balances related to exposition, certification exams, royalties and other miscellaneous programs and are stated at the amount management expects to collect from outstanding balances at year-end. Management provides for probable uncollectible amounts through a provision for bad debt expense based upon a review of outstanding balances, historical collection information and current economic conditions. Balances that are still outstanding after management has used reasonable collection efforts and the potential for recovery are considered remote are written off through a charge to the allowance. Management believes the allowance for doubtful accounts of approximately $399,000 at December 31, 2020 is adequate to absorb reasonably foreseeable losses.

Inventory

Inventory consists primarily of publications including standards, handbooks, education and training materials, procedure manuals and other and is valued at lower of cost or net realizable value. Cost is determined by the actual expenditures incurred in the production process. Net realizable value is defined as the estimated selling prices in the ordinary course of business less reasonably predictable costs of completion, disposal, and transportation.

Prepaid Expenses

Expenditures relating to programs for the next fiscal year are reported as a prepaid asset and are expensed during the next year as the related program function takes place.

Investments

The Organizations report investments in marketable securities with readily determinable fair values and all investments in debt securities at fair value. Purchased securities are stated at fair market value based on the most recently traded price of the security at the combined financial statements date. Donated securities are recorded at fair value and sold immediately. Investment gains and losses, including realized and unrealized gains and losses on investments, interest and dividends, are included in the accompanying Combined Statement of Activities. Investment management fees are recorded in the caption "Gain on investments, net" in the accompanying Combined Statement of Activities.

Other Assets

In connection with the purchase of Weldmex, LLC in 2012, AWS fully allocated the purchase prices to an indefinite-lived intangible asset identified as the rights to the Weldmex show (NOTE 5). In 2016, AWS purchased 30% of the COATech show; the purchase price was fully allocated as an indefinite-lived intangible asset (NOTE 5).

Indefinite-lived intangible assets are evaluated for impairment at least annually and more often when events indicate that impairment exists. AWS follows an accounting standard which permits an entity to make a qualitative assessment of whether it is more likely than not that an asset's fair value is less than its carrying value before applying the two-step impairment model. If it is determined through the qualitative assessment that the asset's fair value is more likely than not greater than its carrying value, the two-step impairment test would be unnecessary. The qualitative assessment is optional, allowing entities to proceed directly to the quantitative assessment using the two-step approach. In the two-step approach, the first step identifies potential impairments by comparing the fair value of an asset with its book value. If the fair value of the asset exceeds the carrying amount, the asset is not impaired and the second step is not necessary. If the carrying value exceeds the fair value, the second step calculates the possible impairment loss by comparing the implied fair value of the asset with the carrying amount. If the implied fair value is less than the carrying amount, an impairment is recorded. An impairment loss of $1,200,000 was recorded for the year ended December 31, 2020 for Weldmex, LLC (NOTE 5).

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Other Assets (Continued)

This intangible asset's useful life are not limited to legal, regulatory, contractual, competitive, economic or other factors. Therefore, management has determined the rights to the Weldmex and COATech shows have an indefinite life as the use of the asset extends beyond a foreseeable horizon and there is no time limit on the period of time over which it is expected to contribute to the cash flows of AWS. AWS reviews the rights annually for impairment and will evaluate the remaining useful life if the rights are determined to be no longer indefinite.

Goodwill

Goodwill, which is an indefinite-lived intangible asset, represents the excess of costs over fair value of assets of businesses acquired. Goodwill is evaluated at least annually, and more often when events indicate that an impairment exists. AWS does not amortize goodwill but tests for impairment annually based on the accounting standard described above. In 2015, AWS acquired WEX LLC (NOTE 6) and allocated the purchase price primarily to goodwill.

Property and Equipment, Net

Property and equipment, net, is defined by the Organizations as assets with an initial, individual cost of more than $1,000 and an estimated useful life in excess of one year. Property and equipment including building improvements is stated at cost and depreciated or amortized using the straight-line method over the following estimated useful lives of the respective assets:

	Estimated Useful Lives (Years)
Building and improvements	14 – 39
Furniture and equipment	5 – 7
Software	3

Impairment of Long-Lived Assets

The carrying value of long-lived assets is reviewed if the facts and circumstances, such as significant declines in revenues, earnings or cash flows, or material adverse changes in the business climate indicate that they may be impaired. The Organizations perform their review by comparing the carrying amounts of long-lived assets to the estimated undiscounted cash flows relating to such assets. If any impairment in the value of the long-lived assets is indicated, the carrying value of the long-lived assets is adjusted to reflect such impairment. There were no impairment losses recorded during the year ended December 31, 2020.

Deferred Membership, Subscription and Seminar Income

Membership, subscription and seminar income is deferred when received and recognized as revenue over the life of the membership and subscription or when the seminar occurs.

Revenue Recognition — Contributions

Transfers of cash or other assets or settlement of liabilities that are both voluntary and nonreciprocal are recognized as contributions. Contributions may either be conditional or unconditional. A contribution is considered conditional when the donor imposes both a barrier and a right of return. Conditional contributions are recognized as revenue on the date all donor-imposed barriers are overcome or explicitly waived by the donor. Barriers may include specific and measurable outcomes, limitations on the performance of an activity and other stipulations related to the contribution. A donor has a right of return of any assets transferred or a right of release of its obligation to transfer any assets in the event the Organizations fail to overcome one or more barriers. Assets received before the barrier is overcome are accounted for as refundable advances.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Revenue Recognition — Contributions (Continued)

Unconditional contributions may or may not be subject to donor-imposed restrictions. Donor-imposed restrictions limit the use of the donated assets but are less specific than donor-imposed conditions. Contributions received and unconditional promises to give are measured at their fair values and are reported as an increase in net assets. The Organizations report gifts of cash and other assets as restricted support if they are received with donor stipulations about the use of the donated assets, or if they are designated as support for future periods.

When a donor restriction expires, that is, when a stipulated time restriction ends or purpose restriction is accomplished, net assets with donor restrictions are reclassified to net assets without donor restrictions and reported in the Statement of Activities as "Net assets released from restrictions." Donor-restricted contributions whose restrictions are met in the same reporting period in which received are reported as net assets without donor restrictions.

There were no contributions or pledges receivable at December 31, 2020.

Revenue Recognition — Exchange Transactions

Reciprocal transfers in which each party receives and sacrifices goods or services with approximate commensurate value are recognized as exchange transactions. The Organizations adopted Accounting Standards Codification ("ASC") Topic 606, Revenue from Contracts with Customers ("Topic 606") on January 1, 2019. The core principle is that an entity should recognize revenue to depict the transfer of promised goods or services to customers in an amount that reflects the consideration to which the entity expects to be entitled in exchange for those goods or services. To achieve that core principle, an entity should apply the following steps: (i) identify the contract(s) with a customer, (ii) identify the performance obligations in the contract, (iii) determine the transaction price, (iv) allocate the transaction price to the performance obligations in the contract and (v) recognize revenue when (or as) the entity satisfies a performance obligation.

The Organizations apply Topic 606 to exchange transactions in which it receives consideration from individuals for membership and other services offered. Under U.S. GAAP, these arrangements are exchange transactions between the Organizations and the individuals participating in the Organizations' programs or using their services.

The following is a discussion of key revenues streams within the scope of Topic 606. The Organizations provide services to customers which have related performance obligations that the Organizations complete in order to recognize revenue. The Organizations' revenues are generally recognized either immediately upon the completion of the service or over time as the Organizations perform the services. Any services performed over time generally require that the Organizations render services each period and therefore the Organizations measure progress in completing these services based upon the passage of time.

The major operating departments are certification, standards development, exposition, membership, educational services, and publishing and editorial. Other departments such as WEMCO, RWMA and ITSA include revenues related to events, membership and advertising which follows the recognition criteria of the related departments.

Membership Dues

Revenue related to membership is recognized on a pro-rata basis over the periods to which the fees relate. Fees collected in advance of the membership period start date are recognized as deferred revenue. Members are provided with monthly access to the Organizations' services, which is accounted for as a single performance obligation.

Other Operating Revenues

All other operating revenues are recognized when the transaction occurs or over time on a pro-rate basis as the products or services are provided and are reported at the amount that reflects the consideration to which the Organizations expect to be entitled in exchange for providing products or services to their customers. Fees collected in advance for these products or services where the performance obligation is not met at the end of the reporting period are recognized as deferred revenue.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Revenue Recognition — Exchange Transactions (Continued)

- **Certification** — The Organizations develop and administer examinations and issue certifications after individuals complete their assessments. Certifications can be active for up to 5 years; however, the obligation is considered substantially met at the time the examination is administered.
- **Standards Development** — The Organizations sell books and subscription services for access to industry related content. The Organizations recognize revenue once access is granted to the customer or when the product is shipped. The obligation for activities that are transactional in nature is satisfied at the time of the transaction. Customers can purchase subscription access for use over a period of time. Subscription revenue is recognized over the subscription term, which is generally one year.
- **Exposition** — The Organizations hold annual expo events where they sell exhibit space to a variety of customers. The obligation for event-driven services is satisfied at the time of the event when the service is delivered. During the year ended December 31, 2020, AWS received insurance proceeds of $1,406,892 due to cancellation of the Weldmex/Fabtech Mexico event.
- **Educational Services** — The Organizations hold various seminars and conferences annually and earn revenue from customer paid attendance. The obligation for event-driven services is satisfied at the time of the event when the service is delivered.
- **Publishing and Editorial** — The Organizations publish journals on a monthly basis and offer feature articles on industry related topics. The Organizations earn revenue from selling advertising space in a variety of its publications. The obligation for services is satisfied at the time the journals are published.

The Organizations' reciprocal revenue sources shown in disaggregated form are as follows, for the year ended December 31, 2020:

Certification	$ 11,971,471
Standards development	10,095,137
Exposition	1,406,892
Membership	3,758,788
Educational services	4,601,268
Publishing and Editorial	1,881,166
Other	259,323
Total operating revenue	**$ 33,974,045**

Rental Income

Rental income commences when control of space has been given to the tenant and the rent commencement date occurs. Rental income from leasing activities is recorded as earned over the terms of the leases.

Volunteer Services

A large number of people have contributed significant amounts of time to the activities of the Organizations. Donated services are recognized as contributions if the services (a) create or enhance nonfinancial assets or (b) require specialized skills, are performed by people with those skills, and would otherwise be purchased by the Organizations. Since these contributions do not meet the criteria for revenue recognition, they are not reflected in the Combined Statement of Activities.

Functional Allocation of Expenses

Functional expenses are those expenses incurred by the Organizations in the accomplishment of their mission. The Combined Statement of Functional Expenses presents expenses by function and natural classification. Expenses that can be directly identified with the program or supporting service are reported as expenses of those functional areas. Personnel expenses are allocated on the basis of estimated time and effort. Depreciation and amortization expense of specific assets are charged based on usage by each department. The remaining depreciation and amortization expense is allocated to management and general. Other expenses are allocated among program and supporting services based on a reasonable basis that is consistently applied.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Inter-fund Payable/Receivable

Amounts represent advances received by the Reserve Fund, Property Fund and the Foundation from the Operating Fund for operating and other expenses. Such funds totaled $1,489,266 at December 31, 2020.

Income Taxes

AWS and the Foundation are not-for-profit corporations and are exempt from federal income taxes under Section 501(c)(3) of the IRC. Accordingly, no provision for federal or state income tax is required for revenues derived from its tax-exempt function.

For income tax purposes, publication advertising revenue and rental income are considered "unrelated business income" and are subject to income tax. The Organizations are taxed on unrelated business income less the related expenses. Due to the operating losses from the unrelated business income activities, no tax has been levied. 8669 Doral, LLC, Weldmex, LLC and WEX, LLC are disregarded entities for tax purposes.

The Organizations recognize and measure tax positions based on their technical merit and assess the likelihood that the positions will be sustained upon examination based on the facts, circumstances and information available at the end of each period. Interest and penalties on tax liabilities, if any, would be recorded in interest expense and other non-interest expense, respectively.

The U.S. Federal and State of Florida jurisdictions are the major tax jurisdictions where the Organizations file informational tax returns. The Organizations are generally no longer subject to U.S. Federal or State examinations by tax authorities for years before 2017.

Adopted Accounting Pronouncements

Simplifying the Test for Goodwill Impairment

In January 2017, the Financial Accounting Standards Board (“FASB”) issued an accounting standard update 2017-04 Intangibles - Goodwill and Other (Topic 350) Simplifying the Test for Goodwill impairment. The update removes Step 2 of the goodwill impairment test, which requires a hypothetical purchase price allocation. The update specifies that a goodwill impairment charge will now be recognized for the amount by which the carrying value of a reporting unit exceeds its fair value, not to exceed the carrying amount of goodwill. The Organizations adopted this accounting standards update during the year ended December 31, 2020. The adoption of this update had no effect on the Organizations’ combined financial statements.

Recent Accounting Pronouncements

Lease Accounting

In February 2016, FASB the issued an accounting standard update 2016-02, Leases (Topic 842), which amends existing lease guidance. The update requires lessees to recognize a right-of-use asset and related lease liability for many operating leases now currently off-balance sheet under current U.S. GAAP. Also, the FASB has issued amendments to the update with practical expedients related to land easements, lessor accounting, and disclosures related to accounting changes and error corrections. The Organizations are currently evaluating the effect the update will have on their combined financial statements.

The update originally required transition to the new lease guidance using a modified retrospective approach which would reflect the application of the update as of the beginning of the earliest comparative period presented. A subsequent amendment to the update provides an optional transition method that allows entities to initially apply the new lease guidance with a cumulative-effect adjustment to the opening balance of equity in the period of adoption. If this optional transition method is elected, after the adoption of the new lease guidance, the Organizations’ presentation of comparative periods in the combined financial statements will continue to be in accordance with current lease accounting. The Organizations are evaluating the method of adoption they will elect. The update was originally effective for fiscal years beginning after December 15, 2019, and for interim periods within fiscal years beginning after December 15, 2021, with early application permitted. The effective dates were extended to fiscal years beginning after December 15, 2021, and for interim periods within fiscal years beginning after December 15, 2022.

1. NATURE OF ORGANIZATIONS AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Reclassifications

Certain items in the 2019 combined financial statements have been reclassified to conform to the 2020 presentation.

Subsequent Events

The Organizations have evaluated subsequent events through April 9, 2021, which is the date the combined financial statements were available to be issued.

2. LIQUIDITY MANAGEMENT AND AVAILABILITY OF RESOURCES

The Organizations maintain a policy of structuring their financial assets to be available as general expenditures, liabilities and other obligations come due. The Organizations invest excess cash net of working capital in instruments as stipulated under the investment policy. The policy is reviewed semi-annually by the Investment Committee, a sub-committee of the Finance and Business Development Committee. Market performance is monitored continuously including review of quarterly reports and watch list of invested funds. Furthermore, the Finance Committee as well as the Board of Directors review the Combined Statement of Financial Position and Combined Statement of Activities results periodically.

The Organizations' financial assets available within one year of the Combined Statement of Financial Position date for general expenditures as of December 31, 2020 are as follows:

	AWS	Foundation	Total
Cash and cash equivalents	$ 5,795,026	$ 490,543	$ 6,285,569
Investments	96,494,005	98,177,687	194,671,692
Account and other receivables, net	2,062,418	-	2,062,418
Total financial assets	104,351,449	98,668,230	203,019,679
Less amounts not available to be used within one year due to:			
Restricted by donors with purpose restrictions	-	22,905,208	22,905,208
Designated for employment agreement	805,068	-	805,068
Less amounts not available to be used without Board approval:			
Board designated - Self support	-	26,931,455	26,931,455
Board designated - Annual Excess Cash Transferred from Operations	-	5,080,365	5,080,365
Board designated - General (For Specific Programs)	-	18,253,848	18,253,848
Board designated - Grants	-	2,250,152	2,250,152
Board designated - Future Matching Program	-	729,356	729,356
Board designated - Workforce Development and Other	-	1,000,000	1,000,000
Minus amounts approved by Board for Expenditure in 2021	-	(3,490,200)	(3,490,200)
Total Board designated	-	50,754,976	50,754,976
Less: Endowed in perpetuity	-	21,237,003	21,237,003
Total financial assets available to management for general expenditures within one year	**$ 103,546,381**	**$ 3,771,043**	**$ 107,317,424**

During the year ended December 31, 2020, the Board approved the budget for 2021. The Board designated amounts in the table above are being reduced by $3,490,200, which are the amounts approved for expenditure in 2021. In managing its liquidity needs, the Organizations invest in mutual funds which are considered highly liquid as there are no preventative lockups or restrictions and can be readily liquidated to pay operating needs.

3. INVESTMENTS

Investments, which are comprised entirely of mutual funds, are presented in the combined financial statements at their fair market values and consist of the following at December 31, 2020:

Vanguard Investments	Reserve Fund	AWS Foundation	Total
Stock Market Index Fund	$ 23,547,630	$ 21,614,574	$ 45,162,204
Bond Market Index Fund	8,404,478	12,731,216	21,135,694
Intermediate-Term Investment Grade Bond	2,615,833	3,829,943	6,445,776
International Bond Index	6,678,248	10,895,330	17,573,578
International Stock Index Fund	19,263,396	18,881,186	38,144,582
Windsor II Fund	8,175,084	7,658,658	15,833,742
Short-Term Investment Grade Fund	7,743,836	5,767,833	13,511,669
U.S. Growth Fund	9,914,988	7,656,363	17,571,351
Extended Market Index	7,980,758	6,930,253	14,911,011
Long - Term Investment Grade Bond	2,117,600	3,252,428	5,370,028
Explorer Fund	28,291	-	28,291
Strategic Equity Fund	23,863	-	23,863
AWS Section Investments	-	(1,040,097)	(1,040,097)
Total investments	**$ 96,494,005**	**$ 98,177,687**	**$ 194,671,692**

AWS Foundation administers investments on behalf of certain affiliated sections. These investments aggregated to approximately $1,040,000 at December 31, 2020 and are not included in the combined financial statements.

Investment gain consisted of the following for the year ended December 31, 2020:

	Reserve Fund	AWS Foundation	Total
Interest and dividends	$ 2,388,440	$ 2,505,957	$ 4,894,397
Net realized and unrealized gain on investments, net of fees of approximately $36,000 and $46,000, respectively	12,713,119	12,731,709	25,444,828
Total investment gain	**$ 15,101,559**	**$ 15,237,666**	**$ 30,339,225**

4. FAIR VALUE MEASUREMENTS

The FASB established a framework for measuring fair value. That framework provides a fair value hierarchy that prioritizes the inputs to valuation techniques used to measure fair value. The hierarchy gives the highest priority to unadjusted quoted prices in active markets for identical assets or liabilities (Level 1 measurements) and the lowest priority to unobservable inputs (Level 3 measurements).

The three levels of the fair value hierarchy are described as follows:

- Level 1 Inputs to the valuation methodology are unadjusted quoted prices for identical assets or liabilities in active markets that the Organizations have the ability to access.
- Level 2 Inputs to the valuation methodology include:
  - quoted prices for similar assets or liabilities in active markets;
  - quoted prices for identical or similar assets or liabilities in inactive markets;
  - inputs other than quoted prices that are observable for the asset or liability;
  - inputs that are derived principally from or corroborated by observable market data by correlation or other means.

4. FAIR VALUE MEASUREMENTS (CONTINUED)

If the asset or liability has a specified (contractual) term, the Level 2 input must be observable for substantially the full term of the asset or liability.

- Level 3 Inputs to the valuation methodology are unobservable and significant to the fair value measurement.

The asset's or liability's fair value measurement level within the fair value hierarchy is based on the lowest level of any input that is significant to the fair value measurement. Valuation techniques used need to maximize the use of observable inputs and minimize the use of unobservable inputs.

Following is a description of the valuation methodologies used for assets measured at fair value. There have been no changes in the methodologies used at December 31, 2020.

Mutual funds: Valued at the net asset value which is determined daily by the individual fund and number of shares held by the Organizations at year end. These investments are redeemable at their net asset value per share on a daily basis and are publicly traded securities.

The preceding methods described may produce a fair value calculation that may not be indicative of net realizable value or reflective of future fair values. Furthermore, although the Organizations believe the valuation methods are appropriate and consistent with other market participants, the use of different methodologies or assumptions to determine the fair value of certain financial instruments could result in a different fair value measurement at the reporting date. The values assigned to certain investments are based upon currently available information and do not necessarily represent amounts that may ultimately be realized. Because of the inherent uncertainty of valuation, those estimated fair values may differ significantly from the values that would have been used had a ready market for the investments existed and the differences could be material.

The following table represents the Organizations' financial instruments measured at fair value on a recurring basis at December 31, 2020 for each of the fair value hierarchy levels:

		Fair Value Measurement at Reporting Date Using:		
Description	Total	Quoted Prices in Active Markets for Identical Assets (Level 1)	Significant Other Observable Inputs (Level 2)	Significant Other Unobservable Inputs (Level 3)
Mutual Funds:				
Equity U.S. Large	$ 78,567,297	$ 78,567,297	$ -	$ -
Equity U.S. Mid/Small	14,963,163	14,963,163	-	-
Equity - International	38,144,582	38,144,582	-	-
Short-Term Bonds	13,511,671	13,511,671	-	-
Intermediate Bonds	27,581,470	27,581,470	-	-
Long-Term Bonds	4,329,931	4,329,931	-	-
Bonds - International	17,573,578	17,573,578	-	-
	$ 194,671,692	**$ 194,671,692**	**$ -**	**$ -**

The carrying amounts for cash, cash equivalents, receivables, accounts payable and certain other assets and liabilities approximate fair value due to the short-term maturity of these financial instruments.

5. OTHER ASSETS

Weldmex

In 2012, AWS completed the purchase of Weldmex, LLC ("Weldmex"), a limited liability company. Weldmex owns and operates the Weldmex Trade Show. Total payments made for the purchase of Weldmex amounted to $2,394,000 and the purchase price was fully allocated to one asset, identified as the rights to the Weldmex show. As a result of the event cancellation in 2020 due to COVID-19 and other factors identified by management, it was determined that the Weldmex intangible asset was impaired and an impairment loss of $1,200,000 was recorded during the year ended December 31, 2020. As of December 31, 2020, the rights to the Weldmex show intangible asset was $1,194,000 and is included under the caption "Other assets" in the Combined Statement of Financial Position.

COATech

In 2016, AWS and its Show Partners, the Society of Manufacturing Engineers ("SME"), the Fabricators and Manufacturers Association International ("FMA"), the Chemical Coaters Association International ("CCAI") and the Precision Metalforming Association ("PMA"), collectively acquired the rights to COATech, a coating and finishing technology show previously located within the Weldmex Trade Show. AWS and its Show Partners are parties to the purchase with ownership percentages as follows: AWS – 30%; SME – 20%; FMA – 20%; CCAI – 15%; and PMA – 15%. Each party will focus on their respective technology as follows: AWS – Welding and Cutting; SME and FMA – Forming and Fabrication and Tube and Pipe; PMA – Stamping; and CCAI – Finishing. The purchase price for COATech was $444,467, of which AWS's payment amounted to $133,340, which represents 30% of the purchase price. The purchase price was fully allocated to one asset, identified as the rights to the COATech show. This amount has been reflected in the caption "Other assets" in the Combined Statement of Financial Position.

6. GOODWILL

Effective July 16, 2015, AWS acquired the business assets and operation of WEX LLC for approximately $1,900,000. Approximately $1,625,000 of the purchase price was considered goodwill. The goodwill arising from this acquisition results from the established business operations that were acquired. Management has determined that an impairment of this goodwill does not exist as of December 31, 2020.

7. PROPERTY AND EQUIPMENT, NET

Property and equipment, net consists of the following as of December 31, 2020:

	Property Fund	Foundation and Operating Fund	Total
Land	$ 6,191,574	$ -	$ 6,191,574
Building and improvements	18,480,301	-	18,480,301
Furniture, software and equipment	-	15,458,936	15,458,936
	24,671,875	15,458,936	40,130,811
Less: accumulated depreciation and amortization	3,820,685	13,978,635	17,799,320
	$ 20,851,190	**$ 1,480,301**	**$ 22,331,491**

Depreciation and amortization expense was approximately $1,928,000 for the year ended December 31, 2020.

AWS is headquartered in a five story, 120,000 square foot office building in the City of Doral, Florida. As of December 31, 2020, AWS occupied 72.9% of the office building and 27.1% was leased out to tenants. Depreciation and amortization expense relating to AWS operations amounted to approximately $1,785,000 for the year ended December 31, 2020 and is reflected under the Operating Fund. Depreciation expense relating to the tenant portion at the facility amounted to approximately $142,000 for the year ended December 31, 2020 and is reflected under the Property Fund. Other depreciation expense of approximately $1,000 is reflected under the Foundation.

8. LEASING ACTIVITIES

As of December 31, 2020, AWS, as lessor, has entered into various operating leases with third parties. The operating leases have various terms expiring through 2024. Rental income from leasing activities is recorded as earned over the terms of the leases. Rental income of approximately $713,000 was earned for the year ended December 31, 2020, and is included within the Combined Statement of Activities — Property Fund.

Minimum future rentals to be received on leases subsequent to the year ending December 31, 2020 are approximately as follows:

For the years ending December 31,		
2021	$	598,000
2022		191,000
2023		61,000
2024		4,000
Total	**$**	**854,000**

9. NET ASSETS WITHOUT DONOR RESTRICTIONS

Net assets without donor restrictions consist of the following as of December 31, 2020:

Operating Fund	$	9,539,350
Reserve Fund		95,688,938
Property Fund		20,474,502
Board Designated Endowment (AWS Foundation)		
Board designated - Self Support		26,931,455
Board designated - Annual Excess Cash Transferred from Operations		5,080,365
Board designated - General (For Specific Programs)		18,253,848
Board designated - Grants		2,250,152
Board designated - Workforce Development and Other		729,356
Board designated - Future Matching Program		1,000,000
Total Board Designated Endowment (AWS Foundation)		54,245,176
	$	**179,947,966**

The Board designated net assets are as follows:

Self-Support — The Board of Trustees designated $26,931,455 to fund the operations of the Foundation in perpetuity including salaries and fringes and other costs to operate and support specific programs during a given time such as the welding mobile exhibit which offers an interactive learning experience. Allocated expenditures for fiscal period 2021 from these funds amount to $1,108,200.

Annual Excess Cash transferred from Operations — Excess cash net of working capital transferred from operations to fund programs as identified by the Board of Trustees. Allocated expenditures for fiscal period 2021 from these funds for programs amount to $347,500.

General Funds — Funds geared towards guaranteed payout of scholarships and programs during any given year where the market performs below the payout rate of 5%. Additionally, such funds provide for annual specific payouts of endowed programs which include District Scholarships, Fellowships, Educator Scholarships and District Welder Training Scholarships and any other program as identified by the Board of Trustees. General Designated Funds amounted to $18,253,848 of which $1,559,500 has been allocated for fiscal period 2021 for specific programs identified by the Board of Trustees.

9. NET ASSETS WITHOUT DONOR RESTRICTIONS (CONTINUED)

Grants — The Board of Trustees designated $2,250,152 for grants to qualifying secondary and post-secondary education and training institutions to enhance and improve welding programs. Funding can be used towards classroom lab materials and supplies, facilities improvement, capital items, expansion of teaching staff, computer and other. Allocated expenditures for fiscal period 2021 from these funds amount to $275,000. The amount endowed to provide for such awards is $5,000,000 and has been included in net assets endowed in perpetuity (NOTE 10).

Workforce Development and Other — The Board of Trustees has designated $729,356 for general workforce development and other programs to build and promote the industry and builds its workforce. Allocated expenditures for fiscal period 2021 from these funds amount to $200,000.

Future Matching Program — Funds in the amount of $1,000,000 were allocated for the matching scholarships program.

10. NET ASSETS WITH DONOR RESTRICTIONS

Net assets with donor restrictions consists of the following as of December 31, 2020:

Accumulated earnings on perpetual endowment restricted by donors for specific purposes	$	22,905,208
Endowed in perpetuity		21,237,003
	$	**44,142,211**

As of December 31, 2020, the net assets with donor restrictions for the Organizations are $44,142,211, of which $22,905,208 were restricted by donors for the purpose of supporting the cost to operate and fund specific programs. The Foundation also received gifts to their endowment. These gifts are made to the corpus of the endowment, therefore, cannot be expended and are treated as donor restricted.

11. ENDOWMENT

The Foundation's endowment consists of two separate investment funds established for welding education, research and other charitable purposes. The endowment includes donor restricted and board designated endowment funds. As required by U.S. GAAP, net assets associated with endowment funds are classified and reported based on the existence or absence of donor-imposed restrictions.

Interpretation of Relevant Law

The State of Florida adopted the Florida Uniform Prudent Management of Institutional Funds Act ("FUPMIFA"). The Foundation has interpreted the FUPMIFA as requiring the preservation of the fair value of the original gift as of the gift date of the donor-restricted endowment funds absent explicit donor stipulations to the contrary. As a result of this interpretation, the endowment classifies as net assets with donor restrictions the historical value of donor restricted endowment funds, which includes (a) the original value of gifts donated to the permanent endowment, (b) the original value of subsequent gifts to the permanent endowment and (c) changes to the permanent endowment made in accordance with the direction of applicable donor gift instruments.

Also included in net assets with donor restrictions is accumulated appreciation on donor restricted endowment funds which are available for expenditure in a manner consistent with the standard of prudence prescribed by the FUPMIFA, and deficiencies associated with funds where the value of the fund has fallen below the original value of the gift.

The Foundation considers the following factors in making a determination to appropriate or accumulate donor-restricted endowment funds:

(1) The duration and preservation of the fund
(2) The purposes of the Foundation and the donor-restricted endowment fund
(3) General economic conditions
(4) The possible effect of inflation and deflation

11. ENDOWMENT (CONTINUED)

Interpretation of Relevant Law (Continued)

(5) The expected total return from income and the appreciation of investments
(6) Other resources of the Foundation
(7) The investment policies of the Foundation.

For the year ended December 31, 2020, the Foundation has elected not to add appreciation for cost of living or other spending policies to its permanently restricted endowment for inflation and other economic conditions.

Summary of endowment net assets at December 31, 2020:

	Net Assets Without Donor Restrictions	Net Assets With Donor Restrictions	Total
Donor restricted endowment funds:			
Original donor-restricted gift amount and amounts required to be maintained in perpetuity by donor	$ -	$ 21,237,003	$ 21,237,003
Accumulated earnings on perpetual endowment restricted by donors for specific purposes	-	22,905,208	22,905,208
Board designated endowment funds	54,245,176	-	54,245,176
Total endowment net assets	**$ 54,245,176**	**$ 44,142,211**	**$ 98,387,387**

Changes in endowment net assets for the year ended December 31, 2020:

	Net Assets Without Donor Restrictions	Net Assets With Donor Restrictions	Total
Endowment net assets, beginning	$ 44,631,178	$ 38,321,587	$ 82,952,765
Contributions and transfers, net	(3,352,785)	6,269,879	2,917,094
Interest and dividends	2,435,943	70,014	2,505,957
Gain on investment, net	12,312,367	419,342	12,731,709
Appropriated for expenditure	(1,781,527)	(938,611)	(2,720,138)
Endowment net assets, ending	**$ 54,245,176**	**$ 44,142,211**	**$ 98,387,387**

Summary of endowment assets at December 31, 2020:

	Net Assets Without Donor Restrictions	Net Assets With Donor Restrictions	Total
Cash	$ 490,543	$ -	$ 490,543
Investments	54,035,476	44,142,211	98,177,687
Property and equipment, net	1,008	-	1,008
Prepaid expenses and other assets	27,450	-	27,450
Liabilities	(309,301)	-	(309,301)
Total endowment assets	**$ 54,245,176**	**$ 44,142,211**	**$ 98,387,387**

11. ENDOWMENT (CONTINUED)

Funds with Deficiencies

From time to time, the fair value of assets associated with individual donor restricted endowment funds may fall below the level that the donor requires the Foundation to retain as a fund of perpetual duration. There were no such deficiencies in the endowment funds as of December 31, 2020.

Return Objectives and Risk Parameters

The Foundation has adopted investment and spending policies for endowment assets that attempt to provide a predictable stream of funding to programs supported by its endowment while seeking to maintain the purchasing power of the endowment assets. The Foundation expects its endowment funds, over time, to provide a rate of return in excess of the principal. Actual returns in any given year may vary.

Strategies Employed for Achieving Objectives

To satisfy its long-term rate-of-return objectives, the Foundation relies on a total return strategy in which investment returns are achieved through both capital appreciation (realized and unrealized) and current yield (interest and dividends).

Spending Policy and How the Investment Objectives Relate to Spending Policy

The Foundation has a policy of appropriating for distribution each year 5 percent of its endowment fund's value over the prior 12 months through the calendar year-end preceding the fiscal year in which the distribution is planned. In establishing this policy, the Foundation considered the long-term expected return on its endowment. Accordingly, over the long term, the Foundation expects to maintain the purchasing power of the endowment assets held in perpetuity or for a specified term as well as to provide additional real growth through new gifts and investment return.

12. INTERFUND TRANSFERS

During year ended December 31, 2020, the following transfers were made:

- To Reserve Fund - $2,500,000 due to positive financial results and cash flows.
- To AWS Foundation - $2,500,000 due to positive financial results and cash flows.
- To Property Fund - $49,018 for capital improvements and other related items.
- To AWS Foundation - $43,000 for other specific programs.
- To Reserve Fund - $4,184,468 excess cash related to inter-fund payable paid by AWS Foundation.

During year ended December 31, 2020, the Property Fund made the following transfers:

- To Operating Fund - $670,000 due to excess cash flow from rental income.

The Foundation has received transfers from AWS over the years due to positive financial results and cash flow. These transfers are recorded within net assets without donor restrictions of the Foundation. During the year ended December 31, 2020, the AWS Board of Trustees restricted $5,919,488 of a transfer made in a prior year to the Foundation. As a result, the Foundation has transferred $5,919,488 to net assets with donor restrictions during the year ended December 31, 2020, of which $4,900,000 is restricted in perpetuity.

13. EMPLOYEE BENEFIT PLAN

The Organizations have an employee benefit plan for all full-time employees. Full-time employees are eligible for participation in the plan the first day of the month after they are employed. Effective June 1, 2008, the Organizations will contribute a maximum of 8% of the employees' base salary, composed of a 4% initial contribution and a match up to 4% of an employee's voluntary contribution. The Organizations made contributions totaling approximately $750,000 during the year ended December 31, 2020.

14. EMPLOYMENT AGREEMENTS

In accordance with the employment agreement with the former Executive Director ("former ED"), AWS funded from 2014 to 2018 an investment account for the sole benefit of the former ED. The benefit was earned by the former ED as of December 31, 2018. At December 31, 2020, AWS has a liability of $805,068 due to the former ED, which is offset by the investment account with a balance of $805,068. The balance in the investment account will be paid to the former ED upon request.

Effective April 6, 2020, AWS entered into an employment agreement with its new Executive Director and Chief Executive Officer. The agreement extends through April 2023 and provides certain benefits for the period set forth in the agreement.

15. COMMITMENTS AND CONTINGENCIES

Operating Leases

The Organizations have entered into various operating lease agreements involving equipment with expiration dates through 2023. Rent expense for the year ended December 31, 2020 totaled approximately $190,000. Minimum annual payments on the non-cancellable portion of the leases are approximately as follows:

For the years ending December 31,		
2021	$	68,000
2022		7,000
2023		1,000
	$	**76,000**

Royalty Agreements

Effective November 30, 2016, AWS amended an existing agreement with The American Society of Mechanical Engineers ("ASME"), whereby ASME has the nonexclusive right to reproduce the 2017 and 2019 editions of the filler metal specifications. ASME will pay AWS royalties equal to 35% of the net sales per quarter for the 2017 and 2019 editions. Under the terms of this agreement, AWS earned approximately $420,000 during the year ended December 31, 2020 and is included within the caption "Standards development" in the Combined Statement of Activities.

Weldmex Trade Show

On January 11, 2013, Weldmex, a wholly owned entity of AWS, entered into an agreement with Trade Show Consulting, LLC ("TSC") for show management services. TSC was paid a fixed fee of $185,000 annually and incentive fees as follows: (1) 4% of Show revenues, (2) 3% of the net profit for the WELDMEX show, (3) 4% of the incremental growth in Show revenues and (4) for so long as Weldmex manages the FABTECH Mexico Show, 3% of net profit and 4% of the incremental growth in Show revenues for FABTECH Mexico. The agreement with TSC was terminated effective August 21, 2020.

On July 13, 2020, AWS entered into an agreement with Meetings Factory S.A. de C.V. ("MF"), a new vendor to provide show management services for the 2021 Weldmex Show. Such services include marketing, sales, logistics and operations services. The agreement may be renewed for subsequent shows within 60 days following the previous show. MF shall be paid a fixed fee of $236,500, payable in monthly installments and the fee can be adjusted annually by up to 5% as agreed by both parties. Incentive fees include a bonus potential of up to $10,000 and commissions as a percent of revenues for new customers at 5%, new sponsorships at 3% and renewals for future shows at 3%. The agreement expires 60 days following the 2023 Show or earlier if not renewed. Either party may terminate the agreement should the other commit a material breach not cured within 30 days of receipt of written notice or should the other party file a petition for bankruptcy, insolvency or ceasing to do business.

Legal Matters

The Organizations are exposed to various asserted and unasserted potential claims encountered in the normal course of business. In the opinion of management, the resolution of these matters will not have a material effect on the Organizations combined financial position or the combined results of its operations.

NOMINATION DEADLINE FOR
AWS FELLOW OF THE SOCIETY

American Welding Society®

Friends and Colleagues:

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

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

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

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

August 1, 2021
Submission Deadline

Remembering Ronald C. Pierce

AWS past president is commemorated for his advocacy of the AWS Foundation

WRITTEN BY HIS COLLEAGUES AT THE AWS FOUNDATION

Ronald C. Pierce, AWS past president and honorary chair and trustee emeritus of the AWS Foundation, passed away on March 18. He is remembered for his passion, dedication, and leadership.

A giant among the dedicated cadre of American Welding Society (AWS) volunteers and a formative figure in the history of the AWS Foundation, has passed. Ronald C. Pierce, AWS past president and honorary chair and trustee emeritus of the Foundation board, died on March 18. He was 87.

Pierce was a mainstay in AWS affairs for many years, and few were so honored for their tasks undertaken and solid accomplishments. He chaired the AWS Foundation for 15 years. In addition to being a tremendous advocate for the mission of the AWS Foundation, he was the third-largest individual contributor. He established the Ronald C. and Joyce Pierce AWS Mobile Section Scholarship, which awards more than $17,000 annually for students studying welding technology in the Mobile, Ala., area.

Pierce began his career in welding upon graduation from Purdue University, where he earned a bachelor of science in mechanical engineering. He went on to earn his professional engineer credentials. He worked at The Lincoln Electric Co. for 11 years as a welding engineer before joining WESCO, now known as WESCO Gas and Welding Supply, in 1966 as a sales engineer. In 1974, he became president and CEO of WESCO after purchasing the company. He was an AWS Life Member, and had been active in the Mobile Section since 1961, serving as Section chair in 1970–1971 and 1989–1990. He was AWS District 9 Director from 1990 to 1993, later becoming AWS president during 1997–1998. He received the AWS William Irrgang Memorial Award in 2004 and was inducted into the AWS Class of Counselors the same year. He served as an AWS Foundation trustee from 1990 to 1993 and as Foundation chair from 1993 to 2008. He was named honorary chair and trustee emeritus of the AWS Foundation in 2008.

In a testament to Pierce, AWS Executive Director and CEO Gary Konarska II said, "Each time I communicated with Mr. Pierce, his dedication and impact to AWS and the AWS Foundation shone through in his passionate commitment to the welding industry."

"His leadership, dedication of his time, financial stewardship, and passion set a significant example for all of us to 'give back' and to assist in developing young people for our industry. He has truly been an icon in our industry," added AWS Executive Director Emeritus Ray Shook.

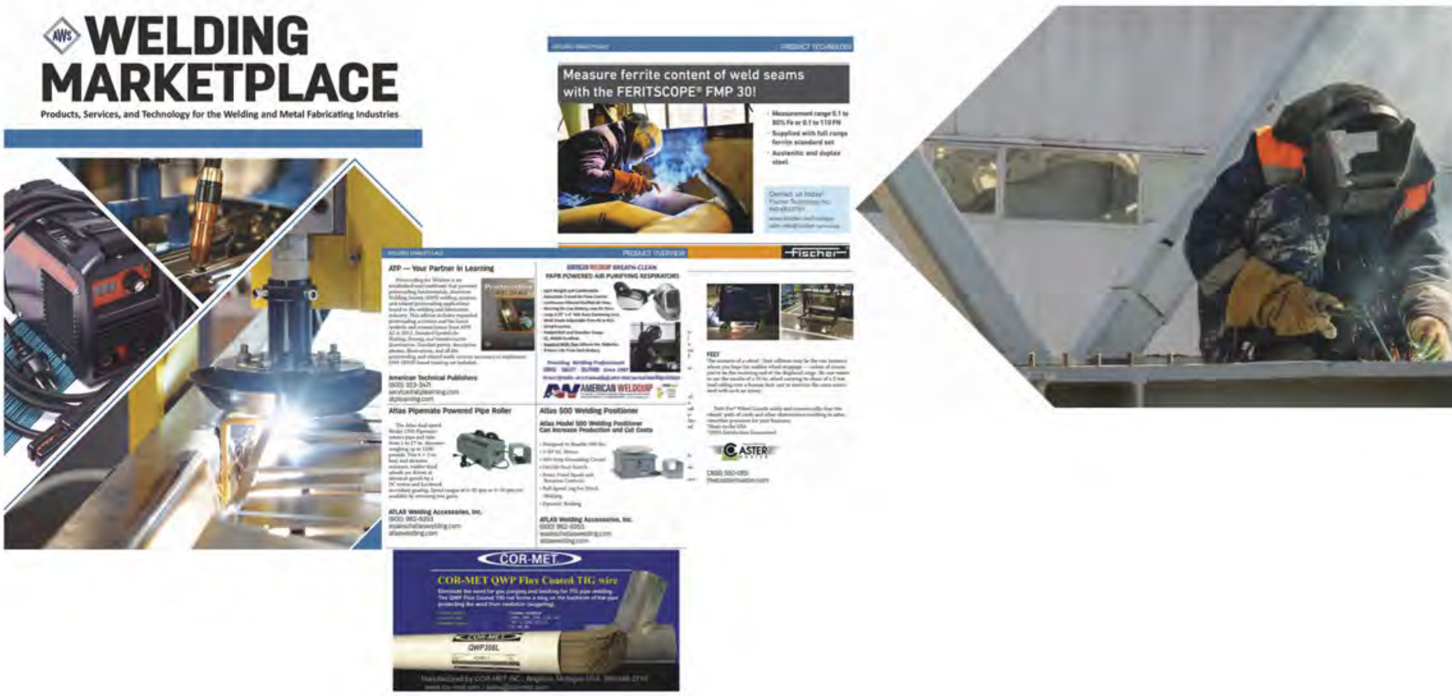
"Ron truly believed in the mission of the Foundation and the importance of educating the next generation of welding professionals. He was always willing to support our efforts, through his personal commitment of time and resources, and by making connections with similar organizations and employers to increase our impact. He was an industry pioneer," said Monica Pfarr, AWS Foundation executive director.

Beyond his many contributions to AWS, Pierce was an avid golfer, who enjoyed playing weekly with friends. He had innumerable successes and accolades in his life, but his greatest pride and joy was always his family. Pierce is survived by his wife of 66 years, Joyce; four children, Jeffery, Judy, Gregory, and Jenny; ten grandchildren; one great granddaughter; and nephews and nieces.

When it is all said and done, the final measure of a life is reflected in how it was lived. It cannot be much more than the picture displayed here — living by a solid set of ideals, commitment to that goal, the attainment of success, and devotion to family and friends — all qualities that Pierce demonstrated continuously throughout his life. None of us can hope to achieve more than this.

Pierce will be deeply missed by his family, friends, and colleagues, who loved and admired him. WJ

The AWS Foundation supports programs to ensure the growth and development of the welding industry through research and educational opportunities. The Foundation is led by a volunteer Board of Trustees with all administrative tasks provided by a small development staff of the American Welding Society.



Reach over 100,000 AWS Members and Customers, Industry Leaders, and Prospects by Advertising in the *Welding Journal*'s Buyers Guide – *Welding Marketplace*.

Generate productive leads with ***Welding Marketplace,*** where a picture is worth a thousand words. Let pictures of your products in ***Welding Marketplace*** win your company new customers and increase sales. ***Welding Marketplace*** gets your products and services into the hands that need them. Show them how your offerings save time and money.

• Use your full-color photos to promote your newest and hottest welding products and services to AWS members and customers. ***Welding Marketplace*** is mailed directly to 60,000 homes and businesses.

• Reach 55,000 AWS members via an email with the digital version of ***Welding Marketplace*** that includes active links to send clients directly to your website.

• Download ***Welding Marketplace*** from the AWS website, which features active links that send clients directly to your website. The AWS website averages 100,000 plus views a month.

Advertise in all four issues to get your brand name and product into the hands of AWS members and customers.

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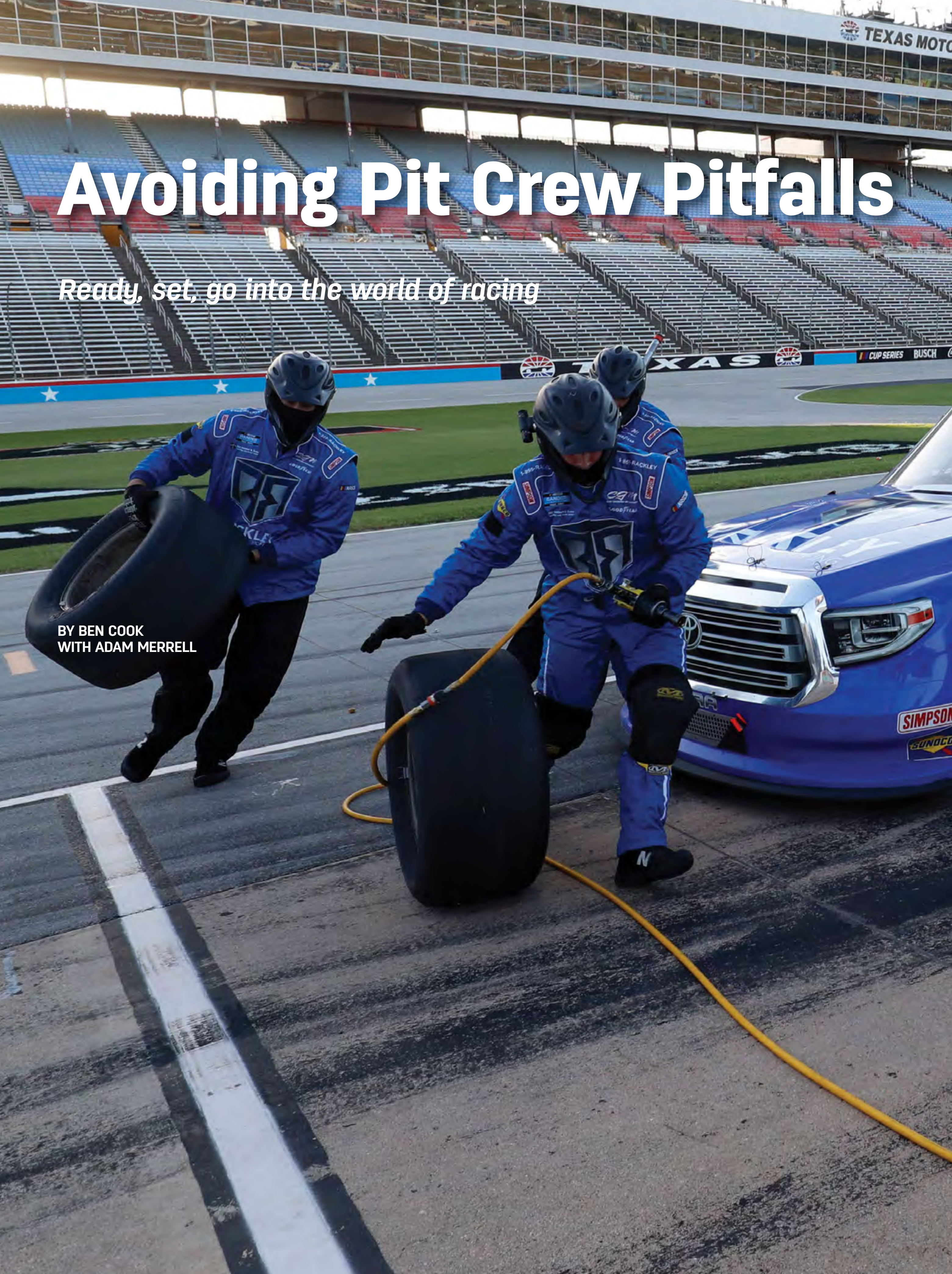
Avoiding Pit Crew Pitfalls

Ready, set, go into the world of racing

BY BEN COOK
WITH ADAM MERRELL



PIT's crews pitting the #68 truck of Clay Greenfield in the NASCAR Camping World Truck Series.

Racing performance among tech professionals has always centered on the mechanics of the racing machine. The machine represents a culmination of skills and technological masteries that can challenge the physics of material, motion, and speed. Although a marvel, the machine alone without the human element is just potential energy with a fancy of kinetic dreams. Racetrack performance is a marriage of machine and human that expands human imaginations with the potential for power and speed. This article puts the pedal to the metal on various factors, from human performance on the racetrack to educating pit crews, and includes an informative Q&A.

Fig. 1 — PIT's current crew with fellow alumni from other NASCAR Cup teams practice together.

Driving Home the Human Element

With their safety and lives in the balance, drivers have always taken the lion's share of racetrack glory — and rightfully so — but all human performance at the track impacts the machine's potential.

In NASCAR, drivers, crew chiefs, mechanics, engineers, engine tuners, tire specialists, spotters, support staff, and pit crews must all perform their best to keep their racing machine at the front of the field in winning potential. Standardization of technology and rule enforcements have made the cars in NASCAR very good for its style of racing. Five hundred miles of three cars wide, on 30 deg of banking, bumper to bumper, fender to fender, at speeds of nearly 200 miles/h, and these cars endure. The racing machines in the series have become dependable and durable, so with cars breaking less often, the performance spotlight shifts to examine what can result in lost performance (hence, the human element).

On the Fast Track to Training

In the area of pit crew performance, Pit Instruction & Training (PIT) (*visitpit.com*) in Mooresville, N.C., has sought to improve the human element through its championship-producing Pit Crew U and 5 Off 5 On pit crew skills training programs.

In addition, the institution offers welding and fabrication courses (*visitpit.com/pit-weld-u*) as well as American Welding Society welder testing through its Weld U program.

PIT has been a provider of pit crew talent for NASCAR teams for the past 20 years (see lead photo), racing nearly 70% of its 860 alumni in one or more of NASCAR's top three series. Not only has the institution been a provider of pit crew bodies at the track, but it has also been a producer of championship performances, with PIT alumni taking part in the spraying of champagne in the winners circle (a celebratory tradition after winning a race) nearly every year since PIT's program began.

Be a Passenger to This Q&A Series

During a conversation, Director of Pit Crew Performance Adam Merrell gave a glimpse of PIT's training philosophy and how it has benefited performance outcome.

Q: Can you describe the typical NASCAR pit crew by position?

Merrell: We have five total positions that service a NASCAR stock car during a pit stop — two changers, one tire carrier, one jack person, and one fueler.

• **Changers** are responsible for removing and installing NASCAR's five lug nuts on both the right and left sides of the car. They pull their own tire off the car's hub, and depending on the stop, the front changer might have to get the front right-side tire safely back to the wall.

• During a four-tire pit stop, a **tire carrier** is responsible for bringing and throwing on both the right rear and left front tires (110–180 lb of total tire/wheel weight). They also must perform all right-side mechanical adjustments, add or remove tape from the nose, and clean the car's grille.

• A **jack person** is responsible for jacking up both the right and left side of the car so that tires can be exchanged. They make mechanical adjustments on the car's left and throw on both the right front and left rear tires.

• A **fueler** is responsible for filling the car with either one or two cans of fuel (100+ lb each).

Q: How is the pit crew program at PIT structured for best performance retention?

Merrell: One of the best qualities about PIT's pit crew program is we start with the basics, not only in each position but also with every scenario a pit crew might see at the track.

For example, if a tire changer cannot flawlessly do a "tap drill" (this is using an airless impact wrench to tap lug nuts for an assigned number), then there is no reason to increase difficulty by adding air to the drill.

Fig. 2 — Pictured is PIT's crew working on pit stop audibles for left side adjustments.

During a pit stop, if a developing pit crew cannot pit the right side of the car with flawless fundamentals — meaning no missed jacking, lug nuts, thrown tires, and adjustments — then there is no reason to travel to the car's left side for a four-tire pit stop. If you are making mistakes on the car's right side, then you will undoubtedly compound the problem by doing it on the left.

At PIT, we preach "practice doesn't make perfect, it makes permanent." If you are repeatedly practicing poor technique, you will instill those mistakes into your development for days, months, and possibly years, making it hard to undo. We try to prevent our players from ever going down that road of needing retraining.

We believe this has helped our PIT athletes with successfully being placed on top tier NASCAR Cup teams — Figs. 1, 2. When you try out for a Cup team, they expect athletes to already know the basics, be able to repeat fundamentals, and do all of this in an efficient amount of time. They are not looking to hire someone so that they can teach them how to change, carrier, jack, or fuel the car. They want people who come in the door ready to go.

NASCAR teams always rate an athlete by pit stop time and average. We teach our crews that saving time requires attention to detail. Make sure you are performing your job safely, then make sure you are not making mistakes, and if you continue to do both objectives consistently, time will take care of itself.

Q: Which is a more critical part of the training, physical or mental?

Merrell: Like many other sports, in the beginning, the physical components are more critical. The athlete is having to develop a skill that they have never physically performed before. This takes a countless number of reps and is a huge physical stress.

However, once a skill is learned and perfected, throughout their career the player's mentality becomes a more critical aspect of training. The athlete now knows how to perform the task of pitting a car, and hopefully can consistently perform to near perfection, but generally what gets in the way of perfection is the space between their ears. Do they have the mental strength to repeatedly perform without mentally checking out? Can they perform at a lower-level racing series, and then when called, jump to a higher level with faster team members around them and repeat the same process? Are they mentally capable of going from being the last place vehicle to coming down pit road in first — knowing that they cannot lose any positions during the stop? And a stressor outside of their control is the knowledge that all the while, people are lined up wanting their job. These occurrences are a constant throughout a pit crew athlete's career.

We tell our athletes that getting to a top crew is less difficult than staying with a top crew because of the mental discipline required.

Parking Time

This article presents important insights from a program employing a successful strategy of being mentally disciplined enough to pay attention to the details of the basics. Sounds like a lesson to help all our crews avoid the pitfalls of performance. WJ

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Heavy Fabricator Trailblazes Welding Analytic App Implementation

BY JON HOFMANN

Digital communication solutions revamped operations for Särkinen Industries

Social critics of the internet say its applications have driven humans further apart. At Särkinen Industries of Tampere, Finland, online data management applications have bridged gaps between management, supervisors, and operations.

Today, the company has an average arc-on time of 20% across a fleet of 20 manual, solid-wire gas metal arc welding (GMAW) stations, more than double the industry average of 8 to 10%. It uses power sources connected to WiFi and a suite of online welding data management apps. However, this isn't a technology story. It is about the success that comes from a better way of communicating based on real-time visibility into the numbers that drive productivity in production welding.

Online data management programs have helped Särkinen Industries maintain high arc-on times, which are critical for production of chassis and other heavy equipment.

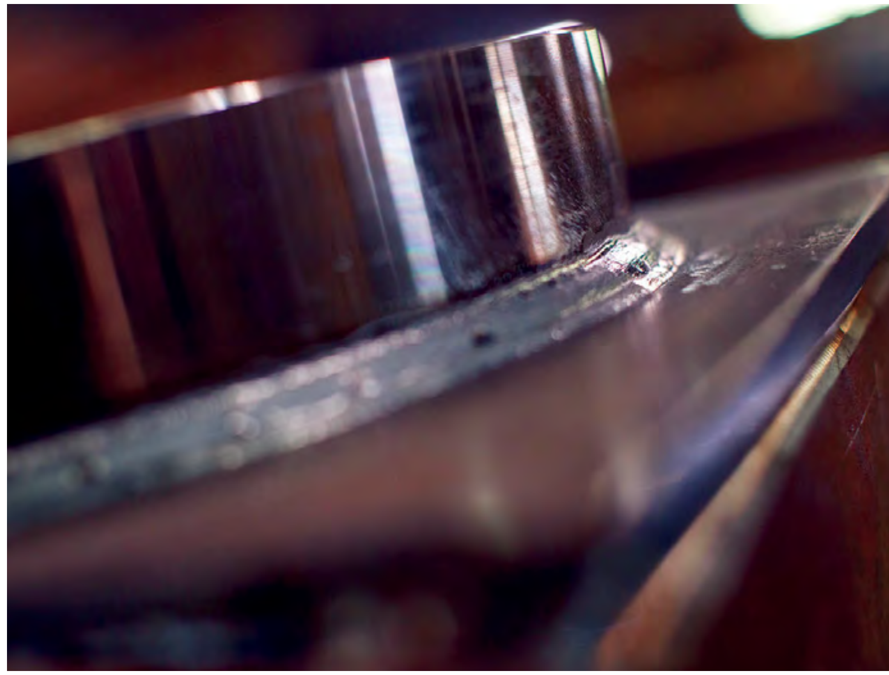

Fig. 1 — Särkinen provides high-quality welded components to customers in heavy steel, energy, marine, wind power, mining, and local industries.

A Company Built on Welding

For nearly 50 years, the company has provided high-quality, heavy-metal structures and solutions to its customers in the heavy steel, energy, marine, wind power, mining, and local industries. It currently runs four manufacturing facilities employing 140 workers in Finland and the Ukraine.

Welding is a mainstay for the business, as it uses more than 50,000 lb of welding wire per year for 10- to 300-mm weldments on parts for rock-crushing machines, massive chassis for heavy conveyors and large bulldozers, and many other heavy industrial structures — Fig. 1. Like most companies where welding is a focus, the fabricator aims to continuously improve welding speed, quality, and efficiency.

"Our customers are located around the world, and they have production timelines to meet," said Samuli Särkinen, CEO of Särkinen Industries. "They want their parts to fit correctly the first time. They don't want to have to fix the parts. We deliver high-quality pieces to them, structures built to withstand the harsh environments of mining applications. We are always looking at ways to improve so we can remain the best at what we do."

Testing Productivity Apps

The shortcut to increasing productivity is to hire more welders, but Finland, like the United States, faces a skilled welder shortage. The only viable strategy to understand the levers of productivity requires an aggregate measure, such as overall equipment effectiveness or first pass yield. The company has focused on each component of the measures to assure efficient production, minimized cost, and controlled quality. However, the time and effort to manually collect data is high, and the results vary greatly between human data collectors.

Against this backdrop, ESAB Business Development Manager Lars Gylling Olesen invited Särkinen to visit the company's research facility in Gothenburg, Sweden, in 2018. ESAB had recognized that previous industry versions of online applications offered subpar performance for a variety of reasons. These included technical (hardware and IT-based) implementation challenges, steep learning curves for app users, and apps that did not focus on fundamental metrics users need.

Särkinen agreed to collaborate with ESAB to test a new generation of welding productivity and fleet management apps at Särkinen Industries' mining products facility in Finland, which has 20 welding stations.

"Like every fabrication company in the world, we know that we have problems in our production. We knew it for a long time, but we didn't have any key how to solve it," Särkinen explained. "When I saw the app prototype, I got really interested because it would help us identify the bottlenecks that we

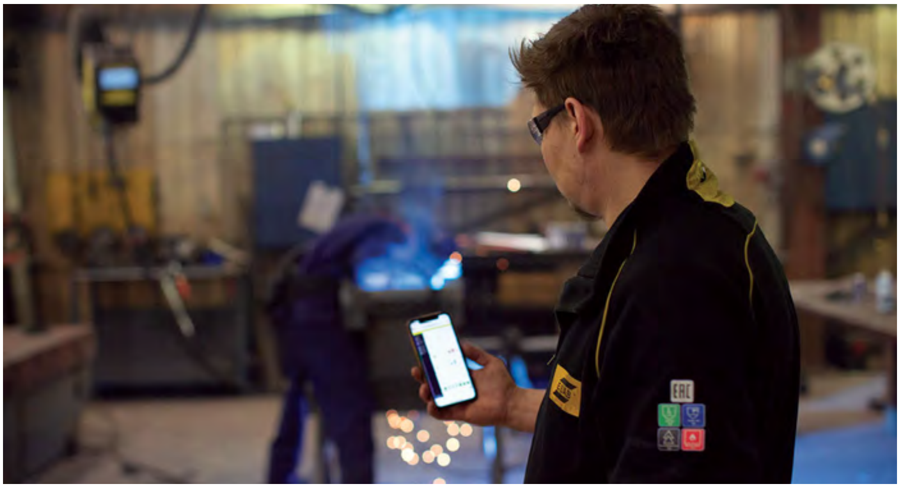

Fig. 2 — The power source's communication module transmits data via WiFi; therefore, all any facility needs is a reliable internet connection.

Fig. 3 — The online data management system fosters better communication between Building Coordinator and Foreman Tony Saarinen (left) and the welding operators.

Fig. 4 — WeldCloud captures data such as volts, amps, and wire feed speed for every weld session.

had in our production."

For those who have the luxury of hiring as many operators as they want, he noted that hiring more people doesn't provide any insight.

"If you don't know what kind of arc-on time you are achieving, then you're just doing more of the wrong work," Särkinen reasoned.

The Right Champion

Many welding operators inherently distrust data management applications. They perceive them as "big brother" watching them. Try having a "suit" from a corner office come down to the production floor to tell operators how the newest online data management tool will transform operations. Hilarity often ensues.

Having grown up in the business, Särkinen realized he needed to find the right person in the mining plant to champion connected technology.

That person was Building Coordinator and Foreman Tony Saarinen. He worked as a production welder at the company for 15 years, but he also worked with computers as a hobby.

"Tony has the fire within himself to try new things and challenge others around him," Särkinen reflected. "The operators respect him because they know he understands issues from their perspective. He was a blue-collar guy that became a white-collar guy."

Communicating Data

One factor easing implementation at the company is that welding power sources with connected capabilities don't look like computers. A power source with embedded technology simply has a communication module inside along with its other boards. For power sources without a factory-installed board, there are two options. For some of the newer inverters, a technician can add an external communication module, which looks like nothing more than a couple of small boxes. For virtually any power source with a positive and negative terminal, a universal connector can capture basic but powerful data. It, too, is a box with a couple of light-emitting diodes that looks nothing like a computer.

The communication module transmits data via WiFi, so all any facility needs is a reliable internet connection — Fig. 2. At Särkinen Industries, this meant installing a few amplifiers on the production floor. If the WiFi goes down, there are no worries. The module continues to collect the data and updates it to the cloud as soon as the connection is restored.

The data management apps used by the company run on the Microsoft Azure cloud-computing platform for building, deploying, and managing data analytics and storage applications — Fig. 3. It is extremely reliable and secure. It is invisible to users, as is the background technology for any app in the app store. In fact, the actual data management apps used by the fabricator are as easy to install as Office 365. They are accessible from PCs, Macs, Android, iOS, or any web-enabled device.

Fig. 5 — Immediate access to cranes eliminated a common production bottleneck.

What to Monitor

The fundamental functions for a weld data production management application are based on capturing arc-on time (or duration of the weld session), the number of weld sessions, and welding voltage and amperage (or wire feed speed) — Fig. 4. It records data for each weld session. Additional information include error codes, maintenance alerts, machine status, and welding process (e.g., short circuit, spray, or pulsed spray transfer).

Analytic functions of the app work with an intuitive click-based menu to "slice and dice" data by machine, operator, groups of machines, shift, facility, or the entire fleet. Comparing and contrast welding stations and shifts brings anomalies to light.

"You're not interested in the machine that's operating at 20% or better arc-on time. You are looking at the ones with five percent arc time and you want to know why," Särkinen explained.

Fig. 6 — The online app helped Särkinen figure out production issues by improving the flow of information to management.

Understanding and Overcoming Challenges

Särkinen realized that as incredibly helpful as this information would be, he didn't want it to scare his operators into thinking they were being watched and criticized by the data. He said that it was important for the operators not to feel like they were going to be blamed for low arc-on time. Rather, the company wanted to understand what their challenges were so it could fix them.

"What we found out [was] that our operators were banging their heads against the wall for two or three years, struggling with the same issues over and over. Data analytics brought this to light, and we were able to fix these problems and make their work easier and much less frustrating.

"The problem was lack of information coming to the management level. The online app helped us figure out our production issues," Särkinen revealed. "In retrospect, the causes were so mundane. Now the operators know we are there to work with them to solve problems."

"Normally we find out that it's not the welding that's the problem," Olesen explained. "It's that the operator is waiting for access to the overhead crane (Fig. 5), the part fitup coming from a cutting or bending station created gap that is 2 mm wide, the operator [is] fixing or fiddling with an erratic piece of equipment, or he needs to

Fig. 7 — Scanning a bar code links operators to welding and production data.

Fig. 8 — Capturing filler metal data improves traceability.

go to another welding station to borrow a tool."

The lack of tools was particularly large because of low arc-on time and a problem Särkinen said was "so stupid." He realized he could have lost skilled welders to a competitor because they were frustrated for lack of a wrench, grinder, or pneumatic needle scaler. Now the company has invested heavily in equipping every operator with a complete set of tools.

"If an operator needs two of something, we'll give him two so that if one breaks and needs to go to service, he still has functioning tools. Now welders are more satisfied," Särkinen said. "Online apps didn't just increase our production, they boosted employee morale."

Feedback Loop

Understanding exact welding productivity at each welding station by shift, and documenting this information into data that was useful for different employees, created an incredible communication tool within the company — Fig. 6.

Särkinen and Saarinen don't just look at analytics in their office and make what can seem like capricious decisions to the operators. Instead, they bring information to the operators and explain it. They show them the arc-on time they had previously and the new number reached after making changes. Then they discuss with the operator other obstacles that prevent them from achieving a higher goal and incentives for achieving that goal.

Communication is so important that Särkinen has hired a new CEO so he can transition into a new role focused on improving productivity and quality, and digital solutions play a large role. The company is currently testing a handheld scanning device that can scan a badge (essentially a quick response or bar code) for information on the operator, wire, gas, welding procedure specification, and more — Figs. 7, 8. They are also implementing apps for fleet management as well as quality, qualifications for welders, procedures, and weld specifications.

Conclusion

"If you remove the bottlenecks, arc-on time will take care of itself," Särkinen assured. Realistically, 20% is about the maximum arc-on time for a handheld GMAW operation. Having reached those goals, Särkinen can fully justify the capital expense for robotic welding stations that offer a potential for arc-on times of 80%. That, too, will require skilled personnel so that the company can compete with suppliers in low-cost countries.

"At Särkinen, having the welders work with management to achieve production goals is the kind of system I am building," Särkinen concluded. "I am building a system to support people to be more interested in their work." WJ

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How to Move from Manual Visual Arc Weld Inspection to Robot Vision

Next-generation inspection system ensures quality in arc-welded automotive components

BY JEAN-PAUL BOILLOT, JEFFREY NORUK, AND SÉBASTIEN LATOUR

Most components produced by original equipment manufacturers (OEMs) and Tier 1 manufacturers are welded using robots, but the majority of the welds are still manually visually inspected. Typically, gauges are not used but instead welds are just visually reviewed and a person makes a subjective go/no-go decision. To assist with this inspection, workmanship or boundary-welded samples are used for comparison purposes. While this approach has been in place since automotive components began being gas metal arc welded in the 1950s, it has resulted in overdesign, excessive repair, and defective parts reaching customers.

Most of these problems can be overcome proactively by using laser vision seam finding and tracking to adapt to typical joint variability, which is the most common reason for unacceptable welds. However, there is still a requirement to verify weld quality by visual inspection.

Fully automated robotic arc weld inspection is not only faster and more reliable than manual inspection, but it also provides valuable data that fits well with Industry 4.0 requirements for both automotive and general industry welded components. This data can help predict when a weld is trending toward becoming defective as well as possibly point to what needs to be improved, such as part quality, fixture repeatability, or the welding process itself. In addition, there is the opportunity to reduce the number of cut and etch destructive tests.

Finding Solutions, Including for Automotive Applications

The applications of interest so far in the automotive industry have centered around the most critical safety-related components, including truck frames, engine cradles, suspensions, axles, airbag cannisters, bumpers, seat frames, fuel tanks, and instrument panels. Another area that has seen a lot of activity recently has to do with the electric vehicle (EV) market and the battery trays/enclosures, which are critical to protect the battery from any damage. Automated weld inspection using 3D robot laser vision is very flexible in that a wide variety of materials, including steel, high-strength steel, stainless steel, aluminum, and even adhesives, can be successfully inspected.

One Needs to Have Practical Expectations

The single biggest hurdle to overcome in using vision systems instead of manual visual inspection is that one has to have knowledge of the welding operation to really understand how to approach the problem the right way.

Arc welding is a complex process with inherent variability, which makes welds more difficult to inspect than circuit boards or other objects. Selecting the right attributes to inspect and measure to determine the weld quality level requires welding technology knowledge. Measuring quantitative values of an idealistic, yet unrealistic, weld bead geometry surely leads to failure.

Most vision companies have not succeeded in providing reliable weld inspection systems because, due to a lack of welding engineering knowledge, they have not been able to extract the proper attributes from the 3D image data that reliably correlate with a measure of the quality level expected from given inspected welds.

Because the current welding quality standards have not been designed nor yet adapted to laser-vision-based weld surface inspection methods, a practical robotic weld inspection system would need to include "welding-specific" 3D weld bead contour map analysis tools. These tools allow the inspection system programmer to use relevant weld bead characteristics that can be reliably compared to reference ones to easily configure the application.

Many who have "inspected welds" with commonly used welding quality standards for years, in truth, have had a low success rate if one looks at it from the level of false positives/false negatives occurring. A proper laser surface-mapping system can generate a thorough analysis of an unlimited number of image maps every second to select important attributes that better reflect the quality of the welds and thus discriminate against poor ones.

Reliable techniques can be used to compare current parts to reference ones. Figure 1 shows the 3D surface image map of a reference weld (golden part) and a defective weld that has

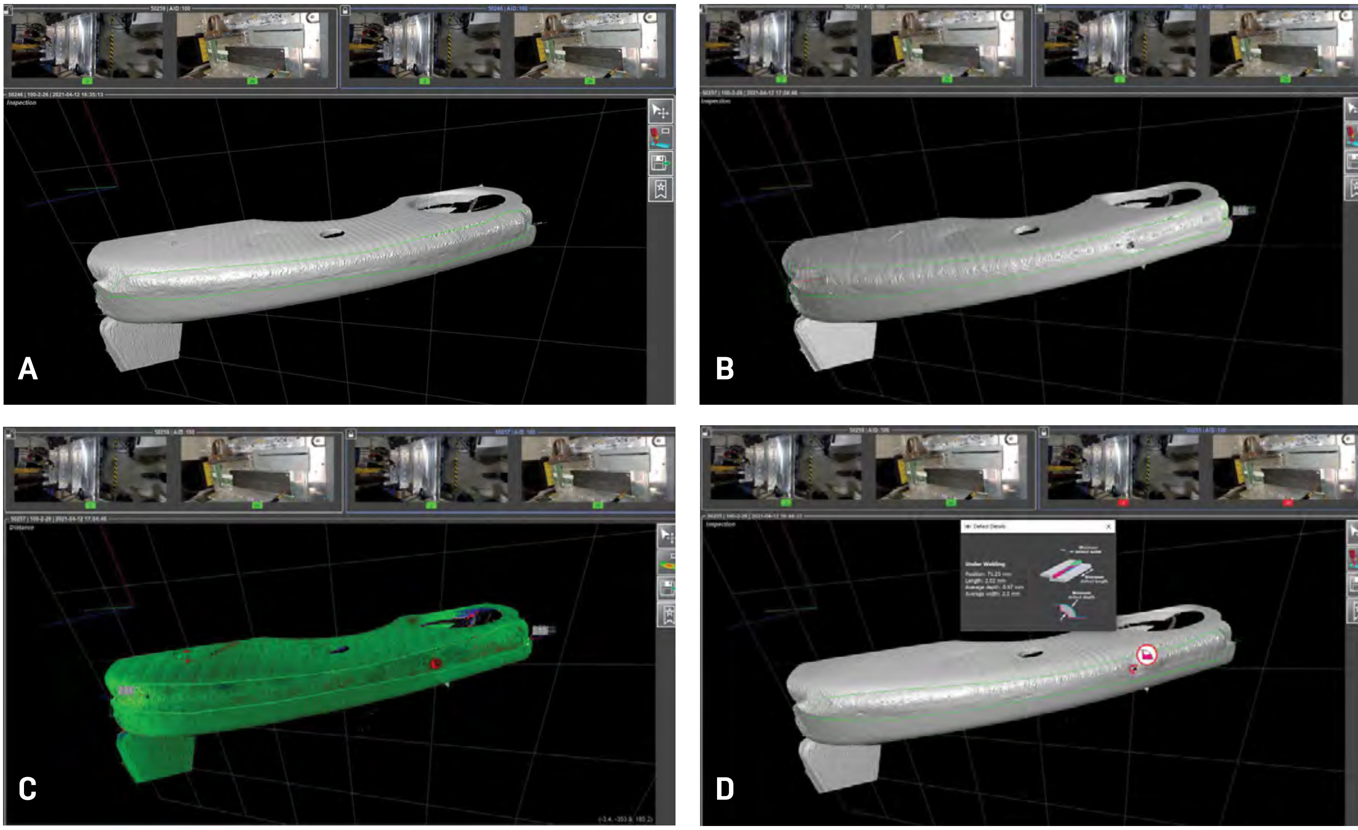

Fig. 1 — 3D robot vision system inspects a weld to a reference. A — Golden reference part scan; B — current production scan; C — color map of the production part vs. the reference part, where green is okay and red is defective; D — detected defect.

been compared and found "out of tolerance." In this case, a Servo-Robot robotic laser vision system was used.

Typically, applied vision techniques rely on mathematical algorithms to evaluate the weld cross section by extrapolating from the visible top surface of the weld bead and to identify specific defects. However, these algorithms are only reliable if the measured attributes are stable enough for the geometric measurement technique to work and if other parameters are met. What might be easy on a perfectly smooth weld will be impossible if tried on a weld that was made with an out-of-boundaries (i.e., out of control,) welding process. This is why more comprehensive attributes than weld bead profile dimensional measurements must be applied instead.

Furthermore, a smart gradation of the inspection logic must be considered. Why start searching for a 0.5-mm surface porosity if the weld bead is not qualified by more obvious quality requirements in the control logic chain? To overcome this, a total weld quality assessment methodology, such as one developed by Servo-Robot, must be designed to ensure that the robotic vision process is technically sound and reliable. If one does not take this approach, failure is guaranteed because the robot vision system will be unreliable and will eventually be turned off because it simply cannot be trusted.

This article is based on more than 35 years of automatic and robotic process management and control experience. It will show the proper steps, tools, and methodology to implement to practically ensure that weldments are produced to consistently meet a defined welding quality level for automotive and other applications.

Recipe for Success

The keys to successfully installing an automated weld inspection system are listed below.

1. Choose a system that is designed for the inspection of arc welds in a high-production arc-welding environment, where the variability and environment are challenging. This system should be based on 3D laser vision scanning technology that utilizes the most precise and rugged 3D laser vision camera.

2. In addition, there must be a seamless and smart interface to the robot, along with associated calibration and verification application software to ensure reliability, and a user-friendly human machine interface to enable quick system installation and monitoring — Fig. 2.

3. Then, one needs software that allows for the implementation of proven methodologies and surface map analysis to validate that the vision system is accurate and repeatable.

4. To properly evaluate a manufacturing process, one needs to begin with a process that is in some level of statistical control. This means one needs to measure actual production welds to see how much they vary from the weld that was tested based on the approved welding procedure specification (WPS). The 3D laser scanning system can uniquely provide the ability to

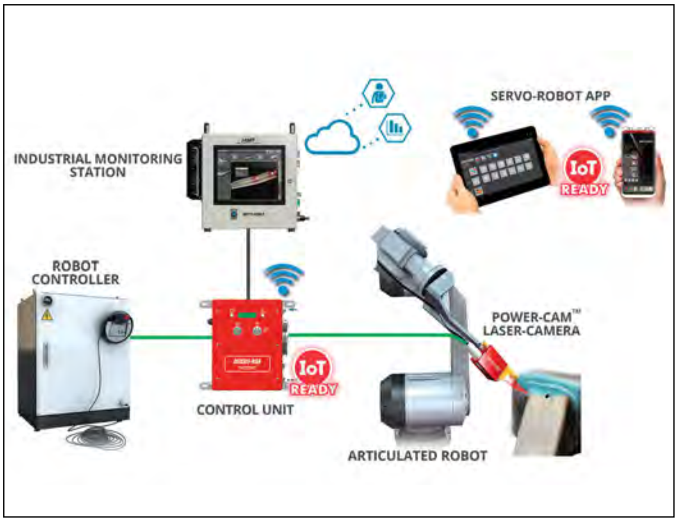

Fig. 2 — Example of the typical configuration of the 3D robot vision weld inspection system.

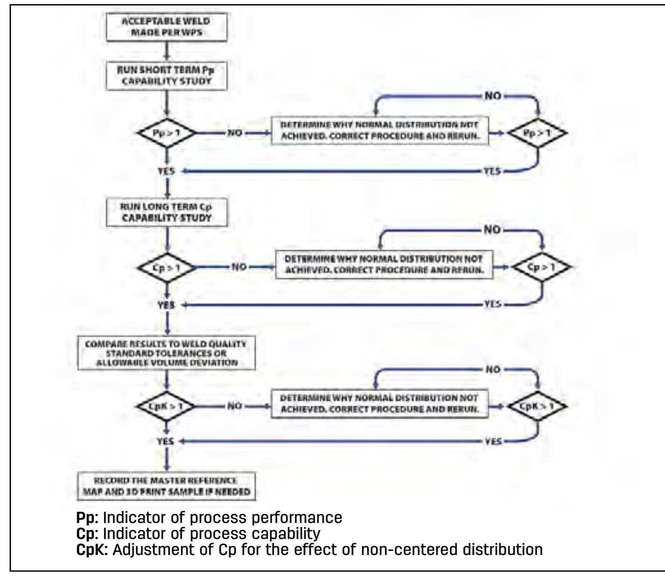

Fig. 3 — Methodology to establish welding process capability suitable for successful automated inspection.

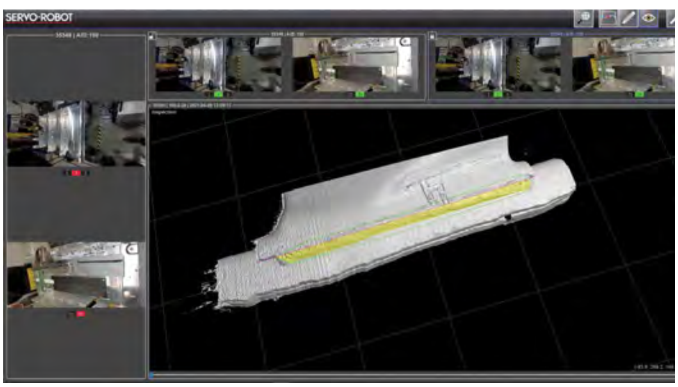

Fig. 4 — Human machine interface showing a weld surface map created by the vision system.

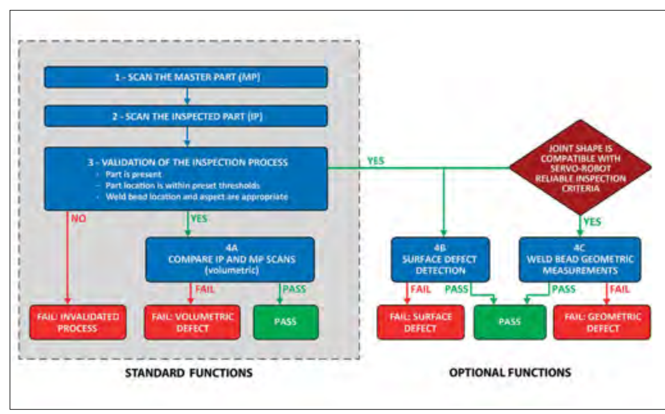

Fig. 5 — Evaluation logic used to inspect welds.

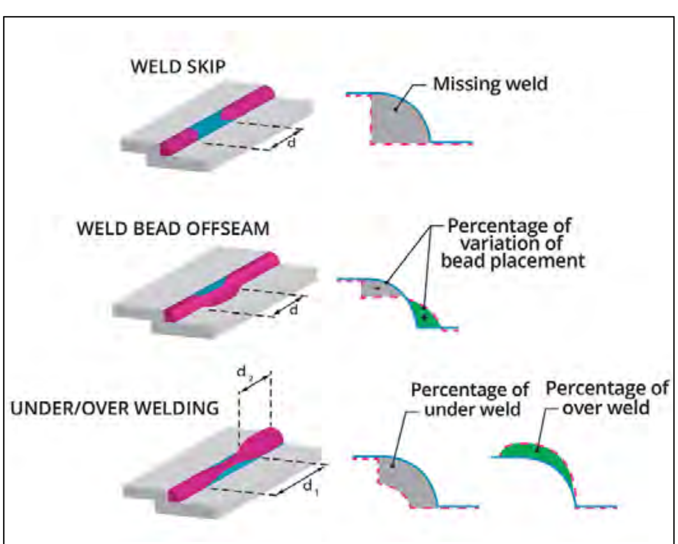

Fig. 6 — Examples of detectable weld defects using the comparative surface map method.

establish this welding processes capability. Figure 3 shows the overall flow chart explaining the methodology required to establish welding process capability.

5. Once the process capability is proven to be acceptable, then a golden part with the gradient of allowable weld tolerances can be generated, and possibly 3D printed, from the surface map created by the scanning system — Fig. 4. This then allows one to ensure the measuring system is properly calibrated, running correctly, and producing the acceptable level of reliability needed.

6. The final step is to test the system in a pilot cell to determine if the allowable differences from the golden part can be detected reliably across normal production weld variability. Figure 5 shows an explanation of the logic used for this evaluation. Examples of defects detectable using this comparative method are shown in Fig. 6.

Conclusion

To be successful, one needs to approach automated weld inspection from a welding technology perspective so all the required prerequisites are in place prior to running the robotic inspection system in production.

There needs to be an effort to update and harmonize the welding quality standards of OEMs, Tier 1s, and American Welding Society (AWS), which have historically been used for manual human inspection, to ensure these standards include what is required for successful weld inspection using 3D robot vision systems.

Automated weld inspection can offer many benefits to both automotive and general industry OEMs and Tier suppliers for the improvement of weld quality, overall productivity, and environmental friendliness. If properly applied, robot vision systems, possibly involving the latest collaborative robots, are very reliable and can replace human inspection, which is costly, tedious, and inconsistent. WJ

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The AWS D8 Committee on Automotive Welding is responsible for the development and maintenance of weld quality standards for resistance spot welding, friction stir welding, laser beam welding, and arc welding of steel and aluminum. We encourage you to join an AWS technical committee because you will be contributing to the industry while learning and making lifelong relationships that will benefit you both professionally and personally. Visit *aws.org/standards/committees* to learn more.

Laser Applications for Electric Vehicle Battery Packs

Laser welding processes allow manufacturers to achieve optimal cost, quality, and productivity

BY PIERSON CHENG

The battery pack enclosure is an integral part of the chassis of battery electric vehicles (BEV). Not only does the enclosure protect the battery and the battery management system (BMS), but it also keeps the vehicle and its passengers safe from battery leakage, fumes, and fire, especially during a crash.

Battery pack manufacturing costs play an important role in an electrical vehicle's total price. For BEV makers, about 10 to 20% of the total cost of a finished lithium-ion battery pack comes from the pack stage production. The battery pack enclosure can be made of either aluminum or advanced high-strength steel (AHSS), and weight and safety considerations as well as structural reinforcement are essential factors in determining and manufacturing the battery pack enclosure.

The selection of materials, structural design, and the joining process used are a balance between technical performance (strength, weight, sealing) and the cost for manufacturing the battery pack enclosure. Aluminum alloy and steels are both used in high-volume production, whereas composite can be found in low-volume and low-range battery vehicles.

A typical battery pack enclosure design has the following structural parts — Fig. 1:

• The top cover plate encloses the pack with good sealing and electromagnetic compatability (EMC).

• The tray encloses the protective housing of the battery pack, electronics, and cooling unit.

• Frames support high loads from impacts and dissipate the energy.

• Crossmembers mitigate deformation during crash impact.

• The thermal management system provides optimum operating temperature range.

Typically, a total of ~ 30 m of weld length is necessary during the construction of a battery tray to join the lower shield plate to the side/crossmembers and brackets to the body in white (BIW) with gas/water tightness. This underscores the need for a robust and productive weld solution with good gap bridging.

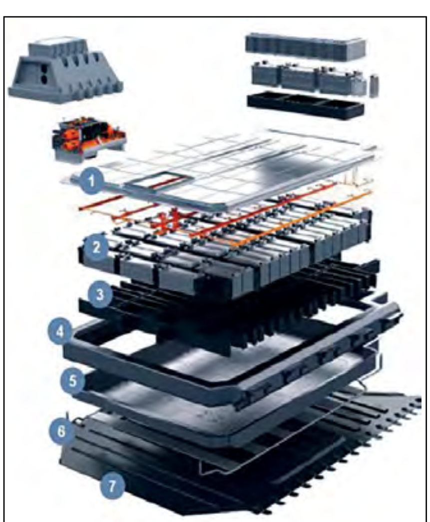


Fig. 1 — A battery pack enclosure design.

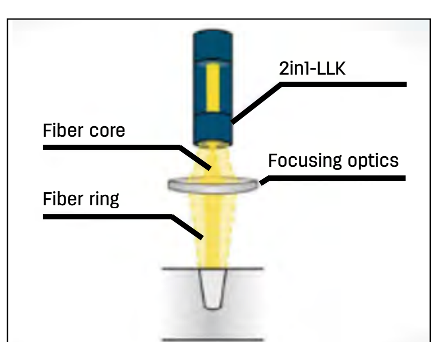


Fig. 2 — BrightLine Weld beam shaping. Note: LLK stands for laser light cable.

Remote Laser Welding, Beam Shaping, and Beam Oscillation

Remote laser welding (RLW) is a well-established joining process in the automotive industry. With RLW, customized weld patterns with different weld shapes, orientation, and distribution can be realized, which is necessary for joint strength and stress optimization when joining the structural parts of battery pack enclosures.

One drawback of RLW is it cannot weld across root openings in butt weld joints, as there is no way of adding filler material. The new wobble method overcomes this problem. Laser beam oscillation with a high-brightness, high-intensity laser beam opens up new possibilities of improving the welding process in terms of compensation of larger tolerances, reduction of porosity, increased aesthetics of the weld joint, and process stability.

During the complete joint penetration process, part of the metal is vaporized and creates a pressured vapor at the bottom of the keyhole. The vapor accelerates the melt pool upward and excessive acceleration causes loss of the material, resulting in spatter. To reduce spatter, TRUMPF's BrightLine Weld technology (Fig. 2) allows free distribution of laser power between the inner core and outer ring; the additional ring beam creates a larger keyhole opening to allow metal vapor to

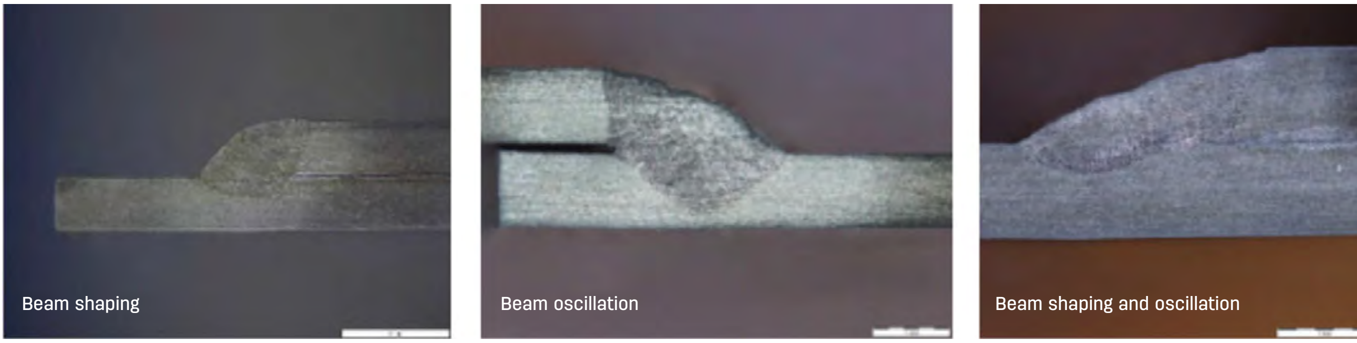


Fig. 3 — Alu600x welding with beam shaping and beam oscillation.

escape. This also helps to create a more stable keyhole to avoid collapse, thus avoiding large pore formations.

The combination of beam shaping and beam oscillation with the autogenous RLW process is an effective solution to improve keyhole stability and maximize the weldability of aluminum alloys and some AHSSs.

Macrocracks can be effectively avoided by using a fillet lap joint configuration; however, random microcracks are still found with certain materials. Figure 3 shows welding result comparisons with beam shaping only, oscillation only, and beam shaping and oscillation combined on 6xxx series aluminum.

Laser Welding with Filler Wire and Hybrid Laser Welding

Autogenous laser welding is preferred in automotive manufacturing. However, certain high-alloy materials and difficult applications require the use of filler material in the welding of battery pack enclosures, including but not limited to the following reasons: weld porosity, part fitup, and macrocracks.

TRUMPF has used its experience in laser welding with filler wire to create FusionLine technology with its TruLaser Weld system — Fig. 4. Both weld and filler wire parameters were developed and optimized to produce good quality welds without cracking or porosity. Using the correct weld geometry allows users to close root openings up to 1 mm wide. Laser welding with filler wire is able to deliver crack-free welds and bridge larger part-to-part root openings; however, it also increases system complexity, reduces welding speed, and adds more consumables costs.

Hybrid laser welding refers to the processes in which laser welding is combined with other arc welding methods. The arc acts on the surface and provides a broader weld joint and root opening. The laser then delivers the high-power densities needed for deep welds and enables high welding speeds. This, in turn, reduces heat input and distortion.

Hybrid laser welding is well suited for welding long joints on relatively thicker and high-strength structural components, such as the crossmember and frames, which require complete joint penetration and good bridging of root openings.

Laser Cleaning and Ablation

Welding and adhesive bonding require clean surfaces free of debris, oils, and corrosion. Cleaning the surface prior to welding or gluing is critical to maintaining weld quality and gas- andwater-tight sealing on battery pack enclosures. In addition, cathodic dip paint (CDP) on battery pack enclosure frames and cover plates must be removed for EMC.

A typical laser cleaning system used in a battery pack enclosure application consists of a nanosecond pulsed laser combined with scanning optics. The scanner makes closed contour movements in an endless loop and is synchronized with robotic movement. Depending on the direction of the robotic movement, the scanner movement can either be programmed as linear lines or circular movement.

In Fig. 5, a high-power, short-pulsed laser system with programmable focusing optics was mounted on a robot to remove CDP coating on the battery pack enclosure cover plate. In this fully automated process, a CDP coating ablation rate of 30 cm^2/s is possible.

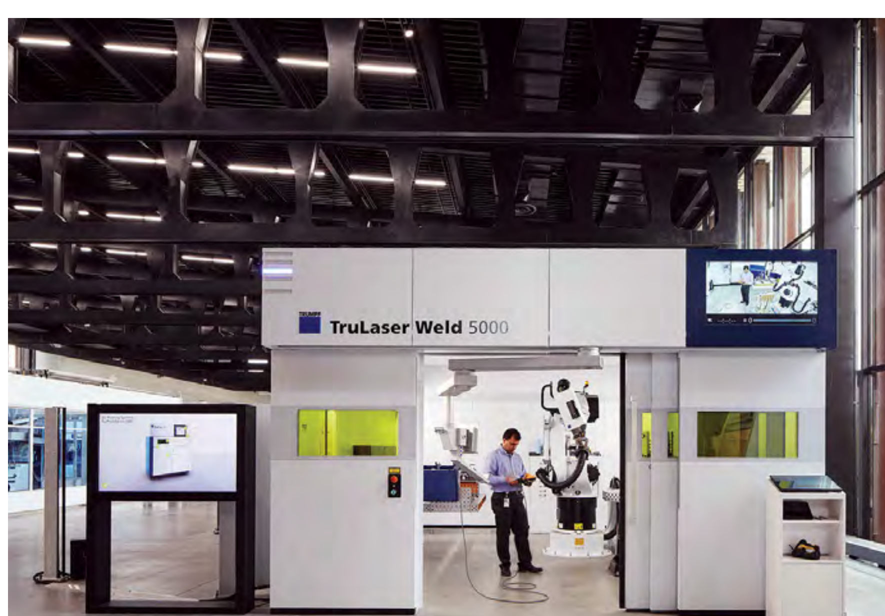


Fig. 4 — The TruLaser Weld 5000 system.

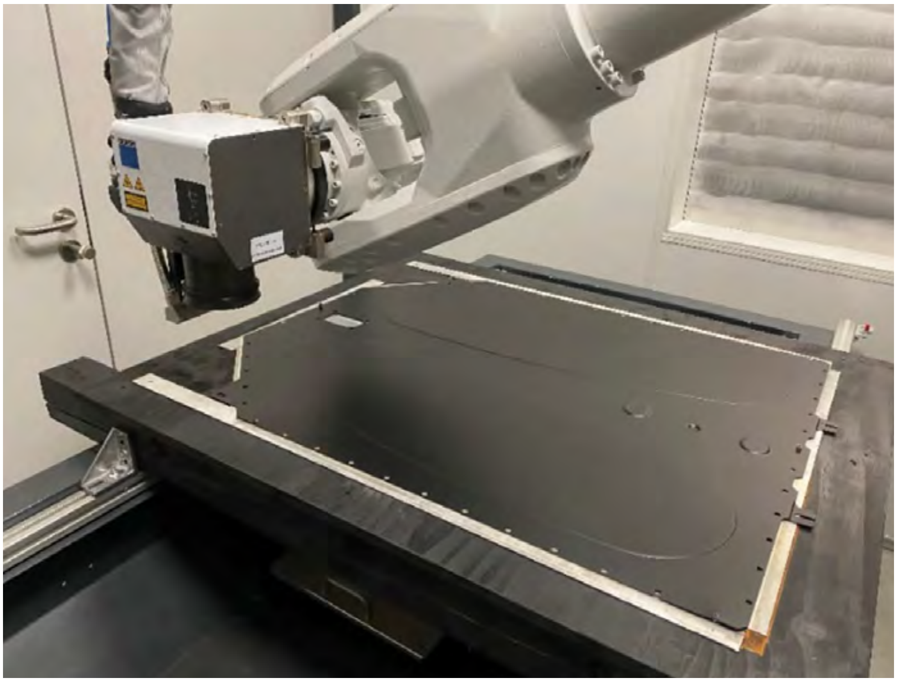


Fig. 5 — Laser ablation of CDP painting.

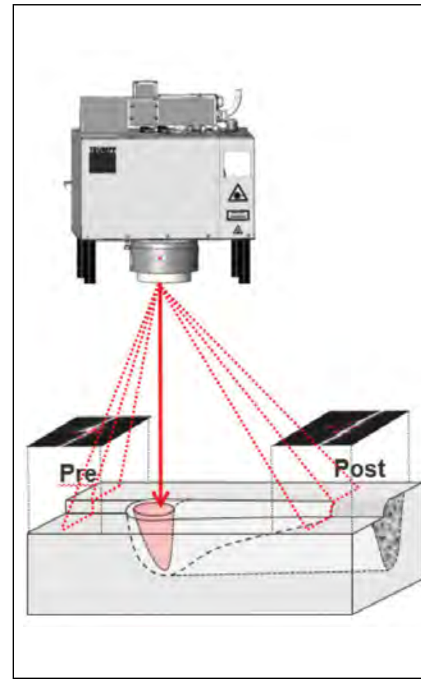


Fig. 6 — Pre-, in-, and post-monitoring.

Beam Tracking, Weld Depth Monitoring, and Weld Joint Inspection

In the mass production of battery pack enclosures, the weld quality can be disturbed by various factors, such as the internal defects of materials or the complex manufacturing environment. To monitor and ensure welding quality, BEV manufacturers prefer to use inline monitoring instead of traditional offline testing methods due to time, material cost, and productivity considerations.

State-of-the-art, real-time, and direct weld quality measurement of the keyhole depth is done through optical coherence tomography (OCT), which has been successfully used in automotive manufacturing, including in the production of battery pack enclosures.

With OCT, light reflections are measured by the Michelson interferometer using the low-coherence properties of a broadband laser source. This is done by comparing the travel lengths of the reflections of the measurement laser beam directed toward the keyhole bottom with that of a reference laser beam inside the interferometer. Any change in the keyhole wall or depth will generate interference fringes, which are translated into a distance measurement.

The monitoring process can be divided into three different parts: preprocessing scanning, in-process monitoring, and post-process diagnosing — Fig. 6.

The preprocess scanning mainly focuses on the weld joint tracking and scanning the root opening between workpieces to ensure that the laser beam is on track, independent from part-to-part variance.

The in-process monitoring pays close attention to the real-time monitoring of welding characteristics in the welding zone, such as keyhole.

The post-measurement can be used for weld quality assessment. The pore, crack, spatter, surface collapse, underfill, etc. are the common defects, which are the critical indicators in the quality evaluation of a weld joint.

Conclusion

Laser welding has proven to be an effective solution for battery pack enclosure manufacturing. The processs allows manufacturers to achieve optimal cost, quality, and productivity.

Remote laser welding, combined with beam shaping and beam oscillation, is an effective solution to improve keyhole stability, reduce spatter, bridge root openings, and maximize weldability for most of the materials commonly used as structure components in a battery pack.

Tactile laser welding (TLW), with the use of filler wire, brings benefits such as reduced heat input and single side access and is able to effectively join materials that require chemical alteration to achieve crack-free welding and large-gap bridging. Both RLW and TLW are used in welding battery pack enclosure components, such as frames, crossmembers, bottom reinforcements, and brackets to BIW.

In addition to laser welding, laser cleaning is able to generate a controllable and accurate removal area with minimal damage to the substrate, thus it is an ideal method to remove CDP as well as a pretreatment for welding or sealing surfaces on top cover or frames.

For battery pack enclosure joining process control and quality monitoring, OCT technology provides real-time and direct measurement for joint tracking, weld depth monitoring, and the inspection of weld joints. Quick setup and intuitive operation are realized by integrating the OCT sensor with the VisionLine camera system. WJ

PIERSON CHENG (pierson.cheng@trumpf.com) is automotive industry manager, TRUMPF Inc., Plymouth, Mich.

Note: The 2021 schedule for all certifications is 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
Louisville, KY	July 11–16	July 17
Phoenix, AZ	July 11–16	July 17
Miami, FL	July 18–23	July 24
Cleveland, OH	July 18–23	July 24
Milwaukee, WI	July 25–30	July 31
Orlando, FL	July 25–30	July 31
Charlotte, NC	Aug. 1–6	Aug. 7
Los Angeles, CA	Aug. 1–6	Aug. 7
Denver, CO	Aug. 8–13	Aug. 14
Salt Lake City, UT	Aug. 8–13	Aug. 14
San Diego, CA	Aug. 15–20	Aug. 21
Chicago, IL	Aug. 15–20	Aug. 21
Kansas City, MO	Aug. 15–20	Aug. 21
Seattle, WA	Aug. 22–27	Aug. 28
Houston, TX	Aug. 22–27	Aug. 28
Benicia, CA	Sept. 12–17	Sept. 18
Minneapolis, MN	Sept. 12–17	Sept. 18
Nashville, TN	Sept. 19–24	Sept. 25
San Antonio, TX	Sept. 19–24	Sept. 25
Indianapolis, IN	Sept. 26–Oct. 1	Oct. 2
Cleveland, OH	Sept. 26–Oct. 1	Oct. 2
New Orleans, LA	Sept. 26–Oct. 1	Oct. 2
Miami, FL	Oct. 3–8	Oct. 9
Norfolk, VA	Oct. 3–8	Oct. 9
Long Beach, CA	Oct. 10–15	Oct. 16
Tulsa, OK	Oct. 10–15	Oct. 16
Detroit, MI	Oct. 17–22	Oct. 23
Houston, TX	Oct. 17–22	Oct. 23
Savannah, GA	Oct. 24–29	Oct. 30
Boston, MA	Oct. 24–29	Oct. 30
Pittsburgh, PA	Nov. 7–12	Nov. 13
Kansas City, MO	Nov. 7–12	Nov. 13
Dallas, TX	Nov. 14–19	Nov. 20
Cleveland, OH	Nov. 14–19	Nov. 20
Sacramento, CA	Dec. 5–10	Dec. 11
Louisville, KY	Dec. 5–10	Dec. 11
Miami, FL	Dec. 12–17	Dec. 18

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
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
Charlotte, NC	July 18–23
Houston, TX	Aug. 8–13
Orlando, FL	Aug. 29–Sept. 3
Sacramento, CA	Sept. 26–Oct. 1
Dallas, TX	Oct. 10–15
Denver, CO	Oct. 24–29
New Orleans, LA	Nov. 14–19

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*.

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.

Note: Due to COVID-19, these events/opportunities are subject to change.

AWS-SPONSORED EVENTS

RWMA Resistance Welding Spring School 2021. June 22, 23. Detroit, Mich. AWS and RWMA team up to offer a two-day school, taught by resistance welding industry experts, that explores concepts and materials outside the scope of the Certified Resistance Welding Technician exam. This intensive overview of resistance welding will include presentations, panel discussions, Q&A sessions, and live demonstrations on fully functioning equipment. It is designed for beginner-to-experienced technicians, supervisors, production managers, operators, trainers, and educators. Contact Sarai Claveria, *sclaveria@aws.org*; (305) 443-9353, ext. 227; or visit *aws.org*.

FABTECH. Sept. 13–16. McCormick Place, Chicago, Ill. A one-stop shop venue where attendees can meet with world-class suppliers, see the latest industry products and developments, find the tools to improve productivity, and increase profits. Visit *fabtechexpo.com*.

2021 International Brazing and Soldering Conference. Oct. 3–6. Denver, Colo. The triennial event will bring together the world's experts in brazing and soldering, allowing them to share ideas, view the latest technology, and see friends. Visit *aws.org*.

2nd Shipbuilding & Aluminum Conference. Oct. 5–7. Holiday Inn San Diego Bayside, San Diego, Calif. Industry experts will deliver the latest research and innovations in both the shipbuilding and aluminum industries. The critical importance of welding in the shipbuilding industry will also be addressed by providing current information on the emerging technologies being developed for shipbuilding applications. Visit *aws.org*.

2021 Sheet Metal Welding Conference XIX — Welding Solutions for Lightweight and Electric Vehicle Production. Nov. 2–4. Laurel Manor, Livonia, Mich. This event provides engineers and researchers from manufacturers, suppliers, universities, and research institutes the opportunity to network and meet experts in the field of welding. The conference will be preceded by a one-day workshop on Nov. 1. Visit *awsdetroit.org*.

U.S., CANADA, MEXICO EVENTS

NDT of Composites 2021. June 22–24. Hyatt Regency Lake Washington, Renton, Wash. This conference will feature presentations on existing, new, and developing methods of materials and fabrication techniques, including advances in composite nondestructive examination (NDE) technology, new product forms, and in-process NDE. Visit *asnt.org*.

74th IIW Annual Assembly and International Conference. July 7–21. Hosted by IIW, the assembly will be held online and include the International Conference, opening and award ceremonies, and a closing event. The event will also feature the 2021 Welded Art Exhibition, including a selection of welded art pieces from different categories from all continents. Visit *iiw2021.com*.

Digital Imaging and Ultrasonics for NDT 2021. July 27–29. Silver Legacy Resort Casino, Reno, Nev. This three-day nondestructive examination conference focuses on two of the most popular testing methods: digital radiography and ultrasonic. Topics to be covered include additive manufacturing, computed tomography, composites, phased array, and more. Visit *asnt.org*.

16th International Symposium on Nondestructive Characterization of Materials. Aug. 10–12. Royal Sonesta Harbor Court Baltimore, Baltimore, Md. This symposium offers presentations addressing issues of current and future interest, covering both theoretical and experimental work. Featured will be presentations about developments and applications where the complex nature of materials is recognized as well as discussions on the applications and possibilities for multitechnique measurements of interdependent parameters and the evaluation of the data through sophisticated computer analyses. Visit *asnt.org*.

ASNT 2021: The Annual Conference. Nov. 15–18. Phoenix, Ariz. Attendees will have the opportunity to receive top content from global nondestructive examination leaders, earn recertification contact hours, network with peers, explore the exhibit hall, and more. Visit *asnt.org*.

Goel UT Challenge. Dec. 3, 4. Atlas Evaluation & Inspection Services (AEIS) Headquarters, South Plainfield, N.J. AEIS will hold its first-ever ultrasonic testing (UT) competition. There will be two rounds. Round one will host up to 56 participants, after which six skilled candidates will advance to round two. Participants must be UT Level II with at least two years of structural UT experience. The first-place winner will take home a trophy and $5000. Visit *aeis.com/GOELUT*.

EDUCATIONAL OPPORTUNITIES

ASME Section IX Virtual Classroom. June 14–17. This virtual course will teach participants how to comply with *ASME Boiler and Pressure Vessel Code Section IX*, *Welding, Brazing and Fusing Qualifications*, including how to address its requirements and its relationship with other code sections. For more information, contact Brian Behnke; *BehnkeB@asme.org*; (212) 591-7122.

ASNT Learn Webinars. Learn about emerging industry trends, management skills, and nondestructive examination applications. Those pursuing recertification can earn contact hours. Go to *asnt.org* and click on "Webinars" to view upcoming live events.

The Atlas of Welding Procedure Specifications. This seminar, scheduled for Aug. 16–23, will address the needs of welders, inspectors, and engineers who are advancing their careers to include the development of welding procedure specifications (WPSs). Attendees will learn how to write a WPS, qualify a WPS, and understand the relationship of the procedure qualification record and WPS for the part B CWI examination. Join via Zoom for the online presentation. Attendees will need to have a computer with a camera and microphone to participate. For more information, contact Albert Moore at *amoore999@comcast.net*.

AWS Certified Resistance Welding Technician (CRWT) Online Exam Preparation Sessions. To help prepare CRWT candidates prior to taking the exam, AWS is preparing an online, instructor-led seminar on July 19–28. Registration is open. For more information, go to *aws.org/crwt*.

AWS CWI Webinar. The 30-min webinar, "What to Expect during the CWI Application and Certification Process," is designed to help individuals navigate the CWI application. The webinar will be held at 2:00 p.m., EST, on the following dates: June 2, July 7, Aug. 4, Sept. 1, and Oct. 6. Register at *aws.org/cwi-application-webinar*.

AWS Professional Development Webinars. These live, instructor-led webinars cover a variety of topics, including WPS, PQR, and WQTR; aluminum welding for fabricators, inspectors, and engineers; introductions to ASME *Section IX*; and a new welding standard for additive manufacturing. Participants can also earn professional development hours and continuing education units. Go to *aws.org* to view the schedule for upcoming webinars.

Business Electronics Soldering Technology (BEST). Online and in-person certification and training classes held in Rolling Meadows, Ill., and Auburn Hills, Mich. Training schedule is available at *solder.net*. Contact BEST at (847) 797-9250.

Canadian Welding Bureau Online/Classroom Courses. Courses in nondestructive examination disciplines to meet certifications to the Canadian General Standards Board or Canadian Nuclear Safety Commission. The Canadian Welding Bureau; (800) 844-6790; *cwbgroup.org*; *info@cwbgroup.org*.

CWI/CWE Prep Courses; CWI Endorsement Seminars. All courses are held at the Welder Training & Testing Institute. For a complete list of seminars, workshops, and training schedules, go to *ndtinstitute.com/upcoming-classes*. To register, contact *Mary@wtti.com*.

CWI Exam Prep Course. The American Institute of Nondestructive Testing (AINDT) offers a hybrid CWI exam prep course. Part A (online) covers the fundamentals of welding technology; part B consists of extensive practical hands-on techniques and will be held at the AINDT in Baxter, Minn.; and part C (online) provides in-depth training to the welding code portion of the exam. Housing at Lakes Area Lodge is included. *instructor@trainingndt.com*; *trainingndt.com*; (855) 313-0325.

Gas Tungsten Arc Welding Aerospace Course. Provided by the Hobart Institute of Welding Technology, this 70-h course will help attendees develop the skills necessary for entrance into the aerospace industry, including working with typical materials, weld joint configurations, and tools involved in production and testing within aerospace manufacturing and repair. For information, contact (937) 332-9500 or visit *welding.org*.

Hypertherm Cutting Institute Online. Includes video tutorials, interactive e-Learning courses, discussion forums, webinars, and blogs. Visit *hyperthermcuttinginstitute.com*, *hypertherm.com*.

Industrial Laser Training. Technical training and support offered for users of industrial lasers in manufacturing, education, and research. There are regularly scheduled classes in laser welding, laser cutting, and drilling. Online learning is available. HDE Technologies Inc.; *laserweldtraining.com;* (916) 714-4944.

Laser Safety Training Courses. Laser training courses for personnel in research, industrial, and medical laser facilities. Courses based on ANSI Z136.1, *Safe Use of Lasers*. For schedule and location, go to *lia.org*. Laser Institute of America; (800) 345-2737.

Machine Safeguarding Seminar. Rockford, Ill. Online seminar teaches how to properly safeguard machinery for OSHA/ANSI standards. Go to *rockfordsystems.com/product/seminar.*

NDE Classes. Moraine Valley Community College, Palos Hills, Ill., offers NDE classes in PT, MT, UT, RT, radiation safety, and eddy current, as well as API 510 exam prep and weld inspection. (708) 974-5735; *ccce@morainevalley.edu*; *morainevalley.edu*.

NDT Classroom Training and e-Learning Course. Waygate Inspection Academy offers courses in UT, RT, MT, PT, eddy current, and remote visual inspection. On-site training is also available. (855) 232-7470; *waygateinspectionacademy.com*.

NDT Courses and Exams. Brea, Calif., and customers' locations. Level I, II, and III refresher courses in PA, UT, MP, radiation safety, radiography, visual, and more. Test NDT LLC; *testndt.com*; (714) 255-1500.

Online Courses in Destructive and Nondestructive Testing of Welds and Other Welding-Related Topics. Online courses meet the requirements of AWS QC1 and can be applied toward professional development hours for recertification of certified welding inspectors and educators. Hobart Institute of Welding Technology; (800) 332-9448; *welding.org/product-category/online-courses/*

Part B Study Group. Scheduled for July 5–9, this session prepares individuals for the CWI part B practical examination. For information, contact Albert Moore at *amoore999@comcast.net*.

Preparation for AWS® — CWI®/CWE® Examination. The two-week class offers nine days of instruction with the test

— *continued on page 90*

AWS Holds First-Ever Women in Welding Conference

On March 25, in honor of Women's History Month, more than 200 professionals gathered around their computers to attend the first-ever Women in Welding Conference. The virtual one-day event was hosted by the American Welding Society (AWS) to celebrate the contributions women have made to the welding industry.

The conference spotlighted prominent women across different sectors of the welding industry and provided a platform for them to share their professional history, the challenges they've overcome, and insight into how they advanced their careers — Figs. 1, 2.

The conference was organized by Monica Pfarr, executive director, AWS Foundation; Stephanie Hoffman, program manager of workforce development, AWS Foundation; and Nancy Porter, Navy ManTech program manager, EWI. The event was sponsored by Air Products, Balance Staffing, Castolin Eutectic, Delta Technical College, Fluor Corp., Igneous Gear LLC, Midwest Technical Institute, Miller Electric Mfg. LLC, Notch Mechanical Constructors, The Lincoln Electric Co., WEG, and Xena Workwear Inc.

The following coverage features some highlights.

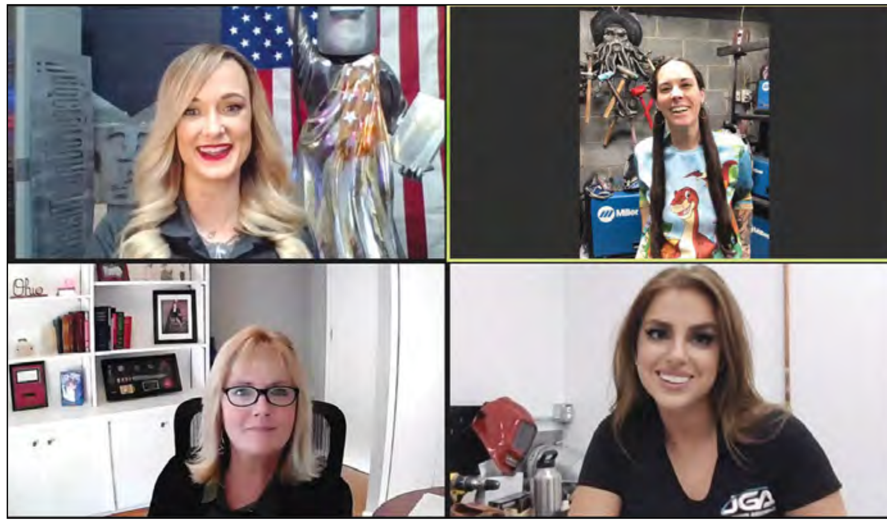


Fig. 1 — The inaugural Women in Welding Conference, held virtually on March 25, brought together successful women across several sectors of the welding industry. Pictured during a panel discussion are (from top left) Stephanie Hoffman, Barbie Parsons, Monica Pfarr, and Chloe Hudson.

Opening Remarks

Pfarr kicked off the conference by praising the event's guest speakers and emphasizing the vital role women play within the welding industry.

"As these women share their stories, you'll learn that our industry needs women from very diverse backgrounds with unique skill sets and a variety of passions and career goals," she said.

Pfarr also discussed how the AWS Foundation works to address the welder workforce shortage. This initiative includes the promotion of careers in welding to young women. She disclosed that while the number of female welders has remained at 5% of the total workforce throughout the past seven years, there has been an increase in women who are applying for, and receiving, AWS's two- and four-year scholarships. According to Pfarr, about 25% of AWS scholarship recipients in 2020 were female.

"Through a combination of our efforts as well as partners and other organizations, we're really truly making a difference, and we're seeing more women enter into the field than ever before," she affirmed. "And thus today's conference is both timely and critical. As we bring more females into our industry, it's imperative that we develop and provide resources to these women to help them navigate, grow, and thrive in their careers."

Meet the Guest Speakers

Chloe Hudson

Chloe Hudson is a welder at Joe Gibbs Aerospace, Huntersville, N.C., which she describes as her dream job. Her talk centered on the gender discrimination she has faced throughout her educational and professional journey.

Because of the prejudice she experienced in her college welding program, Hudson admitted she left school in favor of a job in nuclear maintenance. This decision led her to gain confidence and experience in many areas.

"There wasn't a job that I didn't say 'yes' to. I said 'yes' to everything," she explained.

However, the job turned Hudson into a "Jack of all trades, but a master of none." Noticing that those who had training in a specialized craft were making more money than her, Hudson decided to return to college. She also took part in SkillsUSA competitions, taking home the first win by a female in her college's history.

After graduation, Hudson battled gender bias in job interviews, but having a strong skill set gave her the confidence to demand that employers give her a chance.

"It still made it difficult with me looking the way I do to find a job," she said about her feminine appearance, "but all those extra accolades helped."

Elaborating on some of her negative experiences at job sites, which included alienation from her male coworkers, Hudson recommended that women find employment where they'll be valued and accepted.

"If someone doesn't want you working for them, there's other people who do. I can guarantee you that," she stressed.

Hudson also emphasized that she didn't waste time feeling sorry for herself and instead worked hard despite how she was treated. That attitude allowed her to forge a name for herself in the welding industry, which eventually led to her being sought after for jobs.

Barbie Parsons

Barbie Parsons, popularly known as "Barbie the Welder," is a metal sculptor, business owner, author, and social media celebrity in Erin, N.Y. She began her speech by describing her life before welding, which included being bullied, surviving drug addiction, living with an abusive husband, struggling with poverty, and trying to survive as a single mother.

Parsons also shared how she worked in the automotive industry for many years. However, she eventually grew tired of the sexism she encountered, as well as the meager pay, and began her own business hauling scrap metal. Despite her hard work, she continued to struggle financially.

According to Parsons, the tide turned when she became interested in welding after watching a scene in the movie *Cast Away* that depicted a woman welding angel wings. Ignoring the discouragement of those around her, she followed her gut and enrolled in a welding course.

"I had zero artistic talent [and] had never welded before, but I knew in my soul I needed to be a metal sculptor," she said.

Parsons again ignored the naysayers when she started her own metal sculpture business. At first, it didn't do well because she didn't know how to sell her masterpieces or market herself. Broke and feeling defeated, she began meeting with a local entrepreneur group that consisted of lawyers and business owners to learn more about growing — and saving — her business.

"I showed up to every meeting and shut my mouth and tried to listen to what they were saying," she recalled.

Absorbing their suggestions, which included changing the business name to Barbie the Welder, Parsons began to see success as both a business owner and a metal artist. She now enjoys a lucrative career in the welding industry and is glad she believed in herself when no one else would.

Fig. 2 — Panelists (from top left) Monica Pfarr, Sue Reiter, Becky Tuchscherer, and Stephanie Hoffman discuss the importance of mentorship during the virtual Women in Welding Conference.

Becky Tuchscherer

Becky Tuchscherer is the group president of commercial and greater China welding at Miller Electric Mfg. LLC, Appleton, Wis. The company is a wholly owned subsidiary of Illinois Tool Works Inc., a Fortune 200 industrial manufacturer of consumables and specialty equipment.

During her speech, Tuchscherer provided information about her early career and education, which included a bachelor's degree in accounting, a master's in business administration, and several positions in finance. Taking a job with Miller Electric in 1988, Tuchscherer has since been promoted multiple times. She admitted that, when she first joined the company, she did not know anything about welding.

". . . [O]ne of the things I learned over my career is I need to know enough, but I don't need — from the business side of things — to be the expert," she affirmed. "I have teams around me to help with that."

Looking back on her more than 30 years in the welding industry, Tuchscherer explained that she has benefitted from taking risks and trying new things. For instance, she revealed she went outside of her area of expertise in finance earlier in her career by accepting a position as a business unit manager.

"There are a couple times in my career where I've learned the most, and that's when I've stepped outside my comfort zone," she said.

In addition to professional challenges and successes, Tuchscherer spoke about the difficulties of juggling motherhood and a career. She credits having a support network to rely on, such as her husband, for helping her focus on growing her career. Detailing some of the sacrifices she made to be able to spend more time with her children, Tuchscherer advised attendees to prioritize what is most important and establish work-life balance.

"Learn how to let go, even if you want to hold on to it tight," she emphasized, "because what you want to do is focus on what matters."

Sue Reiter

Sue Reiter is the Americas distributor manager at Air Products, Allentown, Pa., a Fortune 500 manufacturer of industrial gases. Over the years, she has served the company in multiple roles.

Reiter kicked off her talk by revealing she got into industrial sales at the recommendation of a college professor. She holds a bachelor's degree in business and a master's in finance and held several jobs in the industrial sector before securing a position with Air Products. Because she had little familiarity with industrial gases, Reiter had to take many classes, including a welding course, to gain the necessary industry knowledge. She admitted the process was overwhelming at times, but she persevered.

"I looked at it as a challenge," she said. "I had to really, really work a lot because I didn't have that technical background."

A female in a male-dominated industry, Reiter described herself as often being the only woman in the room. This meant she had to be careful with how she navigated herself.

"As a female, and you're trying to get your point across, sometimes if you're too aggressive, you might be known as a bitch," she said with a laugh. "Or if you're too soft, you're too weak, so you just have to try to find your balance."

However, Reiter stressed that she had people in the industry who supported her, and that helped. She further recommended that female professionals get to know their male counterparts along with their spouses as well as the spouses of clients.

"I put that to use as I was moving up the corporate ladder as far as being more inclusive than exclusive," she explained.

"If someone doesn't want you working for them, there's other people who do. I can guarantee you that." — Chloe Hudson

Because her roles with the company have included a lot of travel, Reiter had to find a balance between work and motherhood. What helped her was having a strong support group to rely on, but she also emphasized the importance of being present for the important moments.

Panel Discussions

The conference also showcased two panel discussions that were fueled by questions from both attendees and speakers.

The first panel discussion (Fig. 1) focused on topics related to welders, which included the following: resources for women working, or thinking of starting a career, in the skilled trades; ways to develop a strong social media following; strategies for transcending negative comments; how the welding industry can be more inclusive of women; the importance of professional networks; and how to price work.

The second panel discussion (Fig. 2) highlighted the corporate side of the welding industry and delved into the following topics: effective ways to attract more women to industrial positions, biases of being a woman or a working mother in the welding industry, pay inequality, obstacles for young women pursing careers in the welding industry, and the importance of mentorship.

Conclusion

The virtual Women in Welding Conference gave attendees the opportunity to hear about the challenges women in the welding industry face. It also allowed attendees to learn how these obstacles can be overcome as well as how professionals can help promote gender equality in the workplace.

To learn more about this event, visit *awo.aws.org/conferences/past-conferences/women-in-welding-virtual-conference-2021*. WJ

Nominations Sought for National Offices

American Welding Society (AWS) members who wish to nominate candidates for President, Vice President, and Director-at-Large on the AWS Board of Directors for the term starting Jan. 1, 2023, may either

1. Send their nominations electronically by July 31, 2021, to Chelsea L. Steel at *csteel@aws.org*, c/o Thomas J. Lienert, chair, National Nominating Committee, or

2. Present their nominations in person at the open session of the National Nominating Committee meeting scheduled for 2:30 to 3:30 p.m., Tuesday, September 14, 2021, at the McCormick Place Convention Center, Chicago, Ill., during the 2021 FABTECH Show.

Nominations must be accompanied by biographical material on each candidate, including a written statement by the candidate as to his or her willingness and ability to serve if nominated and elected, letters of support, and a 5- × 7-in. head-and-shoulders color photograph.

Note: Persons who present nominations at FABTECH must provide 20 copies of biographical materials and written statements.

TECH TOPICS

New Standards Projects

Development work has begun on the following new or revised standards. Affected individuals are invited to contribute to their development. Participation in AWS technical committees is open to all persons.

B2.1-1/8-010:2015 (R20XX), *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Carbon Steel (M-1/P-1) to Austenitic Stainless Steel (M-8/P-8), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*. This standard contains the essential welding variables for welding carbon steel to austenitic stainless steel in the thickness range of 18 to 10 gauge using manual gas tungsten arc welding. It also cites the base metals and operating conditions necessary to make the weldment, filler metal specifications, and allowable joint designs for fillet welds and groove welds. Stakeholders: manufacturers, welders, engineers, and AWS Certified Welding Inspectors. Revised Standard. Contact: J. Rosario, ext. 308, *jrosario@aws.org*.

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. Standards open for public review can be found at *aws.org/standards/page/standards-notices*.

This column also advises of ANSI approval of documents.

A5.18/A5.18M:20XX, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*. Revised Standard. $36.00. Contact: R. Gupta, ext. 301, *gupta@aws.org*.

A5.20/A5.20M:20XX, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*. Revised Standard. $36.00. Contact: R. Gupta, ext. 301, *gupta@aws.org*.

A5.31M/A5.31:20XX, *Specification for Fluxes for Brazing and Braze Welding*. Revised Standard. $36.00. Contact: K. Bulger, *kbulger@aws.org*, ext. 306.

B2.1-1-018:20XX, *Standard Welding Procedure Specification (SWPS) for Self-Shielded Flux Cored Arc Welding of Carbon Steel (M-1/P-1, Group 1 or 2) ⅛ inch [3 mm] through 1½ inch [38 mm] Thick, E71T-8, in the As-Welded Condition, Primarily Plate and Structural Applications*. New Standard. $136.00. Contact: J. Rosario, *jrosario@aws.org*, ext. 308.

ANSI Z49.1:20XX, *Safety in Welding, Cutting and Allied Processes*. Revised Standard. $38.00. Contact: S. Hedrick, *steveh@aws.org*, ext. 305.

Opportunities to Contribute to AWS Committees

The following committees and their subcommittees 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 at *aws.org/standards/committeesandstandardsprogram*. Also visit this website for the complete list of AWS subcommittees.

A — Fundamentals

- A1 Metric Practice (C, E)
- A2 Definitions and Symbols (E)
- A5 Filler Metals and Allied Materials (E)
- A9 Computerization of Welding Information

B — Inspection and Qualification

- B1 Methods of Inspection (C, E)
- B2 Procedure and Performance Qualification (E, G)
- B4 Mechanical Testing of Welds (E, G, P)

C — Processes

- C1 Resistance Welding (C, E, G, U)
- C2 Thermal Spraying (C, E, G, U)
- C3 Brazing and Soldering (C, E, G)
- C4 Committee on Oxyfuel Gas Welding & Cutting (C, E, G)
- C6 Friction Welding (C, E)
- C7 High Energy Beam Welding and Cutting (C, E, G)

D — Industrial Applications

- D1 Structural Welding (C, E, G, P, U)
- D3 Welding in Marine Construction (C, E, G, U)
- D8 Automotive Welding (C, E, G, U)
- D9 Sheet Metal Welding (C, G, P)
- D10 Piping and Tubing (C, E, U)
- D11 Welding Iron Castings (C, E, G, P, U)
- D14 Machinery and Equipment (C, E, G, U)
- D15 Railroad Welding (C, E, G, U)
- D16 Robotic and Automatic Welding (C, E)
- D17 Welding in the Aircraft and Aerospace Industry (C, E, G)
- D18 Welding in Sanitary Applications
- D20 Additive Manufacturing (C, E, G)

F — Safety and Health (SHC)

- SHC Safety and Health (E, G)

G — Materials

- G1 Joining of Plastics and Composites (C, E, G)
- G2 Joining Metals and Alloys (E, G, U)

J — Welding Equipment

- J1 Resistance Welding Equipment (C, E, G, U)

MEMBERSHIP ACTIVITIES

AWS Member Counts
May 1, 2021

Sustaining	*574*
Supporting	*337*
Educational	*838*
Affiliate	*666*
Welding Distributor	*62*
Total Corporate	***2477***
Individual	*56,687*
Student + Transitional	*9,171*
Total Members	***65,858***

2021 Membership Challenge

Listed here are the members participating in the 2021 Membership Challenge — point standings as of April 19. The campaign runs from Jan. 1 to Dec. 31, 2021. Members receive 5 points for each Individual Member and 1 point for every Student Member they recruit.

For more information, visit *aws.org/membership/page/sparking-connections* or call the AWS Membership Dept. at (800) 443-9353, ext. 480.

J. W. Morris, Mobile — 25
G. L. Gammill, NE Mississippi — 20
C. A. Donnell, NW Ohio — 16
T. W. Zablocki, Pittsburgh — 15
B. M. Williams, West Michigan — 15
C. A. Galbavy, Idaho/Montana — 15

New AWS Supporters

Affiliate Corporate Members

Accrotool
401 Hunt Valley Rd.
New Kensington, PA 15068

ALTO Technologies Corp.
86 Leominster Rd., P.O. Box 399
Sterling, MA 01564

Apex Manufacturing Group Inc.
825 Dawson Dr., Ste. 1
Newark, DE 19713

Architectural Shade Products
425 Wilbanks Dr.
Ball Ground, GA 30107

Blackwater Welding LLC
1039 Carolina Springs Rd.
Rocky Mount, VA 24151

Diversified Building Professionals
1616 Hoover Ave.
National City, CA 91950

Division 5 LLC
99 Cooper Ln.
Stafford Springs, CT 06076

EDC Engineering Ltd. Liability Co.
300 Lenora St., #338
Seattle, WA 98121

EGW Utilities Inc.
1406 Hutton Dr.
Carrollton, TX 75006

Evapco Alcoil Inc.
3627 Sandhurst Dr.
York, PA 17406

Extreme Precision Industrial Contractors LLC
1540 Business Cir.
Gillette, WY 82716

Ezarc Welding Inc.
235 W. 700 S., P.O. Box 452
Pleasant Grove, UT 84062

Hartwig Mechanical Inc.
20800 E. Brink St.
Harvard, IL 60033

JOB Erection & Engineering Inc.
506 Eagle Ln.
Gwinner, ND 58040

La Habra Welding Inc.
10819 Koontz Ave.
Santa Fe Springs, CA 90670

Plasan North America
3236 Wilson Dr. NW
Grand Rapids, MI 49534

Primitive Precision Metalcraft Inc.
4430 Lyndale Ave. N.
Minneapolis, MN 55412

Reverence Engineering
600 B St., Ste. 300
San Diego, CA 92101

Scalable Robotics Inc.
34 Ellsworth Ln.
Ellington, CT 06029

Senior Metal Bellows
1075 Providence Hwy.
Sharon, MA 02067

Tri-State Fabricators Inc.
1146 Ferris Rd.
Amelia, OH 45102

Ward Fabrication Inc.
7 Beechwood Rd.
Sandown, NH 03873

Educational Institution Members

Adi Institute of Quality Engineers
Door No: 039/1529, 1 Fl. Kolatheri Bldg.
Near S. Railway Station
Cochin Kerla 682016 India

B&B Consultant Group
1510 W. Whittier Blvd., #230
La Habra, CA 90631

Careerline Tech Center
13663 Port Sheldon St.
Holland, MI 49424

Chapel Hill High School
13172 State Hwy. 64
Tyler, TX 75707

Chariho Career & Technical Center
459 Switch Rd.
Wood River Junction, RI 02894

East Carteret High School
3263 Hwy. 70
Beaufort, NC 28516

Fannin County High School
2290 E. First St.
Blue Ridge, GA 30513

Florida Technical College
3831 W. Vine St., Ste. 50
Kissimmee, FL 34741

Mars Ultor
Calle Teniente Enrique, Deluchi 240
Barranco, Peru

Midland High School
1301 Eastlawn Dr.
Midland, MI 48642

Monroe High School
901 Herr Rd.
Monroe, MI 48161

Nexus Indian Oaks
101 N. Bramble St.
Manteno, IL 60950

Northlands Job Corps Center
100A MacDonough Dr.
Vergennes, VT 05491

Pratt Community College
348 NE State Rd. 61
Pratt, KS 67124

Saroquis S.A.
Primero de Mayo E1-74 y Alfonso
Lamiña, Comuna Lumbisí
Quito 170184 Ecuador

Strike & Walk Da Cup Welding LLC
2501 W. 6 Ave.
Gary, IN 46404

Texas Elite Welding Academy LLC
7508 Blanca Aurora Ln.
Brownsville, TX 78520

Wayne State University
4855 4 St.
Detroit, MI 48201

Supporting Company Members

NuWeld Inc.
P.O. Box 3482, 2600 Reach Rd.
Williamsport, PA 17701

Quality Products
4600 Westinghouse Blvd.
Charlotte, NC 28273

U.S. Tsubaki Conveyor and Construction Chain Division
1010 Edgewater Ave.
Sandusky, OH 44870

Sustaining Corporate Members

Blox LLC
2625 5 Ave. N., Bldg. C
Bessemer, AL 35020

Bolzoni Auramo Inc.
7711 U.S. Hwy. 278
Sulligent, AL 35586

Celtic Engineering Inc.
4757 The Grove Dr., Ste. 220
Windermere, FL 34786

Welding Handbook Committee Seeks Volunteers

The AWS *Welding Handbook* will need volunteers (chapter chairs and chapter committee members) for Vol. 3 of the 10th Ed.

For more information, contact Kathy Sinnes, *ksinnes@aws.org*, (305) 443-9353, ext. 255.

AWS Names the 2020 Employee of the Year

Elienai Piloto proudly holds her 2020 Employee of the Year trophy.

The American Welding Society (AWS) 2020 Michael A. Rowland Exemplary Employee of the Year Award was given to Elienai Piloto, customer relationship management (CRM) administrator, during a virtual event held on March 12. At the time of this event, Piloto was the certification systems manager but has since been promoted.

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

Summarizing the nomination forms, AWS Executive Director and CEO Gary Konarska II praised Piloto for her mastery of the CRM system that is used throughout the organization as well as her willingness to take the time to find solutions to any CRM-related challenge.

" . . . [She] is widely known as the de facto CRM expert within AWS," he said. "She is regularly called upon to troubleshoot some of the more complex report-polling problems."

Additionally, Piloto was applauded for her recent work with launching a CRM training program.

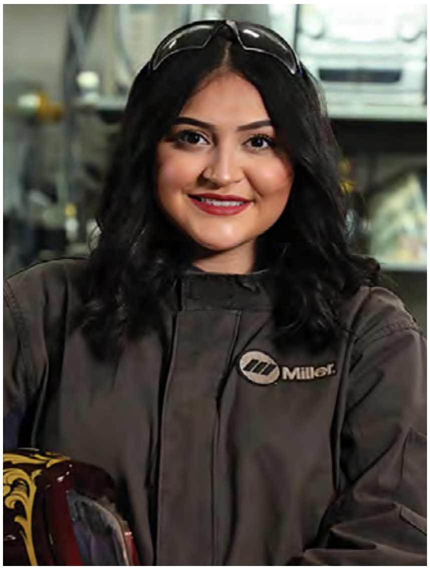
"Elie created a comprehensive CRM training program that enhanced the overall capability of AWS tremendously," Konarska affirmed.

Konarska also remarked that several of the nomination forms lauded Piloto's bright outlook and dedication to helping others.

"Her positive attitude and solutions-providing approach doesn't just help the Certification department but helps all of us here at AWS," Konarska read.

As the 2020 Employee of the Year, Piloto received $1500, an engraved trophy, a restaurant gift certificate, and a designated parking space for one year.

AWS Member Profile



Olivia Arreola

"Being a female in a male-dominated industry has had its ups and downs, but I do not let my gender define what I can and can't do as an individual in this industry." — Olivia Arreola

"Welding is a man's job." This was the comment Olivia Arreola received from multiple people when she first shared she wanted to try welding. Being an optimistic 16-year-old high schooler at the time, Arreola set her mind on proving them wrong by signing up for dual-credit welding classes at Fox Valley Technical College, Appleton, Wis.

Once in the program, Arreola discovered welding competitions, which she credits for propelling her passion in the craft. She has competed in the welding, welding sculpture, and job interview categories at SkillsUSA. In her two years of competing, she brought home several medals and prizes from the district, regional, state, and national levels. In her senior year of high school, she placed fifth nationally in the welding sculpture category.

Age 16 was a busy year for Arreola. In addition to taking up welding and entering competitions, she also landed her first job as a welding apprentice and assembler at Specialty Enterprises, Wautoma, Wis. This job allowed her to hone her abilities in gas tungsten arc welding by joining aluminum sprayer booms, a device used to apply liquids to crops. A few months later, Arreola moved on to a welding apprenticeship job with Mayville Engineering Co., Wautoma, Wis., where she worked her way to a full-time position as a production gas metal arc welder. During the two years Arreola worked for the company, she also took on a second job at Miller Electric Mfg. LLC, Appleton, Wis., as a welding engineer intern. Several years later, Arreola is still with Miller Electric and has held several positions within the company.

Her fuel for being such a hard worker comes from seeing her father struggle with making ends meet.

"Growing up, I watched my dad work very hard to provide for our family, as we were living each month paycheck to paycheck. I wanted to pursue a career in something where I wouldn't have to experience that life any longer," she recalled. "With welding, I felt like more and more doors kept opening for me to explore at such a young age to find my passion so quickly."

Despite being busy with school, work, and competitions, Arreola has always found time to volunteer. She has held multiple volunteer positions, including one that allowed her to support Fox Valley Technical College's welding camps. These welding camps give students first-hand welding experience and allow them to hear the stories of other welders, including Arreola.

"I always found myself to be very fortunate for the resources and opportunities that helped me gain experience and knowledge in the welding field. As I continue to grow as an individual, I wanted a way to pay back the welding community," she explained. "My way of paying back is to share my background, welding experience, and knowledge [as well as] become a mentor/resource for other individuals."

Arreola graduated with an associate's degree in industrial welding technology from Fox Valley Technical College in 2018. After being on a two-year waiting list to attend Ferris State University, Big Rapids, Mich., Arreola was disappointed when the school's 2020 summer program was canceled due to the COVID-19 pandemic. However, she is set to begin the college's fall 2022 semester and pursue a bachelor's in welding engineering.

In the meantime, Arreola will continue to grow her knowledge and skills at Miller Electric, where she is a weld technician. Her job entails helping to develop new products, supporting current products, and providing customer support. When asked what her favorite part of the job is, she highlighted the people as well as the ability to be creative every day. She's hoping her future career as an engineer will also allow her to stretch her creative wings.

"My dream job would be to obtain a full-time welding engineering position at a company that will allow me to be creative, innovative, and grow as an individual," she said. "It is very important to me to be in an environment that has potential for me to grow."

Although Arreola's story is full of moments of success, she admits that being a female welder has not always been easy. However, she stressed that she doesn't allow gender discrimination to stop her.

"Being a female in a male-dominated industry has had its ups and downs, but I do not let my gender define what I can and can't do as an individual in this industry. I have had some encounters throughout my journey where people have doubted my skill set, but I always knew what I am capable of and never let it get to me," she affirmed. "In my experience, being in the welding industry, no matter what gender you define as, you will always have to prove your work ethic and skill set in some way to gain the respect of others."

BY CINDY WEIHL — *cweihl@aws.org*

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BIRMINGHAM/JEFFERSON STATE STUDENT CHAPTER

March 30

Location: Fultondale, Ala.

Summary: Student Chapter members led the charge to help victims of a tornado that tore through Alabama in January. Student Chapter Chair John Decker and Vice Chair Zack Rickles came up with the idea to ask fellow Jefferson State Community College students for monetary donations to help out the storm victims. The Chapter members used the money they collected to purchase Walmart and Target gift cards in increments of $20. The members then turned the cards over to Fultondale Mayor Larry Holcomb. The mayor and his team will distribute the cards to those most in need.

BIRMINGHAM/Jefferson State Student Chapter — *Fultondale, Ala. Mayor Larry Holcomb (center) was presented with gift cards for tornado victims. The cards were purchased with funds raised by Student Chapter members. Pictured with the mayor (from left) are Section Media Chair Amelia Wright, Vice Chair Zack Rickles, Chair John Decker, and Welding Instructor Danny Taylor.*

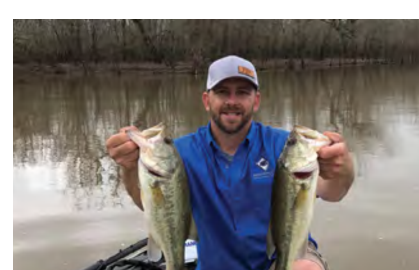
CENTRAL LOUISIANA

March 13

Summary: The Section hosted its inaugural scholarship bass fishing tournament and had a great turn out with 27 boats participating. The top five places were paid out with the first-place winners taking home $1200. Members are already excitedly planning next year's tournament and looking to make it even bigger and better. This tournament would not have been possible without the help of all members and the Section's executive board, including Chair Tom Malo, First Vice Chair Mike Stucklik, Second Vice Chair Sean Jones, Board Member David Moore, Librarian Don Sanders, and Treasurer Brandon Dubroc.

CENTRAL LOUISIANA — *Executive board members (from left) Tom Malo, David Moore, Don Sanders, and Brandon Dubroc are seen at the Section's inaugural scholarship bass tournament.*

CENTRAL LOUISIANA — *Randy Pittman and Brandon Pittman placed first in the Section's bass tournament with a winning weight of 20 lb.*



CENTRAL LOUISIANA — *Section Treasurer Brandon Dubroc holds up two of the bass he caught while showing fellow board members around the lake.*

MOBILE
March 18

Summary: The Section held its first in-person executive committee meeting since June 2020 at the Original Oyster House Chart Room. With COVID-19 restrictions in place, the committee has been taking care of business via email. Now that restrictions are being lifted, the team hopes to be able to have more in-person meetings. Plans are also being made to resume with monthly in-person membership meetings as well. Because in- person meetings had been put on hold, the executive committee decided to present 2020 AWS Section and District awards to its recipients at the March gathering. Derrick Lett received the award for Section Educator of the Year and Chris Pawlowicz received the Section Meritorious award. Both awards were presented to the recipients by Section Chair Jody Heusman. Additionally, Gregory Pierce and Jeff Pierce both received their AWS Life Member awards but were unable to attend the meeting. Instead, both Greg and Jeff were presented with their awards by their father, Ron C. Pierce, former AWS Foundation chair and trustee emeritus, at his home. (Ron passed away in mid-March. Please go to page 54 of this issue to read a tribute.) Furthermore, Clay Byron presented Paul Richardson with the District Educator award for 2020 at Tom P. Haney Technical Center in Panama City, Fla., where Richardson is a welding instructor. Lastly, the Section and District 9 selected Brandon Neely as a CWI of the Year for 2020. Neely chose to receive his award at a later date.

District 10

Tom Kostreba, director
(814) 881-0632
kostreba@hotmail.com

District 11

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

DETROIT
April 6

Presenter: Mike Karagoulis, welding master mechanic, welding development, General Motors retiree
Summary: In the first of a series of four events that took place on Tuesdays throughout the month of April, Karagoulis led a virtual meeting that covered resistance welding fundamentals and process controls. The presentation touched on four types of resistance welding, aluminum vs. steel, current flow, heat generation, process setup, heat dissipation, material properties, weldability, and reducing process variation. Series attendees will be granted professional development hours.

District 12

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

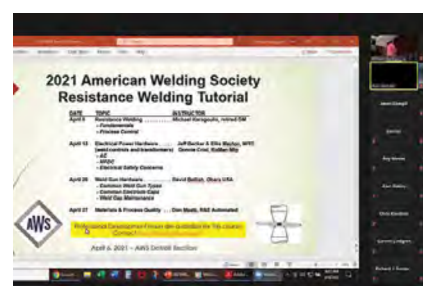
District 13

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

CHICAGO
April 14

Location: Mama Luigi's Restaurant, Bridgeview, Ill.
Summary: The Section's board members gathered to discuss old and new business as well as the upcoming District 13 conference.

MOBILE — *Section Chair Jody Heusman (center) presented the Section Educator of the Year award to Derrick Lett (left) and the Section Meritorious award to Chris Pawlowicz.*



DETROIT — *Thirty-six members joined the Section's April virtual meeting for a presentation on resistance welding by Mike Karagoulis.*

MOBILE — *The late Ron C. Pierce (center) presented sons Greg Pierce and Jeff Pierce with their AWS Life Member awards in March.*

MOBILE — *Clay Byron (right) presented Paul Richardson with the 2019–2020 District 9 and Mobile Section Annual Educator award.*

CHICAGO — *April meeting attendees included (sitting, from left) Cliff Iftimie and John Hesseltine as well as (standing from left) Jeff Stanczak, Craig Tichelar, James Greer, and Dave Viar.*

District 14

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

District 15

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

NORTHERN PLAINS
March 13

Location: Bismarck, N.Dak

Summary: Lynnes Welding Training (LWT) hosted a local Boy Scouts of America Welding Merit Badge event. Scouts learned the gas metal arc welding process, which they used to weld a small airplane, and the flux cored arc welding process, which they used to make an eagle. The airplane and eagle cutouts were provided by The Lincoln Electric Co. They were also taught the plasma arc cutting process and used it to cut their initials into a plate of steel. LWT President Dave Lynnes — with the help of LWT Instructors Mike Morris, Joey Krussow, Barry Schneider, and AWS District 15 Director Mike Hanson — led the event.

District 16

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fogleman3@cox.net

District 17

J Jones, director
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drtourch@yahoo.com

CENTRAL ARKANSAS
April 7

Location: University of Arkansas Community College at Morrilton (UACCM), Morrilton, Ark.

Summary: The Section held a hybrid meeting at UACCM and virtually through Zoom and Facebook Live. Steve Belew introduced Jessica Rohlman, UACCM director of workforce development and community education, who discussed the importance of UACCM being the first school in Arkansas to be AWS accredited. Robert Keeton, UACCM dean of technical studies, also emphasized the importance of the welding program to the school and its industry partners. The meeting ended with giveaways from ESAB, Miller Electric Mfg. LLC, Lexicon Inc., and Welsco Inc.

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NORTHERN PLAINS — *Participants of the Boy Scouts of America Welding Merit Badge event are seen with (front row, left) Joey Krussow as well as (back row, from left) Mike Hanson, Barry Schneider, Mike Morris, and Dave Lynnes (far right).*

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CENTRAL ARKANSAS — *Nicholas Bowen received a Tweco® welding helmet from Lexicon Inc.*

CENTRAL ARKANSAS — *Marissa Lindsey received a welder's package from Welsco Inc.*

CENTRAL ARKANSAS — *Joseph Biasco received a welding helmet from ESAB.*

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American Welding Society

Huntington Ingalls Elects President of Ingalls Shipbuilding Division

K. Wilkinson

Huntington Ingalls Industries (HII), Newport News, Va., America's largest military shipbuilding company, has appointed Kari Wilkinson as executive vice president and president of its Ingalls Shipbuilding division. In this role, she will be responsible for all programs and operations at Ingalls, including the U.S. Navy's amphibious assault and surface combatant ship programs as well as the U.S. Coast Guard's National Security Cutter program. She previously served as Ingalls' vice president, program management. Wilkinson began her career with the company as an associate naval architect in 1996. She supported major shipbuilding production events and milestones from positions in engineering, worked closely with business development on requirements and preliminary ship designs for both domestic and international customers, and coordinated the prioritization of equipment and processes in operations during the Hurricane Katrina recovery effort. In 2007, she was promoted to ship program manager for the *San Antonio*-class landing platform dock program.

Hobart Promotes Vice President/General Manager

B. Bilokonsky

Hobart Brothers LLC, Troy, Ohio, a manufacturer of filler metals and subsidiary of Illinois Tool Works Inc., has named Bob Bilokonsky as vice president/general manager. Bilokonsky joined Hobart in 2010 as a sourcing manager and served as a supply chain manager for the company for two years. He has taken on more responsibilities as a business unit manager for several filler metal segments, most recently overseeing metal-cored and aluminum products. In this position, he will have overall profit and loss responsibility for the company's filler metal division. He and his team will also be concentrating on customer growth and retention, with a continued focus on innovation and operational excellence.

Lincoln Electric Appoints Vice President, Corporate Controller

L. Shapiro

The Lincoln Electric Co., Cleveland, Ohio, has promoted Lisa Shapiro to vice president, corporate controller. She will be responsible for overseeing global accounting and control functions, financial reporting, tax compliance, and finance shared services. Shapiro joined the company in 2016 as senior manager of external reporting and has served as director of financial reporting since 2018. Prior to joining the company, she held various positions at PricewaterhouseCoopers.

VELO^{3D} Recruits Head of European Commercial Operations

California-based metal additive manufacturing (AM) provider VELO^{3D} has hired Jon Porter to head its commercial operations in Europe. Based in the U.K., he will oversee the company's ongoing expansion efforts into this region. Porter comes from Renishaw, where he worked in the business development team of the AM division. While there, he was involved with the international organizations (SAE International, ASTM International, and British Standards Institution) that develop new standards for the industrial 3D-printing sector. He began his career in the 1990s working for engineer-entrepreneur James Dyson. As the company became a leader in the floorcare and appliance business, he became involved in its early investment in AM technology.

J. Porter

GNS North America Names Board of Director Member

S. R. Wybo

GNS North America, Holland, Mich., a global automotive supplier, has added Steven R. Wybo to its board of directors. He will also serve as chairman of the board's newly formed finance committee. During 2020, Wybo was instrumental in the financial restructuring of the company. He currently holds the position of senior managing director and chair of the automotive practice of Conway MacKenzie. He has served with the firm for more than 20 years as a senior restructuring and management consulting professional with experience in providing turnaround, reorganization, and financial advisory services.

Obituaries

Carl Dean Lundin

Carl Dean Lundin passed away at his home on March 30, surrounded by his family. He was 86. Lundin attended Rensselaer Polytechnic Institute (RPI) on a Navy Reserve Officers Training Corps Scholarship and graduated in

C. D. Lundin

1957 with a bachelor's degree in metallurgical engineering. Following graduation, he served three years of active duty in the U.S. Navy as a lieutenant before returning to RPI and receiving his doctorate in materials science and engineering in 1966. He was appointed to assistant professor in the materials division and continued as supervisor of welding research. In 1968, he left RPI to join the University of Tennessee as an associate professor and established the Materials Joining Laboratory in the chemical and metallurgical engineering (now materials science and engineering) department. He was appointed full professor of metallurgy in 1975, a position he held for 45 years. He also served as an industrial consultant to government agencies and the private sector since 1966. Lundin received numerous honors and recognitions over the years, including being named the Tennessee Tomorrow Professor for his contributions to excellence in the college of engineering and Magnavox Professor of Engineering for his excellence in engineering teaching and research. He also received the Chancellor's Research and Creative Achievement Award and the University of Tennessee College of Engineering Outstanding Teaching Award.

Additionally, he belonged to multiple professional organizations and held various leadership positions. He joined the American Welding Society (AWS) in 1967, achieving Life Member status in 2002 and Gold Member status in 2017. He earned multiple AWS awards, including the Comfort A. Adams Lecture Award, Adams Memorial Membership Award, McKay-Helm Award, Warren F. Savage Memorial Award, and William Spraragen Memorial Award. In 2013, he was chosen as the AWS District 8 Educator of the Year. He was also named an AWS Fellow in 1991 and a Fellow of the American Society for Materials in 1986. In 2010, he received the E.O. Paton Award from the International Institute of Welding (IIW). In 2012, he presented the Houdremont Lecture at the IIW Annual Conference. He is preceded in death by his parents and daughter, Carole Leigh. He is survived by his wife, Delores "Dee"; two daughters; stepson; eight grandchildren; and two great grandchildren. To honor him, contributions can be made to The Carl D. Lundin Scholarship Endowment for the materials science and engineering department at the University of Tennessee, Knoxville.

Kenneth "Ken" Richard Karwowski

K. R. Karwowski

Kenneth "Ken" Richard Karwowski passed away at his home on March 12. He was 75. Karwowski was a lifelong teacher, a welder, and an American Welding Society (AWS) Certified Welding Inspector. He graduated from William Horlick High School in Racine, Wis., in 1963. At the age of 25, while supporting a young family and working two jobs, he graduated with a degree in education in industrial arts from the University of Wisconsin–Stout. He then earned his master of education degree at Colorado State University. He worked many years in construction as a pipefitter and boilermaker and was a longtime member of the Pipefitters Local 118. Karwowski began his teaching career at Wisconsin Indianhead Technical College in New Richmond and later at Gateway Technical College in Elkhorn. In 1991, he started ARK Welding Inspection Services, providing welding certifications and inspections to companies throughout Wisconsin. He trained and/or certified thousands of welders during his career. He was also an AWS member since 1988, holding various board positions in the Racine-Kenosha Section. He served as chair from 2004 to 2007, first vice chair from 2007 to 2021, technical representative from 2000 to 2021, and secretary twice from 2001 to 2007 and 2013 to 2021. He achieved Silver Member status in 2016 after 25 years of continuous membership. He is survived by his wife, Renee; three daughters; five grandchildren; two brothers; and many relatives and friends.

Charles Freeman Paxton

Charles Freeman Paxton passed away on February 19, 2020. He was 96. Paxton enlisted in the U.S. Navy in 1942 and served in WWII and Korea in all operational theaters. He was awarded many medals and citations, including the Combat Action and Naval Unit Commendation citation. His career began as a managing director of Weltronic Ltd., Slough Bucks, England. He was then appointed as president and general manager of Worldtronic and, later, co-owner/president and general manager of Weltronic U.S.A., Southfield, Mich. He was an American Welding Society (AWS) member for 71 years, joining in 1950. He became an AWS Life Member in 1985 and Gold Member in 2000. He was a frequent speaker at AWS events. He was also named a Fellow of the British Institute of Welding. He held patents on the application of computers for automation, welding, and energy management. Additionally, he was the author of *The Control and Resistance Welding, A Manual for the User*. After retirement, Paxton served in Honor Guards as a member and commander of American Legion Post 343 and commander of Veterans of Foreign Wars posts 7987 and 7845. He achieved All-State Commander twice and All-American Commander in 2005. He is survived by his wife of 71 years, Shirley; sons, Mark and Kent; seven grandchildren; and 11 great grandchildren. WJ

C. F. Paxton

PRODUCT & PRINT SPOTLIGHT

— continued from page 25

States, adoption of magnesium alloy in the automotive welding industry, emergence of laser welding, and the advent of welding intelligence. Covering 25 vendors, the 120-page report is segmented into these end user categories: automotive, construction, shipbuilding, aerospace and defense, and others.

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roll tension deforms soft aluminum wires and leads to feeding problems, the welding gun possesses an internal preset drive roll tension mechanism that reduces the risk of wire deformation and ensures proper feeding. The drive rolls are also electrically insulated to prevent microarcing, a common source of performance issues. For enhanced ergonomics, the welding gun showcases an angled cable-to-gun connection combined with a ball-and-socket strain relief that improves balance and reduces the perceived cable weight. Additionally, its easy-to-grip handle features a short-stroke trigger to facilitate activation. Offered as an air-cooled model, the welding gun feeds wire diameters from 0.030 to 0.052 in., has a rated duty cycle of 60% using mixed gas, comes with a 20- or 33-ft cable length, and uses standard Tweco 16APS contact tips.

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COMING EVENTS

— continued from page 76

being administered on the tenth day. It includes a backpack for the convenience of carrying books and other study materials. Hobart Institute of Welding Technology; *hiwt@welding.org*; (800) 332-9448; *welding.org*.

Protective Coatings Training and Certification Courses. At various locations and online. The Society for Protective Coatings; (877) 281-7772; *sspc.org*.

Resistance Welding Seminar. Subjects covered include basics of resistance welding, resistance welding terms, pneumatic systems and troubleshooting, welding transformer operation and troubleshooting, basic resistance welding machine setup and weld lobe development, electrode selection and maintenance, quality assurance, operator safety, and identifying problems and solutions. Online, one-day, and in-plant training seminars are available. For the complete schedule, visit T. J. Snow Co. (*tjsnow.com/seminars*) or contact Cheryl McDonald, *CherylMcDonald@tjsnow.com*, (423) 308-3214.

Veterans Goodwill Weld Training Program. South Burlington, Vt., and Eagle River, Wis. AWI and Veterans of Foreign Wars offer veterans a complimentary two-day training at AWI facilities. Contact (802) 660-0600, (715) 337-0122, or *awi.edu*.

Welding Educator Workshops. National Center for Welding Education & Training (Weld-Ed). The professional development workshop series will feature seven training modules designed exclusively for welding educators and industrial trainers. Workshop participants can earn four continuing education units (CEUs) and 40 professional development hours (PDHs), with the exception of the three-day NDT workshop, which offers 2.5 CEUs and 30 PDHs. For descriptions, training locations, and registration links for each workshop, go to *weld-ed.org* or call (866) 529-9353.

WJM Technologies Welding Training Courses. WJM Technologies. Courses include Resistance (Spot) Welding, Laser Welding and Materials Processing, TIG/MIG Welding, and Metallurgy and Welding. Classes are offered online and on-site. For more information, contact Girish P. Kelkar, *girish@welding-consultant.com*, or go to *welding-consultant.com*.

Combining Modular Fixturing with CAD Modeling

This software can help you create fixturing systems for increased workshop efficiency

BY JOEL CHINCHILLA

In the past, fixturing a workpiece meant you had to fabricate custom fixturing elements from several parts, such as laser-cut pieces, tubing, risers, jigs, and clamping tools, just to name a few. But now, with the growing use of modular fixturing systems, designers can build fixtures quicker and more efficiently, all while reducing costs and freeing up valuable floor space. The process is facilitated further by combining modular fixturing with a computer-aided design (CAD) software.

Keep reading to find out how using CAD models can help you create and verify modular fixturing designs for increased efficiency in the workshop.

Modular Fixturing Explained

What exactly is a modular fixturing system, and how can it improve your fixturing process? A modular system consists of a heavy-duty table or base platform designed with an array of equally spaced pinholes used to locate and mount fixturing elements — Fig. 1. The pinholes can range from ⅝ to 1 in. in diameter for the larger and heavier workpieces. All pinholes and faces get machined to tight tolerances, allowing them to be used as a measuring tool for locating and documenting fixturing setups. Modular fixturing systems are designed to deliver enough clamping capacity to securely hold a workpiece during welding and machining processes.

Modular systems enhance versatility by enabling different types of fixturing elements to be combined to construct unique fixture structures. Fixture structures can be used to make custom risers, supports, jigs, or any tooling. This versatility is one of the most beneficial features of a modular fixturing system because of the unlimited amount of combinations that can be generated. The possibilities are limited only by the imagination of the designer.

Additionally, modular systems are highly adaptable because they can easily be torn down and rebuilt with excellent precision and consistency. Their adaptability provides space savings by freeing up the shop floor space that is usually necessary to catalog and store bulky, heavy fixtures. This also reduces the consumption of raw materials required to build permanent fixtures. A modular system's efficiency in

Fig. 1 — This modular fixturing system consists of the Strong Hand Tools BuildPro® MAX table and fixturing devices to hold the workpiece in place.

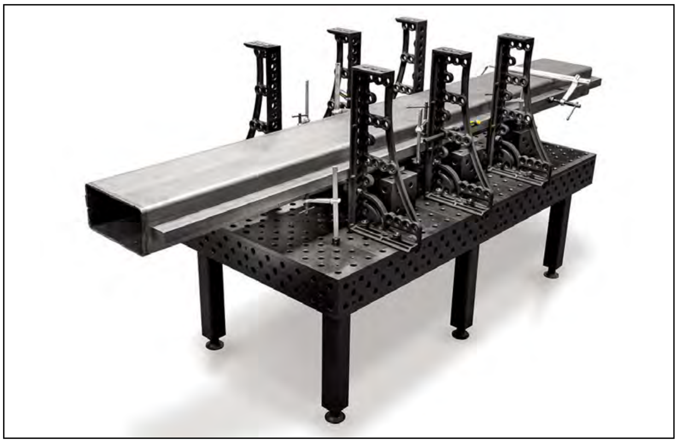

Fig. 2 — This modular fixturing system utilizes the Strong Hand Tools PRO28 table to aid in the production of a large rail.

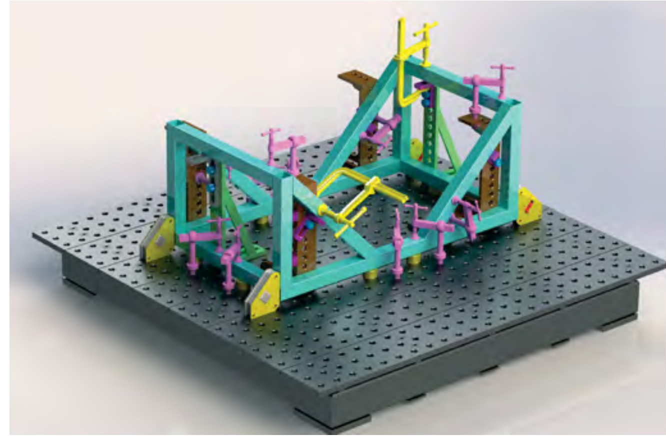

Fig. 3 — The SolidWorks® CAD software enables users to rapidly visualize, analyze, and verify fixture designs in a 3D environment.

quickly building fixture structures is significant when working with short production runs where investing precious time and materials on designing and building permanent fixtures is not an option.

How CAD Facilitates Fixture Design

There are many advantages to using CAD, making it a valuable tool to include in the design process. For example, if you have ever needed to design a fixture for a workpiece that contained odd shapes, angles, or planes, you know that this can sometimes become a challenging task — Fig. 2. The CAD software simplifies this task by allowing the fixture to be designed in a virtual 3D environment — Fig. 3. This 3D environment eliminates the physical restrictions that slow people down when they go through the process of building a fixture in real life. A user can design and verify a complete fixture setup using CAD in a fraction of the time it takes to build one physically, and all without having to set one foot onto the shop floor.

Another benefit of working in CAD is that the user can test fixture setups with fixturing elements that might not exist in the shop, enabling components to be tested before they are acquired. CAD also gives notification alerts for problems that may arise, which helps users analyze part geometries for possible collisions between the workpiece and fixturing elements.

Important Fixture Design Principles to Follow

There are numerous benefits to working in a 3D environment, but it is essential that fixture design principles are followed to attain those benefits fully. For starters, fixtures should always be designed to ensure the workpiece is secured well enough to maintain a solid and consistent hold on the workpiece. Users should make sure the fixturing table or base area is large enough to locate and hold down the workpiece securely with enough room for locators and stops to be set up around the workpiece. When the workpiece is considerably smaller than the table, it should be placed near the edge or corner of the table to give the operator proper access to the workpiece. It is also a good idea to check the latest CAD model is being used, and it is dimensionally accurate.

Additionally, most modular fixturing system manufacturers provide CAD models that a user can access online and download for free. It is good practice and a big time saver to store CAD models locally and organize them into a library with the fixturing elements that will be used.

Lastly, it is crucial that mates in the CAD model be used appropriately. In almost every CAD application, mates are used to locate and position components in space. In a 3D environment, mates should be applied to components to define and fix their locations. Mates also create relationships between the mating faces of all interfacing parts. It is important that mates be applied to CAD models in the same way the components will interface in real life. In other words, the mating faces of stops or locators that will press against the workpiece should be the same faces used to fix the CAD model into place.

Conclusion

Modular fixturing systems provide clamping abilities to securely hold a workpiece in place during welding and machining processes. The greatest benefits of modular fixturing systems are their versatility and adaptability. Despite these benefits, creating fixtures can be challenging, especially when odd geometries are involved. CAD software simplifies this task by allowing users to design fixtures in a virtual 3D environment. However, there are several fixture design principals that must be followed to obtain the full benefits of creating and verifying modular fixturing systems in CAD. When used correctly, CAD can help you increase efficiency in the workshop. WJ

JOEL CHINCHILLA (joel@stronghandtools.com) *is the marketing manager at Strong Hand Tools, Santa Fe Springs, Calif.*

Portland Community College's Welding Technology Facility Gets a New Look

The recently renovated facility will provide additional training opportunities and meet workforce demand

BY KATHERINE MILLER

A Portland Community College welding technology student practices his gas metal arc welding skills in the $6-million, newly remodeled welding facility at the school's Rock Creek campus. (Photo courtesy of Wendy Wright, PCC.)

The United States is currently experiencing a shortage of qualified welders as many employees are reaching retirement age. As such, a strong job market is expected for new hires through the next decade. At Portland Community College (PCC) in Oregon, the 50-year-old welding technology shop at the Rock Creek campus is making changes to meet students' needs and the demand for skilled welders.

After Portland voters approved a bond measure in 2017, the college's Office of Planning & Capital Construction (P&CC) initiated a $6-million remodel to transform the shop into the current 10,000-sq-ft, modern welding facility that instructors call the best of its kind on the West Coast.

With no major renovations since its original construction in the 1970s, the PCC welding lab was in notable need of updating due to aging and insufficient electrical infrastructure; exhaust needs; and, most notably, a concern for the safety of its students and instructors.

"With classes being offered from 7 a.m. to 10 p.m., Monday through Friday, every aspect of our shop was being taxed," said PCC instructor Matt Scott. "Given this demand, and the advances in facilities and welding equipment technology, the shop was due for major technological upgrades."

Instructors and students struggled with "antiquated equipment," Scott added. "The circuit breakers couldn't handle the load. The ventilation was inefficient and needed to be repaired all the time." In addition, the 65 booths could only be used for single-process welding techniques, some of which were no longer in demand.

Moreover, an energy audit identified several areas where energy consumption could be improved.

With a waiting list for students and ongoing workforce demand, PCC constructed a state-of-the-art welding lab to provide additional training opportunities and meet the hiring needs across Oregon.

Fig. 1 — The remodeling project includes an energy-efficient exhaust system and flexible, multipurpose welding booths. (Photo courtesy of Wendy Wright, PCC.)

Fig. 2 — The welding shop's exhaust snorkels are controlled by electronic sensors that automatically shut off when a welding equipment isn't being used. The old system ran continuously five days a week, from 7 a.m. to 10 p.m. (Photo courtesy of Wendy Wright, PCC.)

Same Space, Expanded Capabilities

Although the current shop has the same square footage as the old one, the remodel has made the space much more efficient. It features a new manifold system and 58 new welding booths (Fig. 1), three of which are Americans with Disabilities Act (ADA) accessible. Students can learn and practice any type of welding, including robotics, at any of the booths. Some of the stations are larger to accommodate bigger projects.

The adaptability of the booths was a priority for the remodel given that PCC's welding technology program has, for decades, offered flexible scheduling (see sidebar).

According to Scott, the flexibility of the booths will allow the shop to accommodate 180 students a day over three shifts, up from 100 a day prior to the remodel.

The improvements also include new equipment. Prior to the remodeling, students were working on old transformer rectifier units. Now, they are equipped with a range of the latest technology that mirrors or mimics what students will use in the workforce. The updated shop has the following new equipment: Lincoln Electric® Power MIG® 350MP gas metal arc welding machines, Flextec® 350X multiprocess welding machines with Power Feed® 25M wire feeders, LN-25 PRO™ wire feeders, and Aspect® gas tungsten arc welding machines, as well as Miller® Dynasty® gas tungsten arc and Millermatic® 350P welding machines.

No Longer Running on Empty

In addition to instructional support and ADA improvements, sustainability was a big impetus for the shop remodel. Laura Ward, mechanical project manager consultant to PCC, asserted the biggest energy drain was the centralized exhaust fans.

"Welding is a 'dirty' process, and it generates lots of particulates, so the way the exhaustion is done is key in the process," she said. "When we scale the exhaust to meet the need, we only run the exhaust in the booths where welding is going on, and the other booths' exhaust remains off. This is a different practice than the prior system where the fans were constantly running."

With the new fume exhaust capture source, electronic sensors monitor the use of the welding equipment and automatically shut off the exhaust snorkel when it's not needed — Figs. 1, 2.

Due to the remodel, the shop is projected to save 262,950 kWh and 28,214 therms annually. According to Ward, the expected $42,000 annual savings in utility costs represent a significant sum considering the square footage of the space.

In addition, the project helped the college receive a one-time incentive of $142,491 from the Energy Trust of Oregon.

Fig. 3 — Due to the shop's new safety plugs, students are not at risk of electrical shock as they work on their welding projects. (Photo courtesy of Wendy Wright, PCC.)

Fig. 4 — The gas manifold system, energy-efficient exhaust snorkels, and safety plugs are part of the 50-year-old welding shop's remodel. (Photo courtesy of Wendy Wright, PCC.)

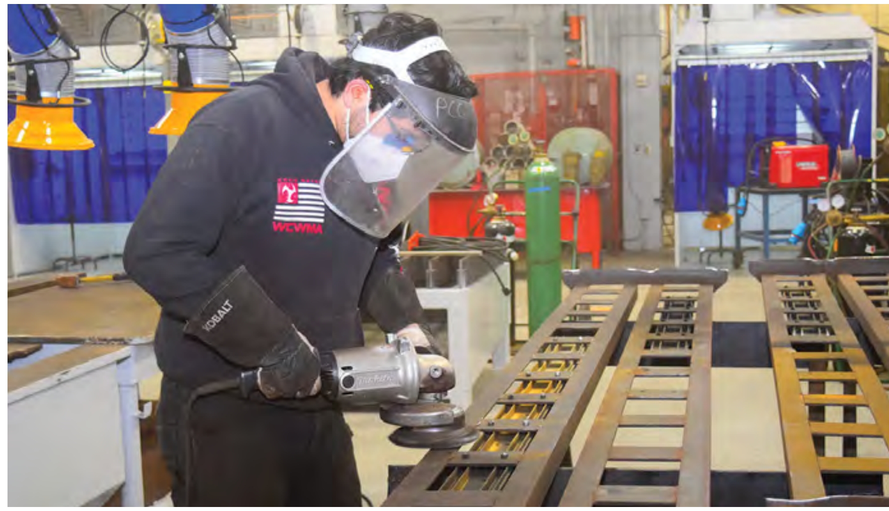

Fig. 5 — A welding student prepares to install track burner racks in a PCC welding class. (Photo courtesy of Wendy Wright, PCC.)

No Risky Business

Safety improvements are another benefit of the shop renovation. For example, the new equipment was installed with safety plugs that prevent students from suffering electrical charges when welding equipment is handled incorrectly — Figs. 3, 4. New welding curtains were also added. Additionally, improvements in air circulation and the new exhaust system protect users more fully against fumes and particulates.

It took a team of dedicated people to create the new safe space. The team tasked with the remodel included P&CC, Opsis Architecture, Pence Construction, PAE, and Glumac.

Zahava Jones, lead project manager for the project, explained that a "user-inclusive" process was used to ensure all needs were addressed. The welding instructors were invited to participate in the planning meetings from the outset of the project.

"In our initial meetings, we discussed broad brush stroke items, such as 'what's on your dream list,' and then moved on to all the details, such as how much electrical power is needed for our right-angle grinders," said Jones. "Although the process was complex, the dividends will be reaped for decades to come."

As an instructor, Scott was delighted that the project team took the user input seriously.

"They brought us in from minute one and really listened to our wish list. Then, we got down to the smallest details. We had weekly meetings and site visits and were able to work through all the inefficiencies of the old shop," he said.

As a result, the students are big fans of the remodel.

"They [the students] are loving it. Everyone has been blown away," affirmed Scott. "We even have a Facebook page for the welders and have been sharing photos of the shop with the students."

Real-World Experience

The remodeled, state-of-the-art weld shop provides a powerful learning environment — Fig. 5. Students will have the ability to learn and practice different types of welding at any one of the booths.

"It is imperative to have a facility to support this dynamic educational venture," Scott added. "We are now better able to provide students with the real-world experience and skills that employers demand." WJ

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Why Choose Welding Technology at PCC?

The Portland Community College (PCC) welding technology program at the Rock Creek campus offers flexible scheduling. Students can register for full- or part-time instruction in an open-entry/open-exit, self-paced format, which allows enrollment at any time throughout the year. They can also earn a two-year associate's degree or 13 welding certificates that require less than a year to complete and offers university transfer options. The program provides training in the following subjects:

- Gas metal arc welding
- Gas tungsten arc welding
- Shielded metal arc welding
- Flux cored arc welding
- Submerged arc welding
- Maritime welding
- Nondestructive examination
- Oxyacetylene cutting and welding
- Plasma arc cutting
- Structural steel codes
- Wire welding

Welding classes are also offered at PCC's Swan Island Trades Center and, starting in fall 2021, at the new Oregon Manufacturing Innovation Training Center at PCC's Columbia County Center.

To learn more about the program, visit *pcc.edu/programs/welding*.

Fundamentals of Arc Welding Power Sources

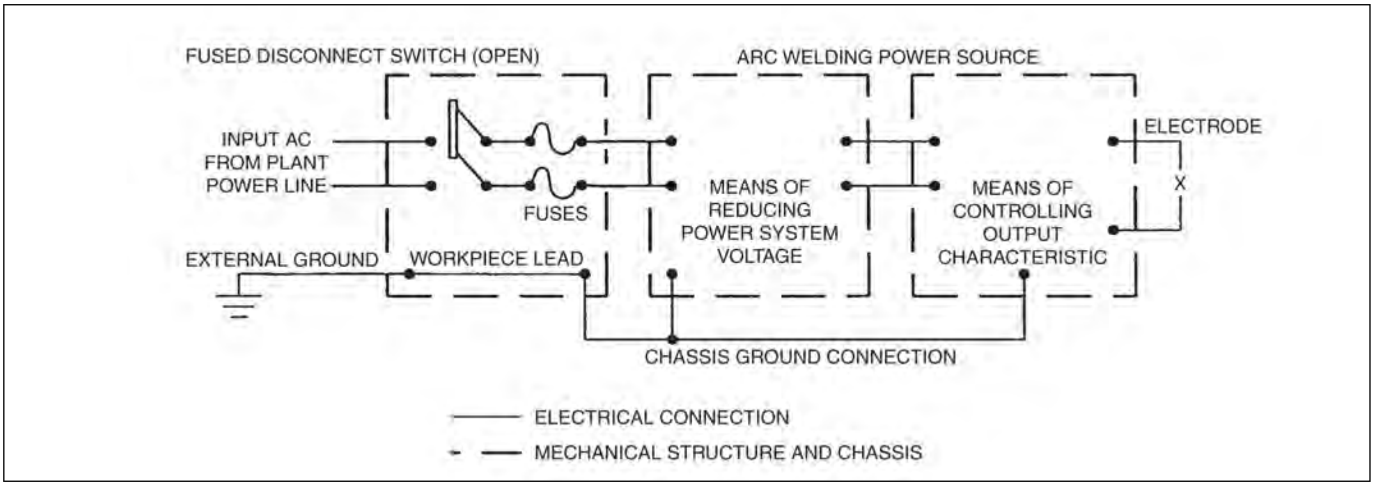

Fig. 1 — Pictured are the basic elements of an arc welding power source.

The voltage supplied by power companies for industrial purposes — 120, 230, 380, or 480 V — is too high for use in arc welding. Therefore, the first function of an arc welding power source is to reduce the high input or line voltage to a suitable output voltage range, which is 20 to 80 V. A transformer, a solid-state inverter, or an electric motor generator can be used to reduce the utility power to the terminal or open-circuit voltage appropriate for arc welding.

Alternatively, a power source for arc welding may derive its power from a prime mover, such as an internal combustion engine. The rotating power from an internal combustion engine is used to rotate a generator or an alternator for the source of electrical current.

Welding transformers, inverters, or generator/alternators provide high-amperage welding current, generally ranging from 30 to 1500 A. The output of a power source may be alternating current (AC), direct current (DC), or both. It may be constant current, constant voltage, or both. Welding power sources may also provide pulsed output of voltage or current.

Some power source configurations deliver only certain types of current. For example, transformer power sources only deliver AC. Transformer-rectifier power sources can deliver either AC or DC, as selected by the operator. Electric motor-generator power sources usually deliver DC output. A motor alternator delivers AC and can deliver DC when equipped with rectifiers.

Power sources can also be classified into subcategories. For example, a gas tungsten arc welding power source might be identified as a transformer-rectifier, constant-current, AC/DC power source. A complete description of any power source should include welding current rating, duty cycle rating, service classification, and input power requirements. Special features can also be included, such as remote control, high-frequency stabilization, current-pulsing capability, starting and finishing current vs. time programming, wave-balancing capabilities, and line-voltage compensation. Conventional magnetic controls include movable shunts, saturable reactors, magnetic amplifiers, series impedance, or tapped windings. Solid-state electronic controls may be phase-controlled silicon-controlled rectifiers or inverter-controlled semiconductors. Electronic logic or microprocessor circuits may control these elements.

Figure 1 shows the basic elements of a welding power source with power supplied from utility lines. The arc welding power source itself does not usually include the fused disconnect switch; however, this is a necessary protective and safety element.

An engine-driven power source would require elements different from those shown in Fig. 1. It would require an internal combustion engine, an engine speed regulator, and an alternator, with or without a rectifier, or a generator and an output control.

Before the advent of pulsed-current welding processes in the 1970s, welding power sources were commonly classified as constant current or constant voltage. These classifications are based on the static volt-ampere characteristics of the power source and not the dynamic characteristic or arc characteristics. The term *constant* is true only in a general sense. A constant-voltage output actually reduces or droops slightly as the arc current increases, whereas a constant-current output gradually increases as the arc length and arc voltage decrease. In either case, specialized power sources are available that can hold output voltage or current truly constant. Constant-current power sources are also known as *variable-voltage* power sources, and constant-voltage power sources are often referred to as *constant-potential* power sources. These fast-response, solid-state power sources can provide power in pulses over a broad range of frequencies. WJ

Excerpted from the Welding Handbook, *Ninth Edition, Volume 2, Welding Processes, Part 1.*

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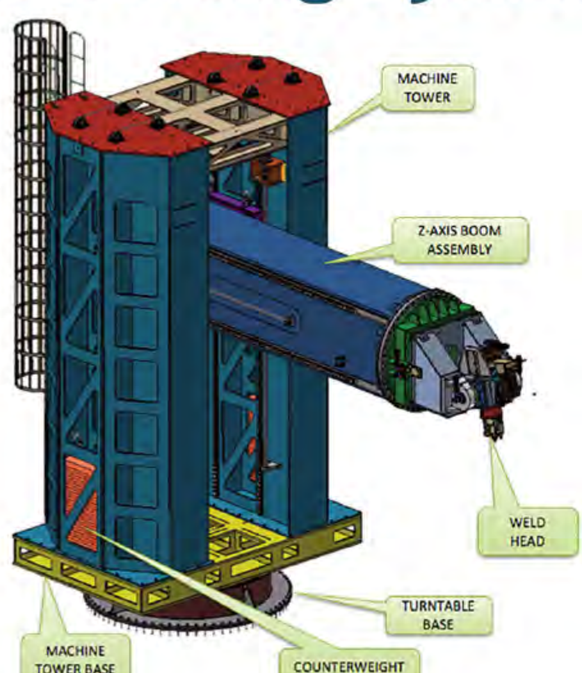

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Recent Advances in Prediction of Weld Residual Stress and Distortion — Part 2

This paper reviews the recent advances in mitigation techniques that have been applied in the structure design, manufacturing, and postweld stages

BY Y. P. YANG

ABSTRACT

Weld residual stress can contribute to the reduction of structure lifetime and accelerate the formation of fatigue cracks, brittle fractures, or stress corrosion cracking. Distortion can have a significant impact on the dimensional accuracy of assembly, structure strength, and fabrication cost. In the past two decades, there have been many significant and exciting developments in the prediction and mitigation of weld residual stress and distortion. This paper reviews the recent advances in mitigation techniques that have been applied in the structure design, manufacturing, and postweld stages. The techniques used in the structure design stage include selecting the type of weld joint and weld groove, using balanced welding, determining appropriate plate thickness and stiffener spacing, and considering distortion compensation. Mitigation techniques used in the manufacturing stage include welding sequence optimization, reducing welding heating input, selecting low-transformation-temperature filler metals, prebending, precambering, constraints, trailing and stationary cooling, in-processing rolling, transient thermal tensioning, and additional heat sources. Postweld mitigation techniques include postweld heating and mechanical treatment. Finally, the remaining challenges and new development needs were discussed to guide future development in the field of mitigating weld residual stress and distortion.

KEYWORDS

• Numerical Analysis • Residual Stress • Distortion
• Finite Element Analysis

Introduction

Welding is one of the main joining technologies used for assembling metal parts in industries such as shipbuilding, bridge construction, oil and gas, automotive manufacturing, etc. Welding processes are characterized by local heating that leads to the melting of filler and base materials. The fast cooling after welding results in permanent plastic deformations that exist in the fusion zone vicinity and cause residual stress and distortion in the welded structure. Residual stresses combined with workload can significantly contribute to the reduction of structure lifetime and accelerate the formation of fatigue cracks, brittle fractures, or stress corrosion cracking (Refs. 1–5). Welds in thin-walled structures often produce residual stresses large enough to cause buckling, which can complicate distortion analysis and prediction (Refs. 6, 7). Moreover, the distortion can cause problems during the assembly of the structure. The elimination of residual stresses and dimensional imperfections using postweld thermal (Refs. 8, 9) or mechanical (Ref. 10) procedures requires additional financial costs, increases production time, and is often unsuitable because of the welded structure size and the location of assembly. To reduce weld residual stress and distortion as well as their consequences, it is necessary to know the shape and magnitudes of residual stresses and distortion as early as in the structure design phase. Numerical models have successfully been used in the prediction of weld residual stress and the development of mitigation techniques (Refs. 11–14) in the past two decades.

Weld residual stress and distortion can be controlled in the structure design, manufacturing, and postweld stages. Controlling weld residual stress and distortion during the product design stage is the most favorable stage because of the low cost and high effectiveness. Related research has been reviewed that includes selecting the type of weld joint and weld groove, using balanced welding, adjusting stiffener spacing, determining appropriate plate thickness, and using proper construction technique, including tack weld size and spacing. Distortion compensation, as an effective way to control distortion in the design stage, was introduced using a shipbuilding application example.

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Multiple mitigation techniques used in the manufacturing stage were reviewed that include welding sequence optimization, reducing welding heating input, low-transformation-temperature (LTT) filler metals, prebending, precambering, constraints, trailing and stationary cooling, in-processing rolling, transient thermal tensioning (TTT), and additional heat sources. Trailing cooling, in-processing rolling, and TTT were mainly used for controlling buckling distortion on thin structures. Prebending and precambering techniques were mainly used for thick structures and cannot be used for buckling distortion control. The rest of the techniques can be used for both stable and unstable distortion control.

Postweld mitigation techniques, including postwelding rolling, postweld heat treatment (PWHT), and postweld mechanical treatment, were reviewed that are not favorable but have to do for certain applications. PWHT and mechanical treatment were utilized for reducing weld tensile residual stress or producing compressive residual stress to improve the fatigue performance of the welded joint. Postweld rolling on the weld can reduce both weld residual stress and distortion.

This paper focuses on the application of numerical modeling in the mitigation of weld residual stress and distortion. It is divided into two parts: mitigation techniques and prospects for future research. The mitigation techniques are classified into three categories based on controlling residual stress and technology in the structure design, manufacturing, and postweld stages. Most of the techniques are in the manufacturing stage category because controlling residual stress and distortion is limited in the design stage and not favorable in the postweld stage unless it is necessary. Each technique is discussed by emphasizing its principle and modeling examples. Finally, the remaining challenges and new development needs are discussed to guide the future development in the field of mitigating weld residual stress and distortion.

Mitigation Techniques

The negative cost, schedule, and performance impacts of welding distortion have led to the development of significant research on distortion mitigation methods. Advanced computational modeling has been a powerful tool to understand underlying mechanisms of weld residual stress and distortion and to evaluate reduction technologies. Weld residual stress and distortion can be controlled in the structure design stage, which is the best time, manufacturing stage, and postweld stage (Ref. 15). In-process control of welding distortion is more desirable than postwelding rectification from the point of manufacturing efficiency and cost. There are a large number of distortion control methods to choose from, with each targeting one or more fundamental modes of distortion (angular, bowing, buckling, etc.). The available methods generally fall into four broad categories (Ref. 16):

1. Component design. With the advancement of numerical modeling methods, it is possible to predict the effect of design selections on unit distortion potential. Through prudent selection of design details (e.g., weld size, stiffener spacing, cut-out locations, etc.), it is possible to increase stiffness and reduce distortion.

2. Welding heat input control. Welding heat input can have a major influence on all forms of distortion, particularly buckling distortion, and must be emphasized. Heat input may be reduced by improving fitting practice and optimizing welding processes as well as through training and vigilance of welders. Emerging welding processes — such as hybrid laser-arc welding (HLAW) or friction stir welding (FSW) — may offer the opportunity to significantly reduce distortion, as compared with traditional arc welding processes.

3. Component restraint. Restraint can have a pronounced effect on reducing angular distortion, and, to a lesser extent, on buckling distortion. Effective restraint can be accomplished by using proper clamping devices, welding fixtures, welding sequences, or assembly sequences.

4. Active mitigation techniques. Some techniques are designed to counteract particular forms of distortion. Backbending, forced cooling, static thermal tensioning, and TTT are examples of active mitigation techniques. These approaches generally require capital investment in specialized equipment and optimization of the techniques for particular applications.

Weld and Structure Design

The increased use of thin plates, like in ships for high-speed operation, results in significantly increased distortion. It is favorable to control weld residual stress and distortion in the design stage. In general, important design-related variables and practices include the type of weld joint and weld groove, using balanced welding, stiffener spacing, selecting the appropriate plate thickness, using the proper construction technique including tack weld size and spacing, and so on (Refs. 17, 18).

The thermo-mechanical model was used to simulate welding processes to study the effect of welding parameters and weld groove on temperature, residual stress, and distortion. Chen et al. (Ref. 19) investigated the effect of welding parameters and plate thickness on the temperature-time history in a butt joint with a Gaussian moving heat source model. Wei and Jiang (Ref. 20) conducted thermal elastic-plastic analysis to evaluate the effect of the weld groove on residual stress and distortions in T-joint welding. The peak value of longitudinal and transverse residual stress in K-groove welding is higher than those in no-groove welding. The influence of groove on distortion in T-joint welding is not significant.

V-, K-, and X-groove types are commonly used grooves of butt-welded joints in heavy industry and shipbuilding. Ye et al. (Ref. 21) developed a 3D thermo-elastic-plastic model to investigate the influence of groove type on welding-induced residual stress and deformation in a SUS304 steel butt-welded joint. Experiments were carried out to validate the simulation model. The numerical results suggested that X-groove is superior to K- and V-grooves for limiting angular distortion.

Properly designing the location, size, and spacing of tack welds is a highly effective approach to reduce distortion in welded structures because of the change in structure stiffness. Camilleri et al. (Ref. 22) numerically investigated the influence of different tack welding fabrication procedures on the final deformations of seam-welded plate structures.

They proposed a fabrication procedure that leads to a minimal out-of-plane distortion. Abid and Siddique (Ref. 23) analyzed the effect of tack weld positions and root opening on welding distortions and residual stresses in a pipe flange joint.

Distortion compensation is a great way to control distortion in the design stage. Yang et al. (Refs. 24, 25) developed a weld-shrinkage data model that can be used to calculate weld shrinkage in ship production panels by inputting weld size and material information (Ref. 26). The weld-shrinkage values are included in the panel design so that the panels have the desired dimensions after welding. In addition, presetting is another method for distortion compensation. The design of a structure is altered in such a way that, after welding distortion, the preferred final shape will be achieved.

Welding Sequence Optimization

Welding sequence has a significant effect on the distortion of welded structures. The deformation adversely affects the subsequent fitup and alignment of the adjacent panels, resulting in loss of structural integrity. It is very costly and time consuming to optimize welding sequences to minimize distortion by experiment. Numerical simulation based on finite element (FE) modeling has been widely used to study the influence of welding sequences on the distribution of residual stress and distortion.

The most commonly used method to optimize welding sequence is a 3D thermo-mechanical analysis, especially for small welded joints (Refs. 27–33). For a large structure, a simplified analysis method such as the local-to-global method was used. Various algorithms for welding sequence optimization, such as a genetic algorithm and an artificial neural network, were attempted to reduce deformation (Refs. 34–36).

Welded Joints

Gannon et al. (Ref. 37) studied the effect of welding sequences on the distribution of residual stress and distortion of a flat-bar stiffener joined to a steel plate with sequentially coupled thermal and structural analyses. The effect of four welding sequences on the magnitude of residual stress and distortion in both the plate and the stiffener was investigated, and the effect on the ultimate strength of the stiffened plate under uniaxial compression was discussed. Mondal et al. (Ref. 38) studied the effect of four different welding sequences on a submerged arc welded (SAW) fillet joint on a stiffened plate panel. A FE model was developed to predict temperature, weld residual stress, and angular deformation. An optimal welding sequence was identified for minimizing the distortion on the panel.

Biswas et al. (Ref. 39) investigated the effect of welding sequence on the distortion pattern of large orthogonally stiffened panels used in ships and offshore structures. These panels primarily suffered from angular and buckling distortions. The extent of distortion depends on several parameters, such as welding speed, plate thickness, welding current, voltage, restraints applied to the job while welding, thermal history, and welding sequence. A FE model was developed for studying the effect of these parameters on the distortion pattern and its magnitude on the fabrication of orthogonally stiffened plate panels. Park and An (Ref. 40) investigated the effect of welding sequence on fillet welding distortion. They proposed a new model based on the joint rigidity method to determine the welding sequence for minimizing welding distortion. Analysis and experiment of welding distortion on the test specimen with different stiffener distances were conducted. Analysis results developed a welding sequence that produced the minimum distortion.

Welded Structures

Rong et al. (Ref. 41) studied the deformation and residual stress of a large marine propeller nozzle induced by hybrid laser-arc girth welding using the local-to-global method. A T-joint was analyzed using thermo-elastic-plastic analysis to obtain the inherent strain. The combination form of a Gaussian surface and a conical heat source model was used to simulate the thermal flux of laser and arc power at the weld zone. An optimal welding sequence was then obtained to produce the lowest deformation and residual stress.

Zhang et al. (Ref. 42) developed a full-size FE model of a vacuum vessel to predict residual stress and distortions induced by multipass welding using ABAQUS. Three different gas tungsten arc welding (GTAW) sequences were simulated on this vessel. Sequence 1 resulted in the minimum weld residual stress and the lowest distortion and was recommended to weld the vacuum vessel.

Huang et al. (Ref. 43) investigated the effect of deck plate materials (American Bureau of Shipping Grade DH36 and HSLA-100 steel alloys) and welding sequences on residual stress distributions and distortion near an aircraft tie-down on a ship deck. Six different welding sequences, designed with multiple stops and starts to reduce locked-in residual stress, were analyzed. The best sequence was identified in terms of final residual stress distribution and the deck plate distortion. The optimized welding sequence had the lowest radial residual stresses among the studied six sequences, resulting in lower final deck plate distortion with similar hoop stresses and negligible axial stresses after welding. The radial residual stresses, acting perpendicular to the weld direction, are the most concerning because of their direct influence on the fatigue life of ship structures under sea-state cyclical and fluctuating environmental loads.

Wang et al. (Ref. 44) predicted and mitigated welding-induced distortion during the fabrication of I-section welded structures in cantilever beams of jack-up drilling rigs using the inherent deformation method. First, welding inherent deformations were taken out from typical welded joints by conducting thermal-elastic-plastic FE analysis. Then, the inherent deformation was applied to the welding interfaces in the welded structure meshed with coarse shell elements. Elastic analysis was employed to predict distortion. Some mitigation practices such as application of inverse distortion, optimization of welding sequence, and constraint methods were conducted and examined. In particular, welding sequence strongly affected the final dimensional accuracy.

Reducing Welding Heat Input

Numerical models have been developed and used in simulating welding processes to develop distortion control techniques. Low-heat input welding methods, intermittent welds, and HLAW were studied to investigate their effect on distortion.

Select Low-Heat Input Welding Methods

Colegrove et al. (Ref. 45) compared welds made by SAW, direct current gas metal arc welding (GMAW), pulsed GMAW (GMAW-P), cold metal transfer (CMT), autogenous laser, and HLAW on butt joints of 4-mm-thick DH36 plate. Autogenous laser and HLAW were found to produce the lowest distortion. GMAW-P and CMT were also good options to lower welding-induced distortion. Bhide et al. (Ref. 46) compared SAW, GMAW, and FSW in terms of buckling propensity on HSLA-65 welded plates. Analyses of the longitudinal residual stresses and distortion measurements revealed that the FSW plate had buckling distortion, while the GMAW and SAW plates had angular and bowing distortions. Yang et al. (Ref. 47) conducted a numerical study to predict the distortion resulting from flux cored arc welding (FCAW) and HLAW on a butt-joined long plate of ship steel. It was found that FCAW produced three times higher distortion than HLAW.

Control Distortion Using Intermittent Welds

As a practical technique, the intermittent welding procedure was employed to decrease the magnitude of welding inherent deformation and sequentially avoid the occurrence of welding-induced buckling (Ref. 48). Analyses were conducted to predict welding-induced buckling distortion on a ship panel welded with continuous welds and with intermittent welds (Ref. 47). Angular distortion and buckling distortion were observed in the continuously welded panel. Small deformation (nonbuckling) was predicted in the intermittently welded panel. This study shows that intermittent welding is an effective method to control buckling distortion in thin ship-panel fabrication.

Control Heat Input and Weld Size

Distortion in a weld results from the expansion and contraction of the weld metal and adjacent base metal during the heating and cooling cycle of the welding process. Typically, high heat input or large weld size induced more weld shrinkages, leading to large distortion. Widespread overwelding causes severe plate buckling in shipbuilding during construction. For a 4-mm fillet weld, the total weld area in a doubled fillet weld is 16 mm^2. If the weld size increases by 2 mm, the weld area will be more than double, which induces additional costs that include filler metal, electricity, and the welder's labor hours. More importantly, the increased distortion due to overwelding will increase the difficulties of down-streaming fitting during structure assembly (Ref. 49).

Significant research has been conducted to develop a cost-effective solution for a welder who is not highly skilled to make smaller fillet welds. Zhang et al. (Ref. 50) and Liu et al. (Ref. 51) developed a 3D vision sensing system to measure the characteristic parameters of the weld pool in real time. The measured characteristic parameters were used to estimate the backside bead width with an adaptive neuro-fuzzy inference system as an emulation of the skilled welder. Dynamic experiments were conducted to establish the model that relates the backside bead width to the welding current and speed. Welding experiments confirmed the developed control system was effective in achieving the desired weld joint penetration under various disturbances and initial conditions. Additionally, Zhang et al. (Refs. 52, 53) proposed the use of a low-cost compact miniature sensor to measure position, orientation, and speed. This sensor can be encapsulated inside the welding torch to monitor its motion (or weld) for position, speed, angle, etc. The torch motion data can be used to ensure the torch movement by a human welder is in compliance with the welding procedure specification, such as proper weld size in ship production.

LTT Filler Metals

A concept was proposed by inducing compressive residual stresses from martensite transformation to reduce tensile residual stresses and improve fatigue life of the welded component (Ref. 54). Efforts were made to design LTT weld filler metals that can induce compressive residual stresses near the weld toe region via phase transformations (Ref. 55). The martensite start and finish temperatures are essential parameters in inducing compressive residual stresses. It is important that the martensite transformation begins at a lower temperature and finishes at a temperature just above the final temperature to which the final weld is expected to cool.

Wang et al. (Ref. 56) studied the effect of geometries on weld residual stress with LTT filler metals. A butt-welded plate and pipe were designed to have the same dimensions in the cross section perpendicular to the weld interface. A clear difference was found in these two joints. Longitudinal tensile stress in the weld zone was efficiently reduced in both joints, whereas longitudinal tensile stress was formed in the base metal near the weld zone in the pipe. A notably greater influence on transverse stress was found in the pipe than in the plate.

Azizpour et al. (Ref. 57) conducted 3D FE simulations with a coupled thermal-metallurgical-mechanical model using SYSWELD software to predict weld residual stresses for both a LTT filler metal and a conventional filler metal on a four-pass butt joint of Domex® 700 MC steel plates. The analysis results, validated by hole-drilling stress measurement, indicated that the LTT filler metal reduced weld longitudinal tensile residual stress from 554 to 216 MPa and transverse residual stress from tensile 156 MPa to compressive 289 MPa.

Jiang et al. (Ref. 58) developed a thermo-elastic–plastic model coupled with solid-state phase transformation (SSPT) to investigate the effect of their designed LTT welding wire on the weld residual stresses in a 25-mm-thick ferrite steel plate. The analysis results, verified by neutron diffraction measurement, demonstrated that the LTT filler metals can significantly reduce the residual stress and even generate compressive residual stress in the weld zone. The higher interpass temperatures related to the microstructure evolution resulted in an increased region of compressive stress within the weldment, which was confirmed by Moat et al. (Ref. 59). Moreover, the longitudinal residual stress in the weld zone gradually changed to tension as the start temperature of martensitic transformation increased.

Prebending and Precambering Techniques

Prebending Technique

Prestaining is widely used to control welding-induced distortion in heavy industries. Before assembling welded structures, plates are bent into a permanent shape based on experience and experiment. After welding, welding-induced distortion makes the bent shape become straight. However, it is costly to determine the prebent shape and magnitudes. With the development of the weld modeling method, it is possible to determine the prebent shape and magnitudes by conducting a numerical modeling experiment. As an example, the prebending technique was used to mitigate distortion resulting from the J-groove circumferential fillet weld between a cylinder and a plate (Ref. 60). Before welding, the end edge of the plate was prebent to about 6–8 mm in the cylinder axle direction. After welding and machining, the prebent plate became almost flat.

Precambering Technique

Precambering is another technique in controlling welding-induced distortions in heavy industries. It is different than the prebending technique in that the welded structure is elastically bent by hydraulic tools to a certain shape just before welding in a specially designed fixture. Precambering techniques can be divided into four steps: 1) assembling plates into a component by tack welding, 2) using hydraulic tools to prebend the component to a certain shape, 3) welding the component, and 4) releasing precambering and fixtures. If the prebent shape and magnitudes are optimized, the component will have very small distortion after welding.

Advanced weld modeling procedures were used to assist the development of the precambering techniques for a large welded structure that was a component in earthmoving equipment. Several test precambering and welding analyses were performed by precambering the component into different shapes and magnitudes in the FE model (Ref. 60). Based on the model-predicted precambering shape and magnitude, the structure was welded by applying the precambering technique. After welding and releasing the precambering fixture, the final distortion was smaller than 1 mm.

Welding Constraints

One of the practical methods for minimizing welding angular distortions is to use fixture/clamping during welding and releasing after welding. Traditionally, the fixed locations and releasing time were determined based on experience and experiment (Ref. 61). With the maturation of FE weld modeling methods, numerical models have been widely used to study the effect of welding constraints on weld residual stress and distortion (Refs. 62–68). Abid and Siddique (Ref. 62) conducted a 3D thermo-mechanical analysis to investigate the effect of mechanical constraints on welding distortions and residual stresses in a pipe flange joint. Liu and Zhang (Ref. 63) used a FE model to find the relationship between restraining force and moment and angular distortion. Chen and Li (Ref. 67) applied the combined 3D solid/shell modeling method to investigate the influence of the mechanical restraints on the residual stresses and deflections of the large panel structures.

Gharib et al. (Ref. 69) studied the effect of clamping time on welding distortion of austenitic stainless steel 304L butt-welded joint by conducting thermo-mechanical analysis. The analysis results showed that the clamping changed the direction of bending and angular distortion (opposite to the one without clamping). Increasing clamping time reduced angular and bending distortion. Compared with the hot release mode (an immediate unclamping after welding), a 70% reduction of angular and bending distortion was observed if the clamping was released after cooling to room temperature. The position of clamping has a significant effect on distortion reduction as well. If the clamping position is moved closer to the weld interface, the distortion can be further reduced. The results from Choobi et al. (Ref. 70) also revealed that clamping release time has a great influence on the distribution of residual stresses and angular distortion. Using clamping during welding and releasing after cooling to room temperature can significantly reduce the amount of angular distortion.

Wei and Deng (Ref. 71) as well as Deng et al. (Ref. 72) clarified the influence of external restraint on welding distortion in three different thin-plate steel welded structures by means of numerical simulation technology. A two-step computational approach was employed to simulate welding distortion in each welded structure. In the first step, the thermo-elastic-plastic FE method was used to obtain inherent deformation for each typical joint. In the second step, an elastic FE method based on inherent strain theory was used to compute welding deformation for three thin-plate panels with different thickness and shape. The effects of external restraint on welding deformation in a thin-plate panel with 5 mm thickness, a thin-plate panel with 10 mm thickness, and an asymmetric curved panel with 10 mm thickness were investigated.

Trailing and Stationary Cooling

Trailing cooling uses an intense heat sink trailing the welding heat source to create a characteristic valley-shaped temperature distribution, as shown in Fig. 1. Various researchers have used different cooling media: water, liquid nitrogen (Ref. 73), and solid CO_2 (Ref. 74). Trailing cooling is an effective technique to control weld residual stress and distortion. Trailing cooling can also change the weld microstructure orientation and grain size to improve the weld-joint mechanical properties of high-strength aluminum alloys (Ref. 75). Trailing cooling has also been used to reduce transverse plastic strain behind the weld pool and eliminate hot cracking of high-strength aluminum alloys (Ref. 75). Trailing cooling with a stationary cooling source was pro-

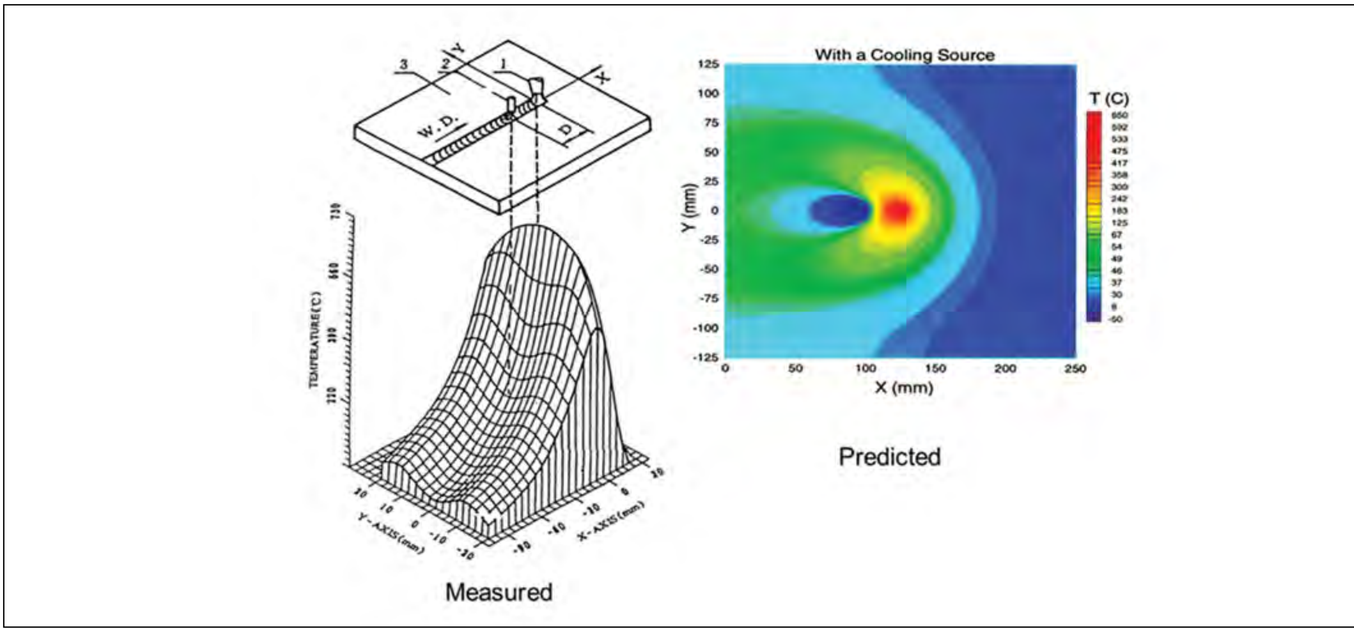

Fig. 1 — Temperature distribution with trailing cooling.

posed by conducting FE analyses to prevent weld intersection cracking in a NASA hydrogen tank. Welding experiments on the small test panel confirmed the feasibility of using such a stationary cooling technique (Ref. 76).

Camilleri et al. (Ref. 77) used cryogenic CO_2 cooling to reduce distortion on welded samples of a butt joint and a T-joint. A fully transient, uncoupled thermo-elastic-plastic model was conducted to investigate the feasible combination of welding process and cooling parameters. In butt-welded plates, a significant decrease in out-of-plane distortion was obtained when applying cryogenic cooling. In fillet-welded plates, cooling had much less effect on welding distortion.

Adak and Mandal (Ref. 78) developed a heat sinking method to control distortion in a butt joint through numerical modeling. Heat sinking has been achieved by circulating water through a channel clamped at the bottom surface of the plates undergoing welding. The results held a great promise for determining the heat sinking parameters for effectively controlling welding distortion.

Joo et al. (Ref. 79) investigated the effect of a trailing heat sink on welding residual stress and out-of-plane displacement using the FE analysis. This numerical simulation indicated that, compared to conventional welding, trailing heat sink welding first showed smaller deformation and residual stress. Secondly, it showed a significantly reduced out-of-plane displacement under optimal heat sink welding conditions. Lastly, it showed a reduced overall residual stress developed, although no significant differences were seen in the maximum values of welding residual stress. The reason for reduced weld deformation is that the effect of the heat sink could prevent the development of the plastic strain near the weld zone during the welding process.

Yang and Dong (Ref. 80) studied the mechanism of trailing cooling with transient thermal-elastic-plastic analysis. It was concluded the heat sink provided a stretching effect on the weld metal undergoing a rapid cooling so that the weld metal shrinkage could be reduced, which not only significantly reduced final residual stresses but also altered the overall distribution. Numerical modeling and experiments showed that three technological parameters — cooling distance, cooling intensity, and cooling area — determine the effectiveness of trailing cooling. This technique can effectively reduce buckling distortion on thin structures.

In-Process and Postprocess Rolling

The in-process rolling technique was first proposed by Yang and Dong (Ref. 80) with the help of numerical modeling. The process setup is illustrated in Fig. 2. During welding, a roller is placed at a distance behind the welding torch. By applying a force on the roller, a compressive plastic deformation is applied on the weld in contact with the roller in the through-thickness direction. The weld metal elongates in the lateral directions, resulting in reduced residual stresses. Some of the major rolling parameters are rolling force, roller width, and the distance between the welding torch and the roller. It should be pointed out that it is not necessary to have both the top roller and bottom roller. For instance, if a solid support can be used at the plate bottom, only the upper roller is needed. Since in-process rolling requires the design of special tooling, welding with electromagnetic trailing peening was developed, which can produce a similar effect as in-process rolling (Refs. 81, 82). In addition, to reduce residual stress and distortion, the in-process rolling technique can also improve weld microstructure and property (Ref. 83).

A recent study (Ref. 84) showed that in-process rolling cannot reduce the distortion on a laser-welded large panel. This is because laser welding typically uses a very fast travel speed, and the rolled location has a high temperature even with a long trailing distance. Residual stress continues to form during the subsequent cooling. Therefore, postprocess rolling was studied with numerical modeling. The analysis results indicate that postweld rolling gives a far greater re-

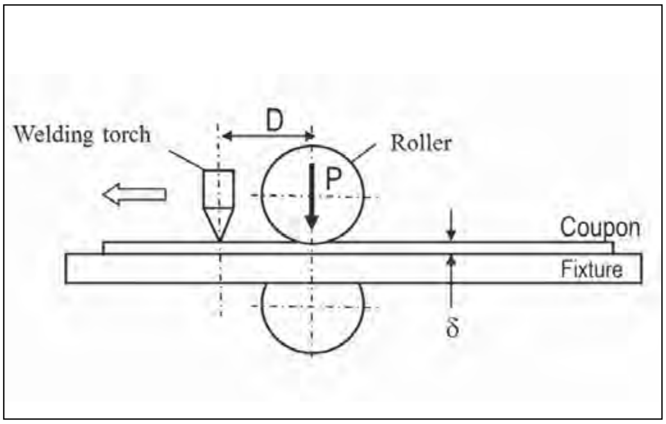

Fig. 2 — A concept of in-process rolling.

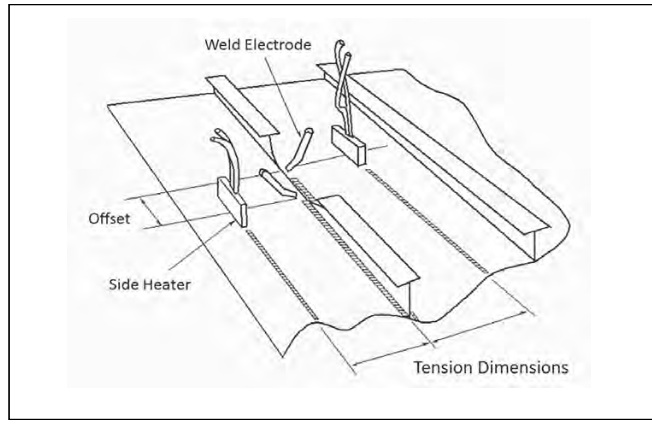

Fig. 3 — Second approach of TTT.

duction in the residual stress field and distortion.

Coules et al. (Refs. 85, 86) investigated the high-pressure rolling technique to eliminate weld residual stresses. Rolling was found to completely change the residual stress state in the weld, creating large compressive longitudinal residual stresses. It was effective for this purpose regardless of whether it was applied directly to the weld seam or to the regions on either side of it. Experiments showed that rolling applied at a high temperature, as welding is carried out, promotes the formation of acicular ferrite in the weld metal. This produces a weld material with a greater yield strength and hardness but a slightly reduced impact toughness compared to unrolled welds. Rolling of the weld metal once it has cooled instead causes work hardening.

Cozzolino et al. (Ref. 86) applied FE analysis to investigate two postweld rolling methods: rolling the weld bead directly with a single roller and rolling beside the weld bead with a dual flat roller. The models showed that both rolling techniques were able to induce compressive stress into the weld region. The distribution of stress was sensitive to the coefficients of friction between the workpiece, roller, and backing bar. High friction coefficients concentrated the plastic deformation and compressive stress within the center of the weld bead. Distortion can be eliminated by rolling; however, the experiments indicated that this was only achieved when applied to the weld bead directly.

He et al. (Ref. 88) proposed a stationary shoulder friction stir welding (SSFSW) method to control weld residual stress and distortion on a butt joint of 6005A-T6 aluminum alloy plates. A thermo-mechanical model was utilized to compare the residual stress distribution between conventional FSW and SSFSW. SSFSW was beneficial to decreasing the peak temperature of the stir zone (SZ) and then obtaining a narrower SZ. The peak residual stress produced by SSFSW was 50% lower than that by conventional FSW, and a narrower tensile stress region was attained by SSFSW. Moreover, the stationary shoulder applied a function of synchronous rolling during welding, which effectively controlled the distortion.

Transient Thermal Tensioning

Thermal tensioning approaches have been investigated since the mid-1990s as a means to reduce buckling distortion (Ref. 89). More recent studies (Refs. 90, 91) have focused specifically on the further development, demonstration, and application of TTT for the control of welding-induced buckling distortion of ship structures. Based on this work, TTT has been shown to be an effective and practical means of controlling buckling distortion in ship structures.

Two kinds of technical approaches were investigated during the development of the TTT process. The first approach developed early is to reduce weld tensile residual stress so that the compressive residual stress is reduced because of stress balances (Ref. 89). The second approach developed later is to directly work on the compressive stress by adding a tensile band in the compressive zone, which is easier to be implemented in production (Refs. 90, 91). Figure 3 shows the concept and experiment setup for the second approach of the thermal tensioning process. Two moving auxiliary heat sources are applied to narrow bands at some distance from the weld to induce the local tension zone where the weld compressive zones would normally exist. Oxyfuel flame heaters are carried along with the welding head. The heat source locally yields and shrinks an area in the plate in a similar manner. The process parameters include the size, location, travel speed, and intensity of the heat sources. Because the TTT heating apparatus are attached to the mechanized stiffener welding carriage, the welding speed dictates the TTT travel speed. In general, the thickness of the plate dictates the required intensity, which is adjusted by means of oxyfuel gas pressure and flow rate. The heat source must be concentrated enough to produce plasticity.

Figure 4 illustrates the principles of TTT with a sketch of longitudinal stress distributions (along the welding torch traveling direction). Without TTT, longitudinal tensile stress is produced near the fillet weld and balanced by compressive residual stress away from the weld. With TTT, two bands of residual tension stress are produced in the two auxiliary heating locations to counter compressive stress and minimize buckling. To confirm the theoretical stress distributions, a simple FE analysis was conducted with a set of TTT parameters on a DH36 plate with one Tee stiffener. Figure 5 shows the predicted longitudinal stress distribution without and with TTT. It was found that a tensile stress band was created in the flame torch heating location, which confirms the theoretical analysis.

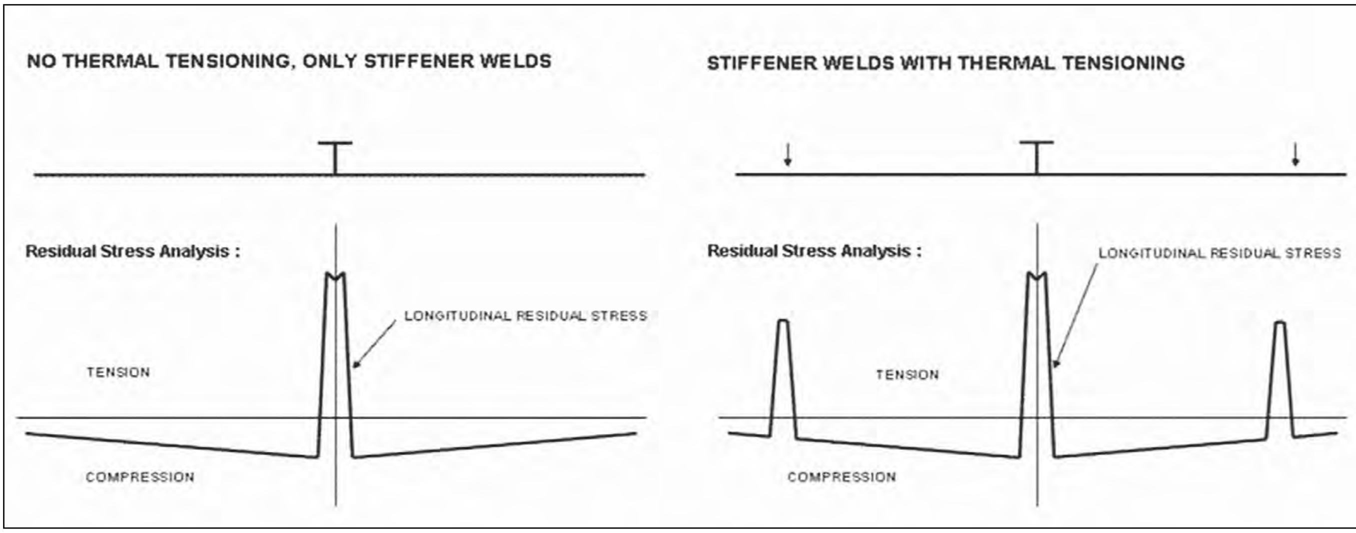

Fig. 4 — Stress distributions of TTT.

Additional Heating Sources

An in-process method for controlling welding distortion in fillet welds was developed by Mochizuki and Toyoda (Ref. 92). A schematic illustration of the proposed method is shown in Fig. 6. It particularly reduced angular distortion by performing reverse-side GTAW heating of the weld interface at a fixed distance ahead of GMAW during the welding process. Various heating conditions were examined by experiment and by the FE analysis to determine the appropriate conditions and study the mechanism by which welding distortion is reduced. It was consequently found that this mechanism is a result of two main effects: the GTAW heating effect on the reverse side, which produces the opposite angular distortion, and the preheating effect.

Pazooki et al. (Ref. 93) studied an in-process heating method to control welding-induced distortion in a large butt joint with experimental and numerical approaches. The additional heating sources were arranged on both sides of a weld. The left-hand side heating was conducted with a leading burner and a trailing burner. The right-hand side heating was conducted with two parallel burners. The mechanisms of distortion reduction in welding with additional heating are complex. The complicated nature of welding stress and strain fields is increased by the large number of parameters involved in welding with additional heating. In the region beneath and close to the burners, compressive residual stresses were reduced in welding with side heating compared with those of conventional welding of AH36. The essential feature of welding with side heating is the creation of a temperature peak at the location of the burners, which results in the creation of tensile residual stresses. This is very similar to the TTT technique.

Saurav and Biswas (Ref. 94) investigated the residual stresses and deformations with and without the effect of preheating by conducting experimental and 3D FE analysis of a butt joint welded with SAW on creep strength enhanced ferritic (CSEF) steel plate. The SSPT or austenitic-martensitic transformation characteristic of CSEF steel was considered in modeling. Thermal history, distortion, and residual stresses were predicted for as-welded and preheated weld models and validated with experimentally measured results. Deep-hole drilling techniques were carried out for residual stress measurement. The residual deformation was measured with a coordinate-measuring machine. It was observed that preheating effectively reduced the edge deflection and angular deformation values by 42 and 54%, respectively. Preheating also exhibited a favorable effect on reducing longitudinal residual stress.

Postweld Thermal/Mechanical Techniques

Over the past several decades, numerous postweld thermal and mechanical techniques (i.e., heat treatment; grinding; GTAW dressing; ultrasonic impact; and hammer, shot, and laser peening) have been developed to improve mechanical and fatigue performance of weld joints. These treatments are generally classified into two different categories: geometry improvement and residual stress modification techniques. Geometry improvement techniques, such as GTAW dressing and grinding, focus on eliminating flaws and reducing the stress concentration of welded components. Residual stress modification techniques, like hammer, ultrasonic, laser, and shot peening, lay emphasis on introducing beneficial compressive residual stresses and improving residual stress distributions of welded joints (Refs. 95, 96).

Postweld Heat Treatment

PWHT is one of the most effective ways to relieve weld residual stress. Extensive numerical models have been conducted to understand the stress relief mechanism and determine the optimal process parameters. Hashmi et al. (Ref. 97) employed the FE method to model PWHT on a two-pass butt-joint welded SUS304 stainless steel pipe. First, the welding process was modeled, and then the stress distribution of the specimen was transferred to a second analysis for stress relaxation modeling. Norton law was used to investigate creep in the stress-relief process. Based on the model-

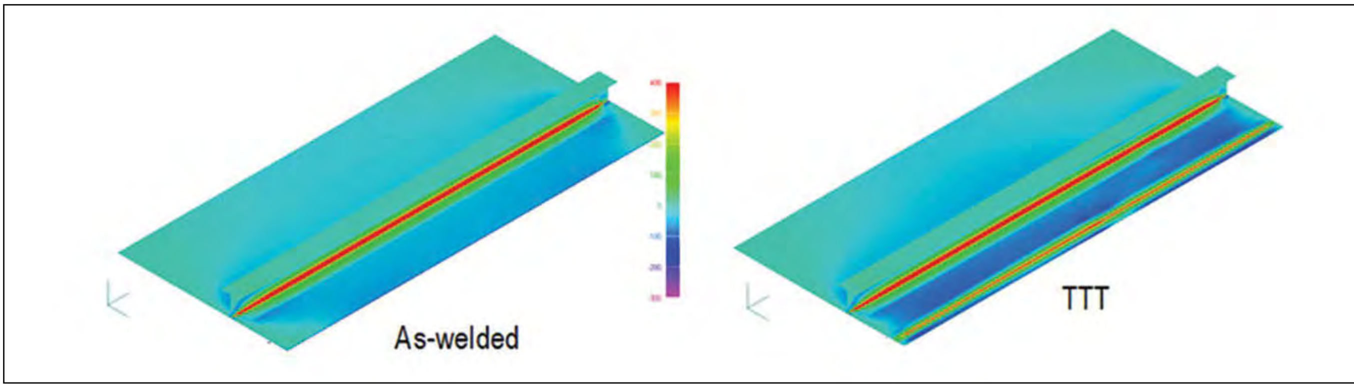

Fig. 5 — Longitudinal stress distributions after TTT.

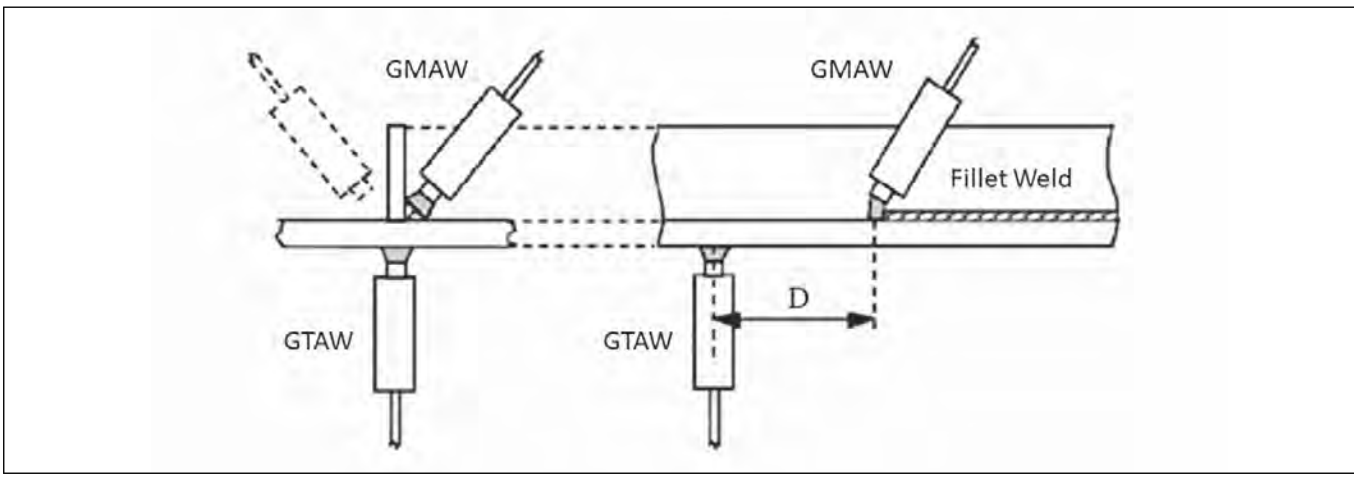

Fig. 6 — Schematic illustration of welding distortion control by reverse-side heating.

ing and experimental results, the tensile and compressive stress distributions were reduced.

Ren et al. (Ref. 98) took a thermo-metallurgical-mechanical coupled computational approach to analyze the residual stress distribution on 2.25Cr-1Mo welded pipe. A 3D FE model and moving heat source model were employed in simulation. The effects of SSPT, tempering, and creep were considered simultaneously. The simulation results showed that SSPT could induce an undulating stress profile and a large stress gradient in the welded zone. The stress gradient could be reduced during local PWHT while there were stress peaks at the edges of the heated region. The tempering effect could decrease the residual stress at the high-stress region by material softening and yielding. Creep caused a global transformation from elastic strain to plastic strain, which led to a macro-scale stress relaxation. Dong et al. (Ref. 99) used FE and analytical methods to study weld residual stress-relief mechanisms associated with furnace-based uniform PWHT. It was found that the most dominant stress relief mechanism is creep-strain-induced stress relaxation. A rapid creep strain development accompanied by a rapid residual stress reduction during the heating stage before reaching PWHT temperature was shown to contribute to most of the stress relief seen in the overall PWHT process, suggesting PWHT hold time can be significantly reduced as far as residual stress relief is concerned. Hirohata (Ref. 100) investigated a sheet-type ceramic heater as a portable heat source for PWHT of welded parts that can be treated in a furnace. Both an experiment and thermal-elastic-plastic analysis were conducted to examine residual stress release on the welded parts between the deck plate and the trough rib. The effect of fatigue-life improvement by the stress release due to heat treatment was investigated.

Postweld Mechanical Treatment

Numerical models have been used to simulate postweld mechanical treatment processes, including ultrasonic impact treatment (UIT) as well as hammer, shot, and laser peening, to study their effect on weld residual stress. UIT has become increasingly popular because it reduces manpower requirements and is easy to apply. UIT uses needles or hammer-like rods to impact the welding surface/toe at a high ultrasonic frequency. It not only reduces the local stress concentration by modifying the weld toe geometry but also introduces compressive residual stresses by eliminating tensile residual stresses (Ref. 101).

Numerical models have been carried out to investigate the effect of the UIT on the weld residual stresses and fatigue performance of weld joints (Refs. 102–104). Foehrenbach et al. (Ref. 102) developed a computationally efficient approach to predict residual stresses induced by the UIT process using a commercial FE software package. It was found that compressive residual stresses up to a base material yield strength occurred after the UIT treatment. Guo et al. (Ref. 103) presented two 3D FE models to simulate the UIT process on 2024 aluminum alloy. In the single-impact mode, the effects of the initial impact velocity, pin size, and shape on the residual stress distributions were investigated. In the two-impact model, the effects of the second impact on the residual stress field induced by the first impact were investigated. Zheng et al. (Ref. 104) studied the effects of UIT on the residual stresses of 304L stainless steel weld joints. The UIT introduced beneficial compressive residual stresses at weld joints, and the maximum compressive stresses exceeded the compressive yield limit of 304L stainless steel. In addition, the effect of the UIT faded with the increasing depth at the weld toe. The depths of the ultrasonic impact treated compression layer of the T-joint and butt joint were up to 3 and 2 mm, respectively.

Prospect for Future Research

Mitigating Welding-Induced Distortion during Product Design

Distortion compensation is a smart way to mitigate distortion during product design. Numerical models can be used to predict the distortion shape and magnitudes that could be included in the structure design. After welding, the structure could deform to the desired dimensions. There have been limited studies in this area. More research is needed to mature this technology.

Structure Design with ICME Approach

In the current welded structure design, a large safety factor is given to account for uncertainties, including weld residual stress and material changes after welding. This design approach increases structure weight, reduces fuel efficiency, and limits structure performance. An integrated computational materials engineering (ICME) approach should be applied into the welded structure design.

Welding Optimization on Large and Complex Structures

Welding process and sequence optimization are studied in small welded structures using a thermo-elastic-plastic analysis method. This method cannot be used for a large and complicated structure because of computational speed limitation. The inherent strain method could be an option for a large structure. But the thermal and mechanical interactions between welds are ignored in this analysis. These interactions are critical for welding-sequence studies.

Control Distortion in the Entire Manufacturing Chain

Distortion in a final product is an accumulation of all manufacturing processes. Welding is one of the processes that induces residual stress and distortion. However, incoming plate deformation during plate milling and transportation, material cutting, and forming also induce residual stress and distortion. There have been limited studies in this area. More research is needed for industrial companies to apply this integrated technology in production.

Integrated Weld Modeling Software with Robotic Welding

Numerical models can be used to optimize welding sequence. The best welding sequence needs to input to a robot to conduct welding. An interface software is needed to automatically pass the welding sequence to a robot.

Concluding Remarks

Residual stresses and distortion existing in the weld can significantly impair the performance and reliability of welded structures. Advanced computational modeling has been a powerful tool to understand underlying mechanisms of weld residual stress and distortion as well as to help develop new mitigation technologies and improve existing technologies by optimizing process parameters. This paper reviewed the recent advancements and provided a prospect for future research. The review focused on discussing the theory of mitigation technologies and the numerical modeling application to optimize these technologies.

The mitigation technologies were classified into three categories based on the stage when they were applicable. In the product design stage, the most favorable stage because of low cost and high effectiveness, the mitigation techniques that could be applied included selecting the type of weld joint and weld groove, using balanced welding, determining appropriate plate thickness and stiffener spacing, using proper construction technique, and considering distortion compensation. In the manufacturing stage, mitigation techniques included welding sequence optimization, reducing welding heating input, LTT filler metals, prebending, precambering, constraints, trailing and stationary cooling, in-processing rolling, TTT, and additional heat sources. Trailing cooling, in-processing rolling, and TTT were mainly used for controlling buckling distortion on thin structures. Prebending and precambering techniques were mainly used for thick structures and cannot be used for buckling distortion control. In the postweld stage, mitigation techniques included postwelding rolling, postweld heat, and mechanical treatment.

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Brazing Si_3N_4 Ceramic to Molybdenum Using an Ag-Cu-Ti Filler

The microstructure and interface formation mechanism of the Si_3N_4/Mo joint was analyzed

BY T. ZHAO, D. F. MO, L. Q. YU, Y. Y. WANG, J. LI, X. LI, D. F. LIU, X. K. WANG, AND H. M. GONG

ABSTRACT

A Si_3N_4 ceramic was successfully joined to molybdenum (Mo) using an Ag-Cu-Ti filler alloy. The interfacial microstructure of the Si_3N_4/Ag-Cu-Ti/Mo joint was investigated by scanning an electron microscopy, energy dispersive spectrometer, and x-ray diffraction. The results showed the joint brazed at 900°C for 10 min was smooth, and there were no holes and cracks at the interface. A continuous reaction layer, which is composed of TiN and $TiSi_2$, was formed near the Si_3N_4 ceramic, with TiN being located near the ceramic. The central part of the joint was composed of Ag- and Cu-based solid solutions. At the side near the Mo metal, there was a formation of the MoTi solid solution. The typical structure of the Si_3N_4/Mo joint was Si_3N_4/TiN + $TiSi_2$ reaction layer/Ag(s,s) + Cu(s,s)/MoTi/Mo. Because TiN and $TiSi_2$ compounds are generated on the ceramic side, the microhardness of the reaction layer on the ceramic side was decreased but still much higher than the hardness of the brazing seam and the Mo base material. The shear strength of the brazed joint was 204 MPa at room temperature.

KEYWORDS

• Si_3N_4 Ceramic • Molybdenum • Brazing
• Interfacial Microstructure • Formation Mechanism

Introduction

Si_3N_4 ceramic has attracted considerable interest in recent years primarily due to its high thermal conductivity, low dielectric loss, good thermal shock resistance, high bending strength, and fracture toughness, so it is considered a potential high-power heat dissipation and packaging material (Ref. 1). However, the hardness and brittleness make it difficult to obtain large-sized and complex components. Therefore, joining Si_3N_4 to metallic materials is important to satisfy its application.

There have been some methods, such as diffusion bonding (Ref. 2), transient liquid phase (Ref. 3), and brazing bonding (Ref. 4), proposed for ceramic metal or joining. Among these methods, brazing bonding has attracted extensive attention due to its simplicity and cost effectiveness (Ref. 5) and has become the most commonly used reliable method to connect ceramics and metals. It has been reported that Si_3N_4 ceramic has successfully brazed together with copper (Ref. 6), TC4 alloy (Refs. 7, 8), TiAl alloy (Refs. 9–11), Invar alloy (Refs. 12–14), and 42CrMo steel (Refs. 15–17).

Molybdenum (Mo) has good thermal conductivity and low coefficient of thermal expansion (CTE). Hadian et al. (Ref. 18) used two Ni-based brazing alloys to braze Mo and Si_3N_4. Mo, Si, and N diffused from the parent materials. Mo compounds were formed at the Si_3N_4/filler metal interface, resulting in brazing joints in the ceramic/filler degumming at the interface. Peteves and Nicholas (Ref. 19) used Mo as a middle layer to braze Si_3N_4 ceramics. Mo was more successful as an interlayer than Cu or Nb, with its CTE matching the ceramic and affecting less the reactive route for the joint formation. Recently, research has focused on adding Mo particles as a reinforcing phase to the brazing filler metal to reduce the CTE mismatch between the ceramic base material and brazing filler metal (Ref. 20), improving the joint strength. However, there are few reports on the joining of Mo/ceramic assemblies using an Ag-Cu-Ti filler. Therefore, it is of great significance to study the brazing process and connection mechanism of Mo and Si_3N_4 ceramics.

In this work, Si_3N_4 was joined to Mo using the traditional Ag-Cu-Ti brazing filler. The microstructure of the Si_3N_4/Mo brazed joint was studied by means of metallographic observation, scanning electron microscopy (SEM), and x-ray diffraction (XRD). At the same time, microhardness tests were performed. The interface formation mechanism brazing parameters on the interfacial microstructure and mechanical properties were also analyzed.

Experimental Procedure

Materials

The materials used in this study were a Mo block and Si_3N_4 pieces. Both Mo, with a purity of 99.9 wt-%, and

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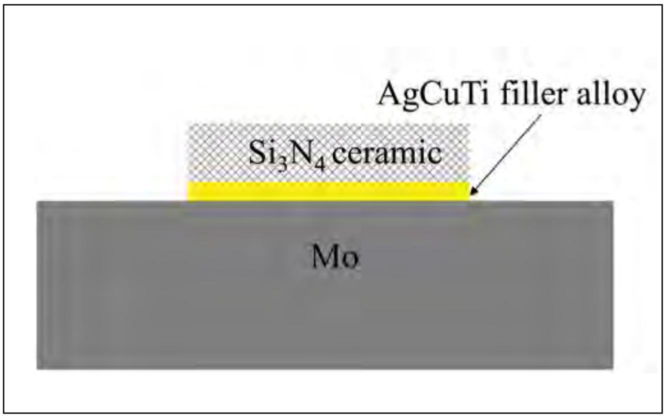


Fig. 1 — Schematic diagram of the sample clamping structure.

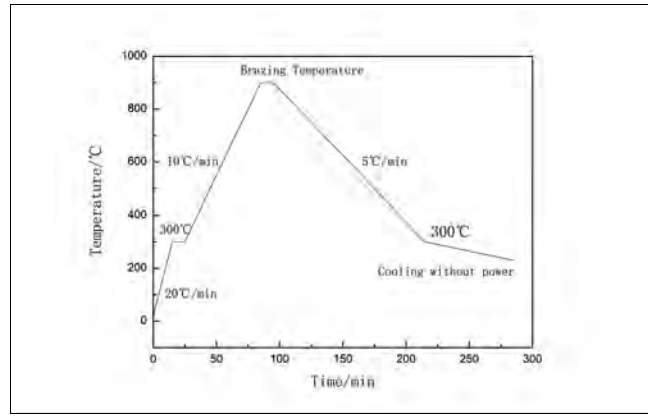


Fig. 2 — Brazing temperature curve.

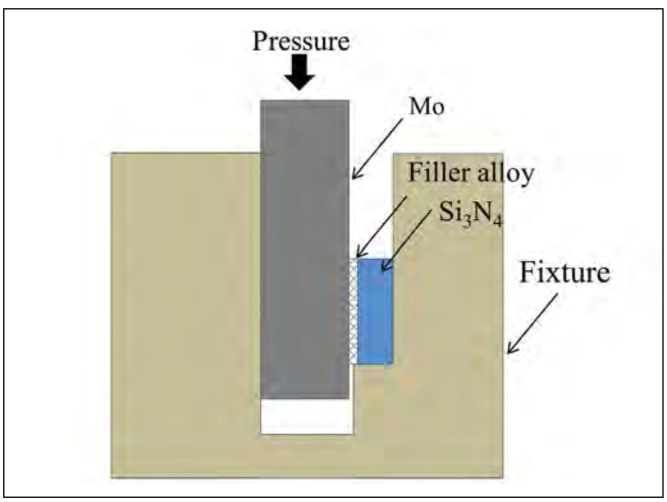


Fig. 3 — Schematic diagram of the shear test specimen.

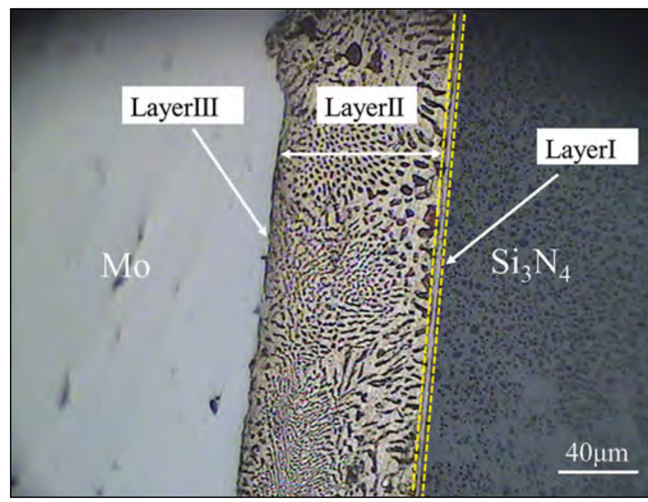


Fig. 4 — Metallographic microstructure of the Si_3N_4/Mo joint.

Table 1 — Main Properties of Ceramics and Molybdenum (Mo) at Room Temperature

Material	Modulus of Elasticity (GPa)	Thermal Expansion Coefficient ($10^{-6}K^{-1}$)	Melting Point (°C)	Thermal Conductivity (W/m·K)	Density (g·cm^{-3})
Si_3N_4	300	3.4	–	80	3.2
Mo	330	5.35	2617	138	10.2

Table 2 — The Main Performance of Ag-27Cu-3.3Ti

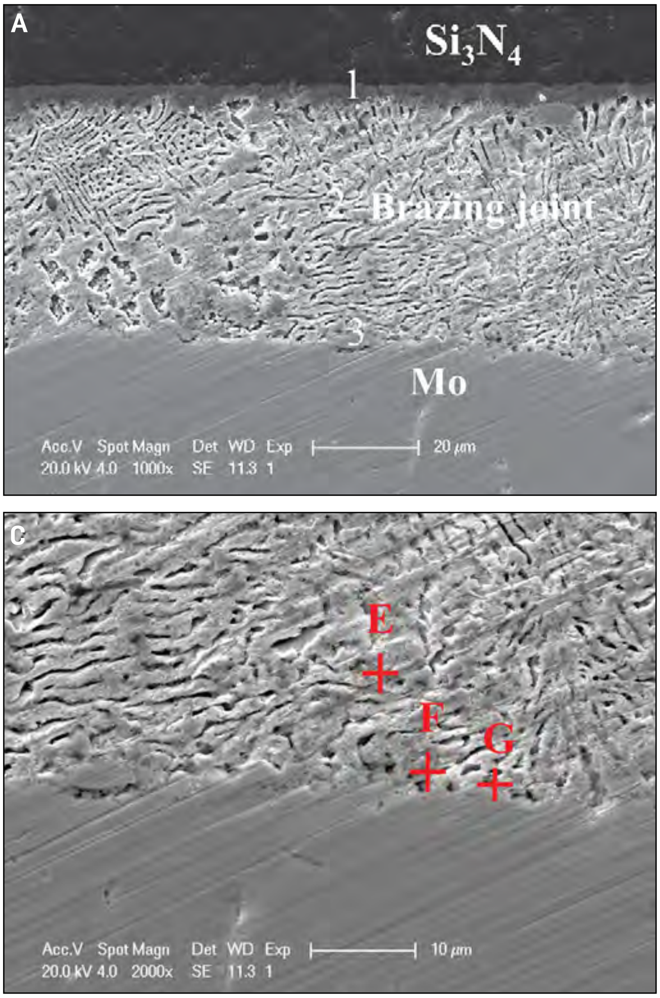
Material	Ingredient (wt-%)	Melting Point (°C)	Thickness (µm)
Ag-Cu-Ti foils	69.7Ag + 27Cu + 3.3Ti	780 ~ 805	100

Si_3N_4, with a density of 3.2 g/cm^3, were supplied by Shanghai Institute of Ceramics, Chinese Academy of Sciences. The Si_3N_4 and Mo samples gave the dimensions of $6 \times 6 \times 1$ and $9 \times 6 \times 6$ mm^3, respectively. The filler metal of 100 µm Ag-27Cu-3.3Ti wt-% foil was processed into a square sheet with a side length of 6 × 6 mm^2 as the faying surface of the joint. The properties and performance of the base materials and filler are shown in Tables 1 and 2.

Joining Process

The joining surfaces of the Mo and Si_3N_4 samples were treated by polishing with a #400 sandpaper followed by ultrasonic cleaning in acetone for 8 min.

The schematic diagram of the brazed joint is shown in Fig. 1. Vacuum brazing of Mo to Si_3N_4 was carried out in a MOV-443-type furnace under a vacuum of 2.0×10^{-4} Pa. The



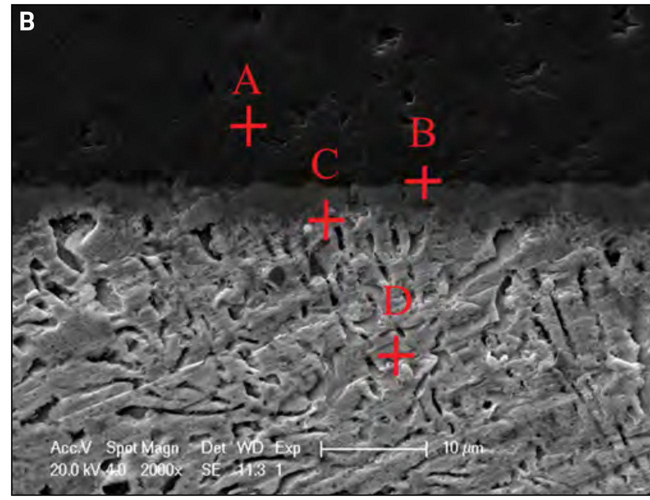


Fig. 5 — Secondary electron imaging of brazed Si_3N_4/Mo joints brazed at 900°C for 10 min: A — Overall morphology; B — Si_3N_4/Ag-Cu-Ti interface area; C — Ag-Cu-Ti/Mo interface area.

temperature curve is shown in Fig. 2. The assemblies were heated from room temperature to 300°C at a rate of 20°C/min and held for 10 min. Subsequently, they were heated up to 900°C at a rate of 10°C/min. After holding for 10 min at the brazing temperature of 900°C, the assemblies were forced to cool to 300°C at a rate of 5°C/min with argon. Finally, the joint cooled with the furnace-to-room temperature in vacuum. During brazing, a self-made fixture was used to apply a certain pressure to prevent the sample from moving when the brazing material melted.

Microstructural Characterization

After brazing, the sample was first embedded by a cold inlay method. Then, the connection surface was polished with different grades of metallographic sandpaper, and the brazed joint was etched by mixed acid (HCl: HNO_3: H_2O = 2:1:3) to facilitate the observation of the metallographic structure under a VHX-500F digital microscope. Before observation, the surface of the joint was wiped with absolute ethanol. Metal salt produced during the etching process can be dissolved in water without introducing other impurities.

The interfacial zones of Si_3N_4/Mo joints were characterized by a XL30FEG SEM equipped with an energy dispersive spectrometer (EDS). The phase identification of the interfacial zones in the joints was conducted by a D8 ADVANCE XRD spectrometer (choose Cu Kα radiation, set current to 40 mA, set acceleration voltage to 40 kV, and set scan speed to 10°C/min).

The microhardness test for the Si_3N_4/Mo joint was performed with a HV-1000 microhardness tester. The test pressure at the weld was 25 gf; the test pressure at the Mo and ceramic sides were 100 and 500 gf, respectively; and the holding time was 15 s. The shear strength was performed by a WDW-10 universal testing machine at a constant speed of 0.5 mm/min. Figure 3 shows the shear test specimen used in this experiment.

Results and Discussion

Brazing Joint Morphology

Figure 4 shows the metallographic microstructure of the Si_3N_4/Mo joint brazed with the Ag-Cu-Ti filler at 900°C for 10 min. It can be seen that the filler had good contact with the base materials on both sides, and there were no obvious cracks or holes in the joint. Between Si_3N_4 and the Ag-Cu-Ti filler, there is a gray interfacial reaction Layer I with a thickness of about 3.8 µm, indicating that the filler reacted with Si_3N_4. Layer II is part of the Ag-Cu-Ti filler, mainly composed of a dark and large, light-colored phase. At a high temperature, the filler melted and overflowed to both sides, making the thickness of the intermediate layer slightly lower than the original thickness of the filler. Layer III is the interface layer of the Ag-Cu-Ti/Mo.

Typical Interfacial Microstructure of Mo/Ag-Cu-Ti/Si_3N_4 Brazed Joints

Figure 5 is the secondary electron imaging diagram of microstructure morphology of the Si_3N_4/Mo joint, and Fig. 5B and C is a magnified micrograph of regions 1 and 3, respectively. Region 1 is the transition reaction layer between Si_3N_4 and the Ag-Cu-Ti filler. From region 2, it can be seen that the middle filler layer is a eutectic structure, and region 3 is a relatively

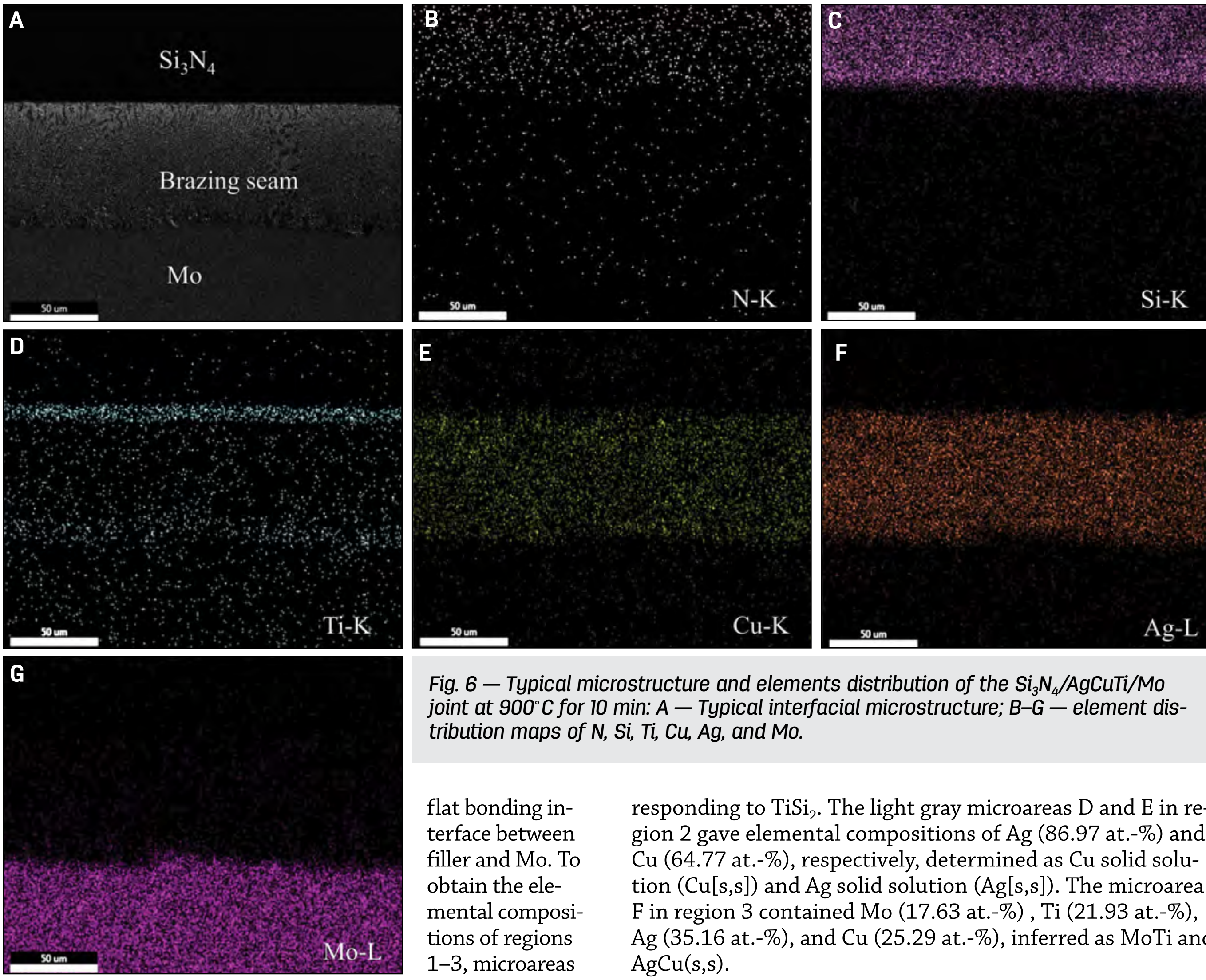


Fig. 6 — Typical microstructure and elements distribution of the Si_3N_4/AgCuTi/Mo joint at 900°C for 10 min: A — Typical interfacial microstructure; B–G — element distribution maps of N, Si, Ti, Cu, Ag, and Mo.

flat bonding interface between filler and Mo. To obtain the elemental compositions of regions 1–3, microareas A–F were measured by an EDS, and the results are given in Table 3.

According to the literature (Refs. 21–23), in the microstructure of the Si_3N_4/Si_3N_4 or Si_3N_4/metal joint brazed with the Ag-Cu-Ti filler, a thin Ti-N layer will be formed on the Si_3N_4 ceramic side and the Ti-Si phase will be formed next to the Ti-N layer. The light gray microarea B in region 1 contained N (41.21 at.-%), Ti (31.97 at.-%), and Si (22.47 at.-%), inferred as TiN and Si. The microarea C located in region 1 consisted of Si (47.61 at.-%) and Ti (22.31 at.-%), corresponding to $TiSi_2$. The light gray microareas D and E in region 2 gave elemental compositions of Ag (86.97 at.-%) and Cu (64.77 at.-%), respectively, determined as Cu solid solution (Cu[s,s]) and Ag solid solution (Ag[s,s]). The microarea F in region 3 contained Mo (17.63 at.-%) , Ti (21.93 at.-%), Ag (35.16 at.-%), and Cu (25.29 at.-%), inferred as MoTi and AgCu(s,s).

Figure 6 presents a back-scattered electron image of the Si_3N_4/Mo joint brazed with the AgCuTi alloy at 900°C for 10 min and the corresponding element distribution maps throughout the joint. It can be seen that during the brazing process, the active element Ti diffused from the middle of the filler to the base materials on both sides, and the Ti content on the Si_3N_4 side was higher than that on the Mo side, indicating that the Ti element diffused toward the Si_3N_4 side. Mo did not diffuse from the base material to the filler and ceramic side.

The phase identification of the interfacial zone in the

Table 3 — Chemical Compositions and Possible Phases of Each Spot Marked in Fig. 5 (at.-%)

Spot	Chemical Compositions (at.-%) Si	N	Mo	Ag	Ti	Cu	Possible Phases
A	55.14	44.86	–	–	–	–	Si_3N_4
B	22.47	41.21	–	00.68	31.97	03.66	TiN + Si
C	47.61	05.17	–	16.65	22.31	08.24	$TiSi_2$
D	03.95	01.19	–	86.97	00.67	07.22	Ag (s,s)
E	–	08.62	03.59	15.58	07.44	64.77	Cu (s,s)
F	–	–	17.63	35.16	21.93	25.29	MoTi + AgCu (s,s)
G	–	–	91.20	08.80	–	–	Mo

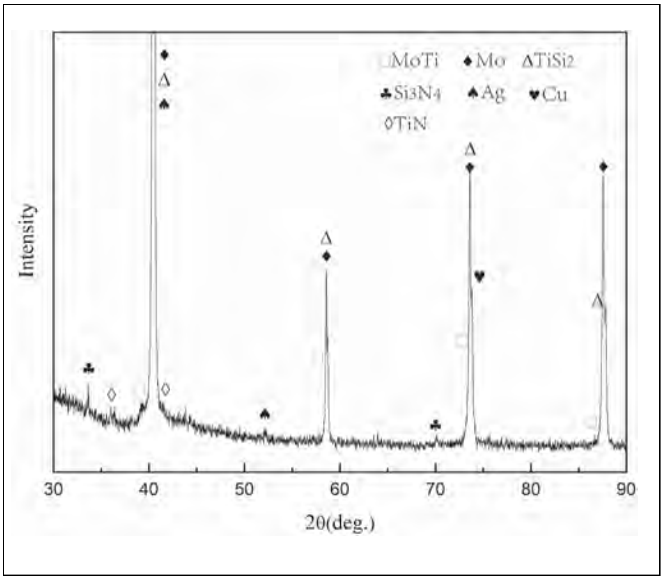


Fig. 7 — XRD analysis of the Si_3N_4/Mo joint.

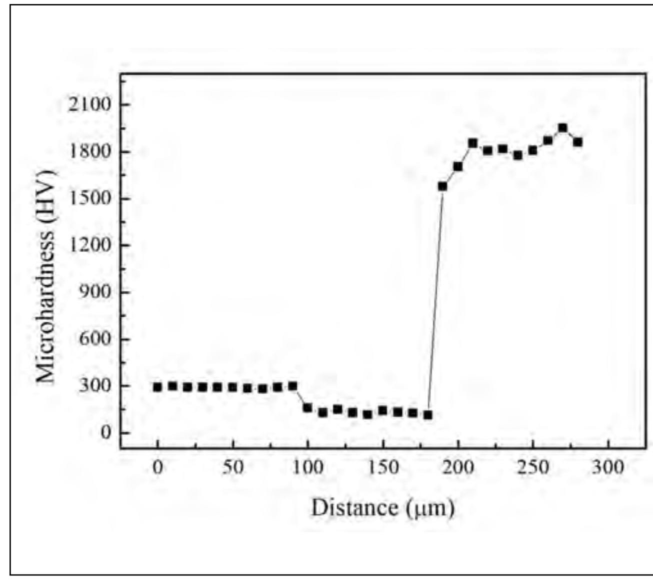


Fig. 8 — Microhardness of brazed joints with different interlayers.

Si_3N_4/Mo joint was performed by an XRD, and the results are shown in Fig. 7. It can be seen that there were TiN, $TiSi_2$, and MoTi solid solutions in the brazing joint. Combined with the analysis of the XRD and EDS results, the interface structure of the brazed joint was indicated as Si_3N_4/TiN + $TiSi_2$/Ag(s,s) + Cu(s,s)/MoTi/Mo.

The microhardness distribution along the Si_3N_4/Mo joint brazed with Ag-Cu-Ti is depicted in Fig. 8. It can be seen from the figure that the microhardness of Mo after brazing was about 300 HV. The average hardness values of the filler layer were lower than those of base materials.

However, the microhardness of Si_3N_4 ceramics was very high, about 1800 HV. During the brazing process, the TiN + $TiSi_2$ compound was formed due to the reaction between Ti and Si_3N_4 ceramic, which reduced the hardness of the reaction layer on the ceramic side, about 1500 ~ 1800 HV, but was still much higher than the microhardness at the brazing seam and Mo. Then, the shear strength of the joint brazed with AgCuTi was 204 MPa at room temperature.

Interface Formation Mechanism of Joint

According to the above analysis, the microstructure formation process of Si_3N_4 ceramics and Mo joints brazed with Ag-Cu-Ti filler can be summarized into several stages, as shown in Fig. 9.

1) During the brazing process, when the heating temperature reached the melting point of the filler, the filler melted transit into a liquid phase, the active Ti element diffused to the base materials on both sides under the driving force of the chemical potential difference, and the Mo element in the metal dissolved into the filler, as shown in Fig. 9A.

2) As shown in Fig. 9B, as brazing proceeded, the Ti element diffused to the ceramic side reacted with the Si_3N_4 ceramic matrix as follows (Ref. 24):

$$1/4Si_3N_4 + Ti = TiN + 3/4Si$$

$$\Delta G^0 \text{ (J/mol)} = -613000 + 40.8T$$

When the temperature reached 900°C (1173 K), TiN began to nucleate in the local region of the ceramic surface, and the generated Si element diffused into the filler under the driving of a concentration gradient. While at the Mo interface, the dissolved Mo element formed a solid solution with the Ti element diffused to the interface.

3) As shown in Fig. 9C, the microstructure of the joint evolved further with the interfacial reaction between the filler and the base materials. At the Si_3N_4/Ag-Cu-Ti interface, the initially formed TiN grains gradually grew and connected to each other, eventually forming a continuous TiN interfacial reaction layer on the ceramic surface. At the same time, the Si element released by the reaction gradually diffused into the liquid filler, and the filler region near the TiN interface reaction layer reacted with the Ti enriched in the interface region as follows (Ref. 24):

$$Ti + 2Si = TiSi_2$$

$$\Delta G^0 \text{ (J/mol)} = -140200 + 5.44T$$

4) In the cooling process after brazing, the high melting point Cu precipitated first, the low melting point Ag precipitated and dissolved certain Ti elements, and finally formed Cu- and Ag-based solid solutions, as shown in Fig. 9D. The microstructure of the joint was Si_3N_4/TiN + $TiSi_2$/Ag(s, s) + Cu(s, s)/MoTi/Mo.

Conclusion

Reliable brazing of Mo and Si_3N_4 ceramic was achieved by using an Ag-Cu-Ti filler. The brazed joints obtained by

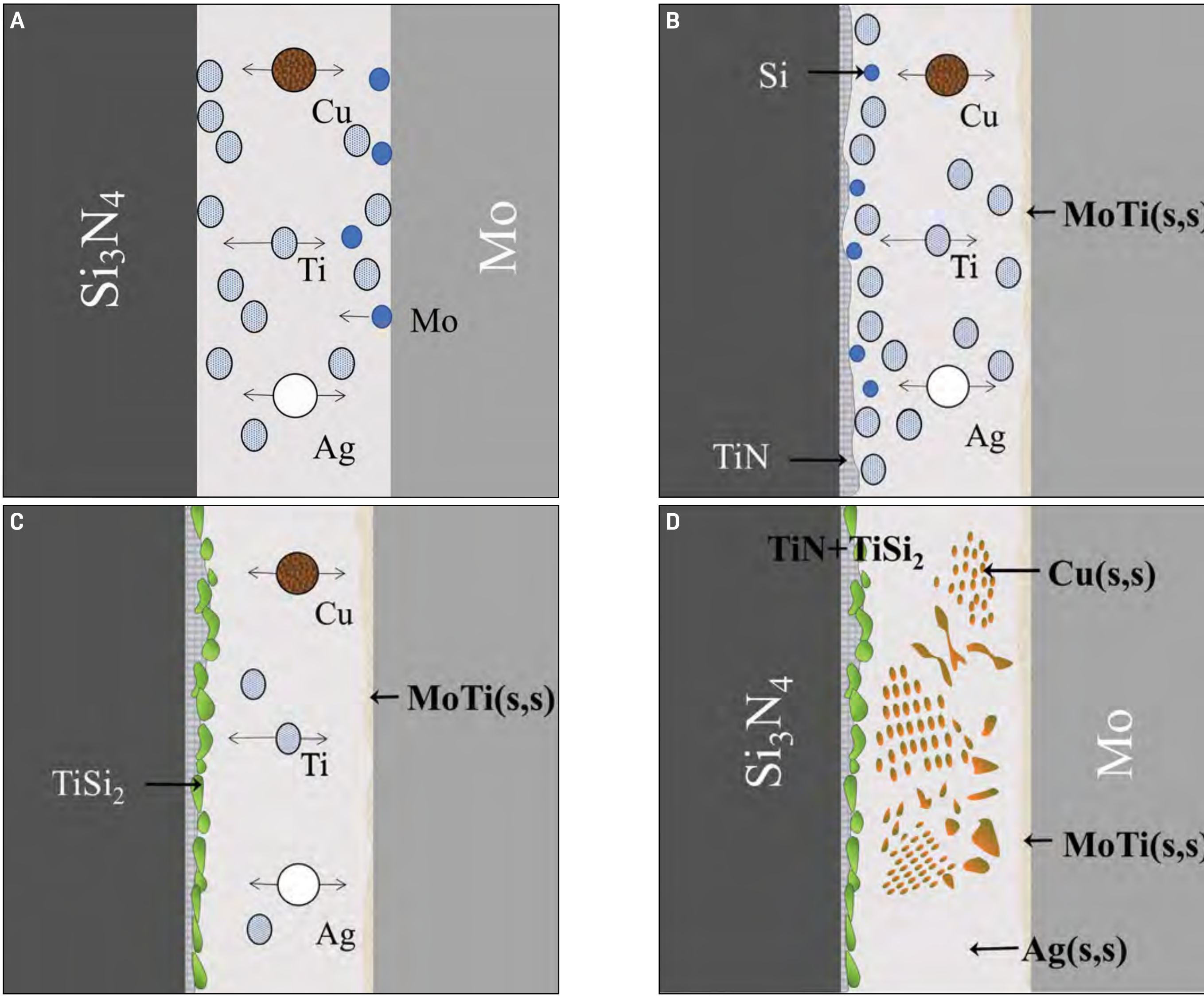


Fig. 9 — Schematic diagram of the formation of the Si_3N_4/Mo joint.

holding 10 min at 900°C were well connected, and there were no holes and cracks at the interface. The interfacial microstructure and joining properties of the Si_3N_4/Ag-Cu-Ti/Mo brazed joint were investigated in this study. Primary conclusions are summarized as follows:

1) The whole brazing joint is mainly comprised of three parts: the interface reaction layer near the ceramic side is composed of TiN and $TiSi_2$, the middle of the brazing joint is Cu-based and Ag-based solid solution, and the formation of MoTi solid solution is near the Mo side. The typical structure of the Si_3N_4/Mo joint is Si_3N_4/TiN + $TiSi_2$ reaction layer/Ag(s,s) + Cu(s,s)/MoTi/Mo.

2) In combination with the composition distribution and data analysis, TiN and $TiSi_2$ compounds are generated on the ceramic side, so the microhardness of the reaction layer on the ceramic side is decreased but still much higher than the hardness of the brazing joint and the Mo base material.

3) The shear strength of the joint brazed at 900°C for 10 min was 204 MPa at room temperature.

Acknowledgments

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α-Ferrite Suppression during Fiber Laser Welding of Al-Si Coated 22MnB5 Press-Hardened Steel

The effect of welding Al-Si coated 22MnB5 steel through a pure nickel coating on the microstructure and mechanical properties of the weld in the hot-stamped condition

BY M. SHEHRYAR KHAN, A. MACWAN, E. BIRO, AND Y. ZHOU

ABSTRACT

During laser welding of an Al-Si coated 22MnB5 steel to produce tailor-welded blanks, the Al-Si coating mixes into the weld and causes the formation of the lower strength ferrite phase dispersed in an otherwise martensitic matrix. It has been shown that the presence of the ferrite phase is the principal reason for premature failure of hot-stamped laser-welded joints. Currently, the Al-Si coating is removed prior to welding, which can be time consuming and costly. This work showed that adding Ni to the fusion zone of laser welded Al-Si coated 22MnB5 steel by welding through a pure Ni coating of a specified thickness, ferrite formation can be suppressed, whereby improving the weld strength and successfully shifting failure from the fusion zone, where it normally occurs, to the base material to achieve 100% joint strength. This work also showed that laser welding Al-Si coated 22MnB5 steel through a Ni coating eliminated the need to mechanically or chemically remove the Al-Si coating prior to welding.

KEYWORDS

- Fiber Laser Welding • Ferrite Suppression
- Tailor-Welded Blanks • Nickel Coating
- Al-Si Coated 22MnB5 • Press-Hardened Steel
- Martensite • Advanced High-Strength Steel

Introduction

The 22MnB5 press-hardened steel (PHS), sometimes known as hot-stamped (HS) steel, is a boron-alloyed ultrahigh strength steel (UHSS), which has the unique characteristic of having an ultimate tensile strength (UTS) of about 600 MPa in the as-received condition but has a fully martensitic microstructure post hot stamping, increasing the UTS to more than 1550 MPa (Ref. 12). Several automotive components such as the A- and B-pillar, bumper, rocker and roof rail, and the tunnel are presently being made from PHS grades. To make the best use of a PHS, PHSs of various strength levels and thicknesses must be joined to produce components with tailored properties (Ref. 11). This is achieved by joining two or more types of sheet metal using laser welding to form a laser-welded blank, also referred to as a tailor-welded blank (TWB). The blank is then HS to form the part with the designed geometry and required properties (Ref. 5). Due to the high temperature that the steel is exposed to during the hot stamping process, it is commonly coated with an Al-Si coating to prevent the formation of oxide scale and provide a strong barrier protection against decarburization (Ref. 4).

The presence of the Al-Si coating poses serious problems during the laser welding of the 22MnB5 PHS, which has been reviewed in detail elsewhere (Ref. 6). During laser welding, the laser will melt the Al-Si coating and the molten coating enters the weld pool, alloying with the fusion zone (FZ) (Ref. 7). As Al is a strong ferrite stabilizer, the increase in FZ Al-content stabilizes the high-temperature delta-ferrite (δ-ferrite) phase, which can be seen by the contraction of the single-phase austenite (γ) region and the expansion of the two-phase (γ + δ) region in the Fe-Al phase diagram leading to a FZ microstructure composed of δ-ferrite islands dispersed in a martensitic matrix (Refs. 10, 13). The presence of the nonequilibrium δ-ferrite in the FZ after welding leads to failure along the fusion boundary (FB) in the as-received welded (ARW) condition (Refs. 3, 13, 14, 15). The suppression of δ-ferrite can be achieved by adding an austenite stabilizing element to the FZ, which improves the mechanical properties of the weld (Ref. 1). Sun et al. showed that suppression of δ-ferrite could be achieved by inserting an interlayer of Ni between the faying surfaces that were then laser welded (Ref. 15). However, the study was limited to the hot-stamped (HS) then welded condition that is rarely used to produce TWBs due to the presence of the heat-affected zone that forms around the FZ, which causes a degradation of the mechanical properties of the material surrounding the weld due to martensite tempering (Ref. 13).

As TWBs made from PHSs are only used in the HS condition, the evaluation of FZ mechanical properties and weld performance has more practical consequences in the welded then HS condition compared to the ARW condition. Therefore, to make the best use of TWBs made from PHSs, the

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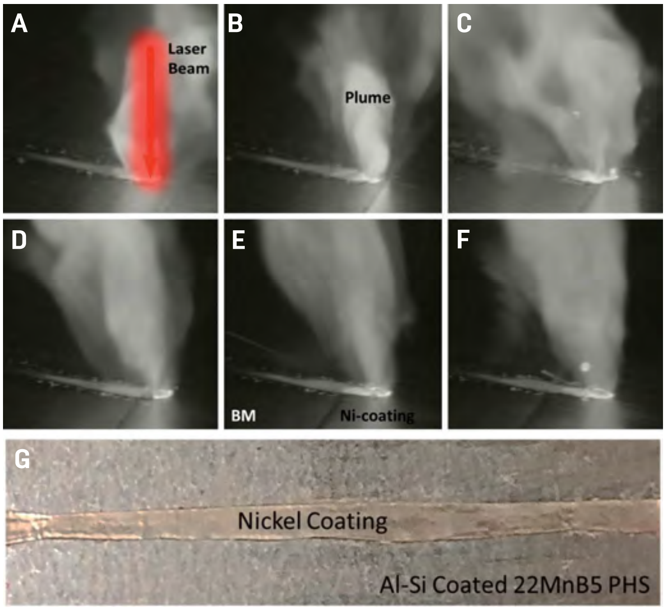

Fig. 1 — Frame-by-frame images of the welding process show the weld being made as the laser traveled from the non-coated substrate (A, B) to the Ni-coated substrate (C–F). The final image (G) shows how the Ni-coating was applied to the Al-Si coated 22MnB5 PHS. The weld was made through the area that is covered by the Ni coating.

steel sheets must first be welded and then HS. This condition is referred to as the as-received-welded then hot-stamped (ARWHS) condition. During the hot-stamping process, the material is heated to a temperature of about 930° to 950°C and held for at least 5 min after which it is quenched in a water-cooled die (Ref. 5). It was shown by Saha et al. that since the material is quenched from a temperature that is between Ac_1 and Ac_3, the high temperature nonequilibrium δ-ferrite transforms to the more stable α-ferrite phase, which is why a relatively uniform distribution of α-ferrite and martensite is obtained in the FZ of the ARWHS condition (Ref. 14). It was also shown by the same author that the ferrite content in the weld increases from about 20% in the ARW condition to about 40% in the ARWHS condition, which suggests that even if complete δ-ferrite suppression is achieved in the ARW condition, it is not a guarantee that complete α-ferrite suppression will be achieved in the ARWHS condition (Ref. 13). This means that an analysis of mechanical properties must be conducted in the ARWHS condition, which will be the focus of the present work.

The current study investigates the effect of welding an Al-Si coated 22MnB5 steel through a pure nickel coating on the microstructure and mechanical properties of the weld in the HS condition. This condition will be referred to as the welded with Ni and then hot stamped (WNHS) condition.

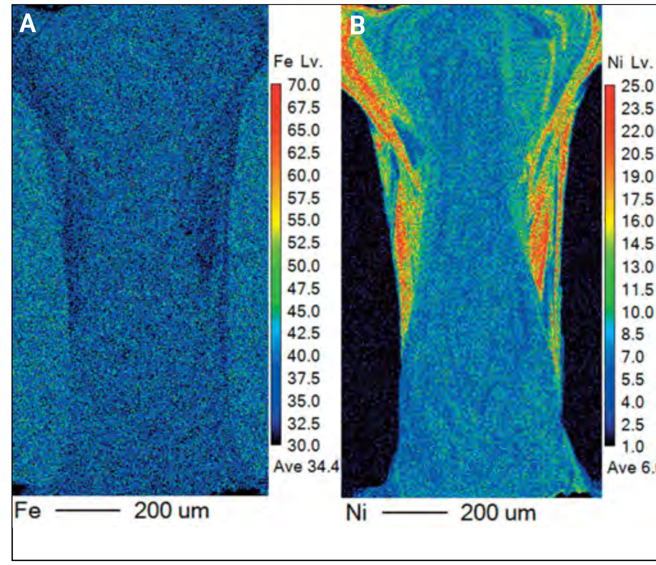

Fig. 2 — EPMA elemental maps: A — Fe; B — Ni showing the dilution of the Ni coating into the FZ for the WNHS condition with the highest concentration of Ni found at the FB, whereas the bulk of the FZ has a more even distribution of Ni content.

The results are compared to the base condition where no nickel coating was used during the welding process. The base condition will be referred to as the ARWHS condition.

Experimental Procedure

This study was carried out on 1.5-mm-thick Al-Si coated 22MnB5 PHS and the base metal (BM) chemical composition is shown in Table 1. Bead-on-plate (BOP) welds were made on 200 × 200 mm sized samples using an IPG Photonics YLS6000 fiber laser mounted to the Panasonic TA1600 six-axis robot. All welds were made perpendicular to the rolling direction of the steel using a laser power of 4 kW (as shown on the laser controller) and a welding speed of 6 m/min with a laser beam diameter of 0.3 mm and a laser defocus of 6 mm, which has been shown to improve the geometry of the FZ (Ref. 19). Further details about the welding system can be found elsewhere (Ref. 20). A 50-μm-thick pure Ni shim was applied to the area being welded using an adhesive, as shown in Fig. 1G. BOP welds were made through the nickel coating as shown by the still images in Fig. 1A–F captured using the XIRIS XVC1000 welding camera at 90 fps. The samples were HS following welding, where they were heated in a furnace for 6 min to an austenitization temperature of 930°C and then quenched using a water-cooled die at a cooling rate of approximately 30°C/s, which resulted in a fully martensitic microstructure in the as-received BM as shown by the high-magnification scanning electron microscope (SEM) images shown in Figs. 5B and 7B.

Table 1 — Chemical Composition of the Base Material Used in the Present Work (in wt-%)

Sample Condition	C	Mn	B	Si	Cr	Ti	Mo	P	Ni	Al	Fe
BM	0.23	1.22	0.0032	0.27	0.20	0.04	0.02	0.01	0.00	0.04	bal.

The FZ and BM microstructure were analyzed using the Clemex Vision Lite image analysis software (v. 8.0.197) to measure the phase concentration (PC) of ferrite and martensite in the FZ. To validate the image analysis results, two separately welded samples for each condition were analyzed. Image analysis for the first set of samples was done for the entire FZ, as shown in Fig. 3. For the second set of samples, three regions of interest located at the FB and the center of the FZ were selected, and image analysis was performed at these regions at high magnification to measure the ferrite and martensite PC, as shown in Figs. 4 and 6. The ferrite PC for these regions was averaged and compared to the first set of samples to verify that the image analysis results were accurate. The Zeiss UltraPlus field emission SEM was used to capture high magnification images of the BM, FB, and FZ to clearly identify the different phases.

Elemental analysis to determine the Al content in the ARWHS condition and the Ni content in the WNHS condition was done using the JEOL JXA-8230 electron probe microanalyzer (EPMA). Hardness was measured using the Clemex CMT (v. 8.0.197) with a 200 gf and a 10 s dwell time. Hardness maps were constructed using OriginPro. Tensile coupons were first cut from the 200 × 200 mm sample using a water jet cutter and then machined to a gauge length of 50 mm in accordance with ASTM E8/E8M, *Standard Test Methods for Tension Testing of Metallic Materials.* Each individual tensile coupon was pulled using the Instron 4206 at a speed of 1 mm/min and an optical extensometer was used to measure the strain. A total of four tensile coupons were pulled for each condition.

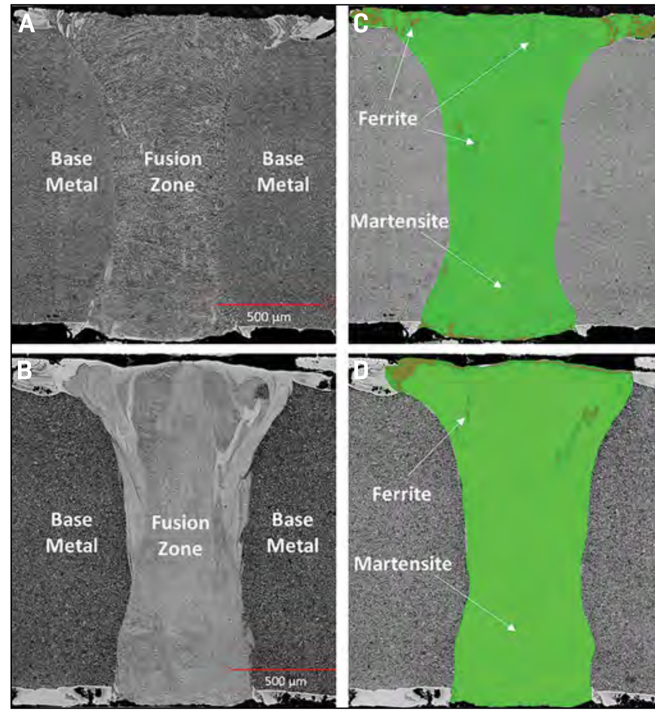

Fig. 3 — Optical micrographs of: A — Weld microstructure with no Ni addition; B — weld microstructure with Ni coating; C, D — image analysis using Clemex Vision Lite showing the PC of ferrite (gray color) and martensite (green color) for both conditions, respectively.

Results and Discussion

Microstructural Analysis

EPMA analysis showed that the FZ of the ARWHS sample had an Al content of 1.02 wt-% with no traces of Ni being found (as shown in Table 2). The local Ni content in the FZ of the WNHS condition ranged from about 1.5 to 15 wt-% and the average bulk Ni content was found to be around 3.5 wt-% due to the dilution of the Ni-coating into the FZ during the welding process. The cross-sectional area of the FZ was measured at approximately 1.16 mm^2 and the cross-sectional area of the applied Ni coating was approximately 0.055 mm^2, which means theoretically if all of the Ni coating was to be diluted into the FZ, a bulk Ni content of about 4.74 wt-% would be expected, which is higher than the measured value of 3.5 wt-%. The low Ni content in the FZ can mainly be attributed to the partial vaporization of the Ni coating when it encounters the laser beam. The partial vaporization can be confirmed by the increase in the size of the vapor plume as the laser goes from the region of the substrate with no Ni coating (Fig. 1B) to the Ni-coated region (Fig. 1C). The elemental map for Fe shows that the concentration of Fe is lower in the FB where the concentration of Ni is the highest as shown in Fig. 2A, B, respectively.

Image analysis was used to identify the PC of each phase present in the weld as shown in Fig. 3. When no Ni coating was used, it was found that the FZ had a ferrite PC of 35.4%, shown by the gray phase in Fig. 3C, and a martensite PC of 64.6%, shown by the green phase. These results are similar to those reported in the literature for phase concentrations of the two phases present in the FZ of the ARWHS condition (Refs. 13, 21). Alternatively, when analyzing the weld using the Ni coating, the ferrite PC was reduced to 4.2% with the remainder being made up of martensite as shown in Fig. 3D and these results have been summarized in Table 3.

To verify the image analysis results shown in Fig. 3, a second set of identical welds were prepared in the ARWHS and WNHS conditions, and the micrographs of the weld cross sections are shown in Figs. 4A and 6A, respectively. Three regions of interest located at the left-side FB, right-side FB, and the center of the FZ (shown as regions b, c, and d in Figs. 4 and 6) were selected so that the microstructure could be observed at higher magnification and image analysis could be performed

Table 2 — Chemical Composition of the Weld Fusion Zone in the ARWHS and WNHS Conditions (in wt-%)

Sample Condition	C	Mn	B	Si	Cr	Ti	Mo	P	Ni	Al	Fe
ARWHS	0.23	1.22	0.0032	0.27	0.20	0.04	0.02	0.01	0.00	1.02	bal.
WNHS	0.23	1.22	0.0032	0.27	0.20	0.04	0.02	0.01	3.52	1.02	bal.

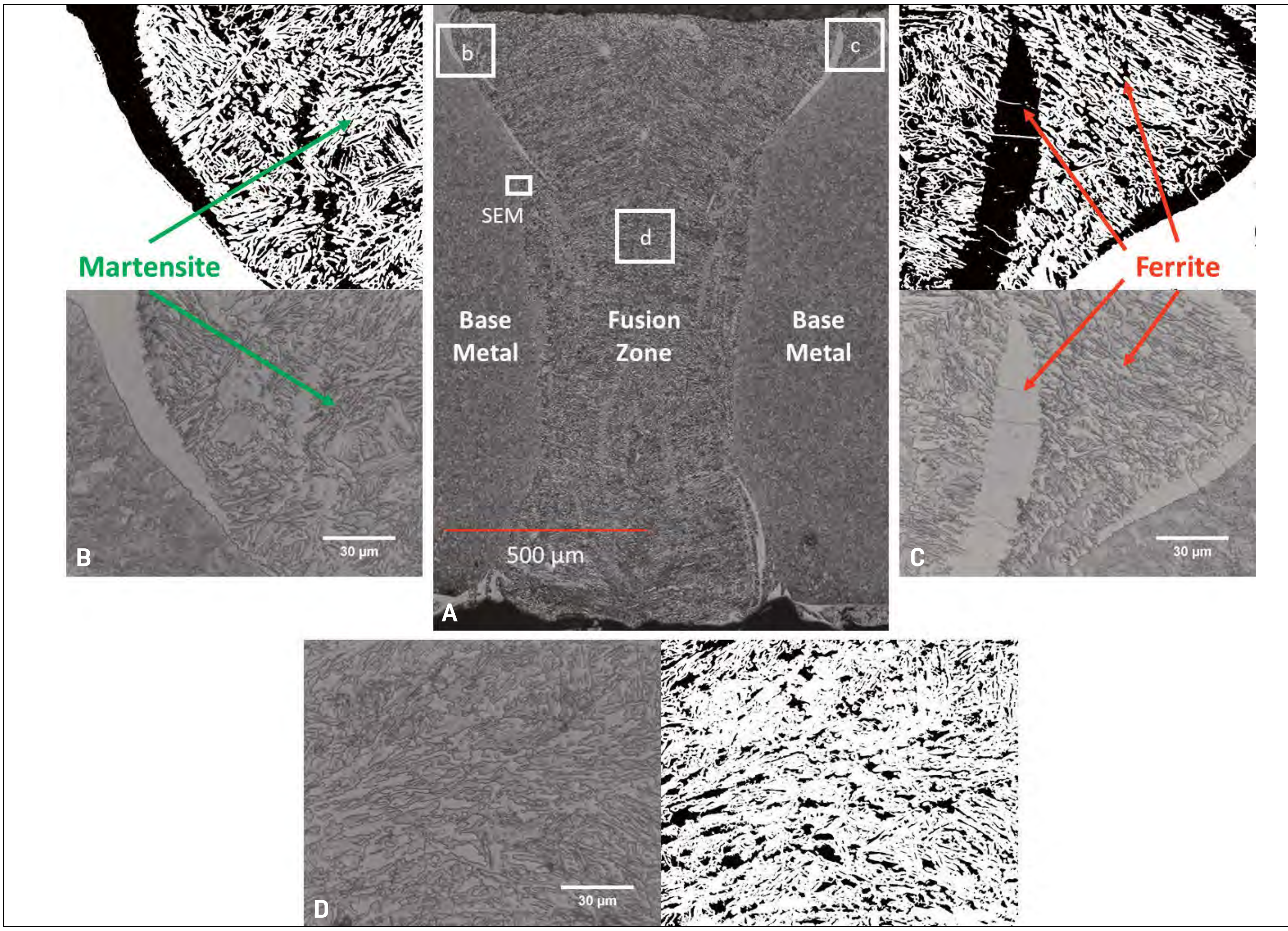

Fig. 4 — Optical micrographs of the: A — Weld microstructure with no Ni addition; B — left-side fusion boundary; C — right-side fusion boundary; D — center of the fusion zone with corresponding images showing the PC of ferrite (black color) and martensite (white color).

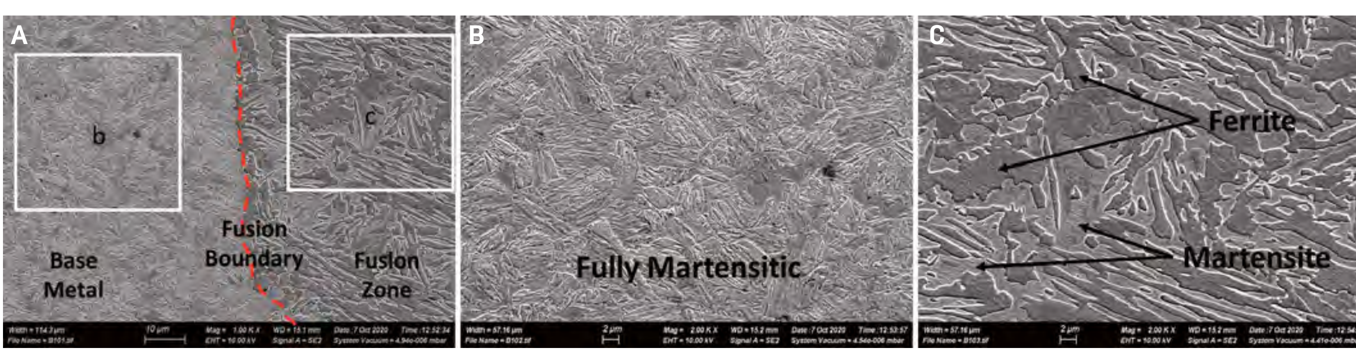

Fig. 5 — SEM images of the: A — Fusion boundary of the ARWHS condition at the location specified in Fig. 4; B — base metal showing a fully martensitic microstructure; C — fusion zone showing the ferrite phase embedded in a martensitic matrix.

for these regions. The measured PC of ferrite for each respective region from the ARWHS and WNHS condition is shown in Table 4. The average ferrite PC for these regions was calculated as 38.1 and 3.0%, respectively, which showed excellent agreement with the image analysis results for the entire FZ as measured for the first set of samples.

High magnification SEM images of the FB region for the ARWHS and WNHS condition are shown in Figs. 5A and 7A, respectively. The SEM images confirm that the BM in both the ARWHS and WNHS conditions were fully martensitic as shown in Figs. 5B and 7B, respectively. However, the microstructure morphology was significantly different for the FZ in the ARWHS and WNHS condition. The FZ in the ARWHS condition is characterized by the darker ferrite islands embedded in a martensitic matrix as shown in Fig. 5C, which is similar to what has been shown in other studies (Refs. 13, 14). The FZ in the WNHS condition was fully martensitic characterized by prior martensite (PM), which formed at the earlier stages of

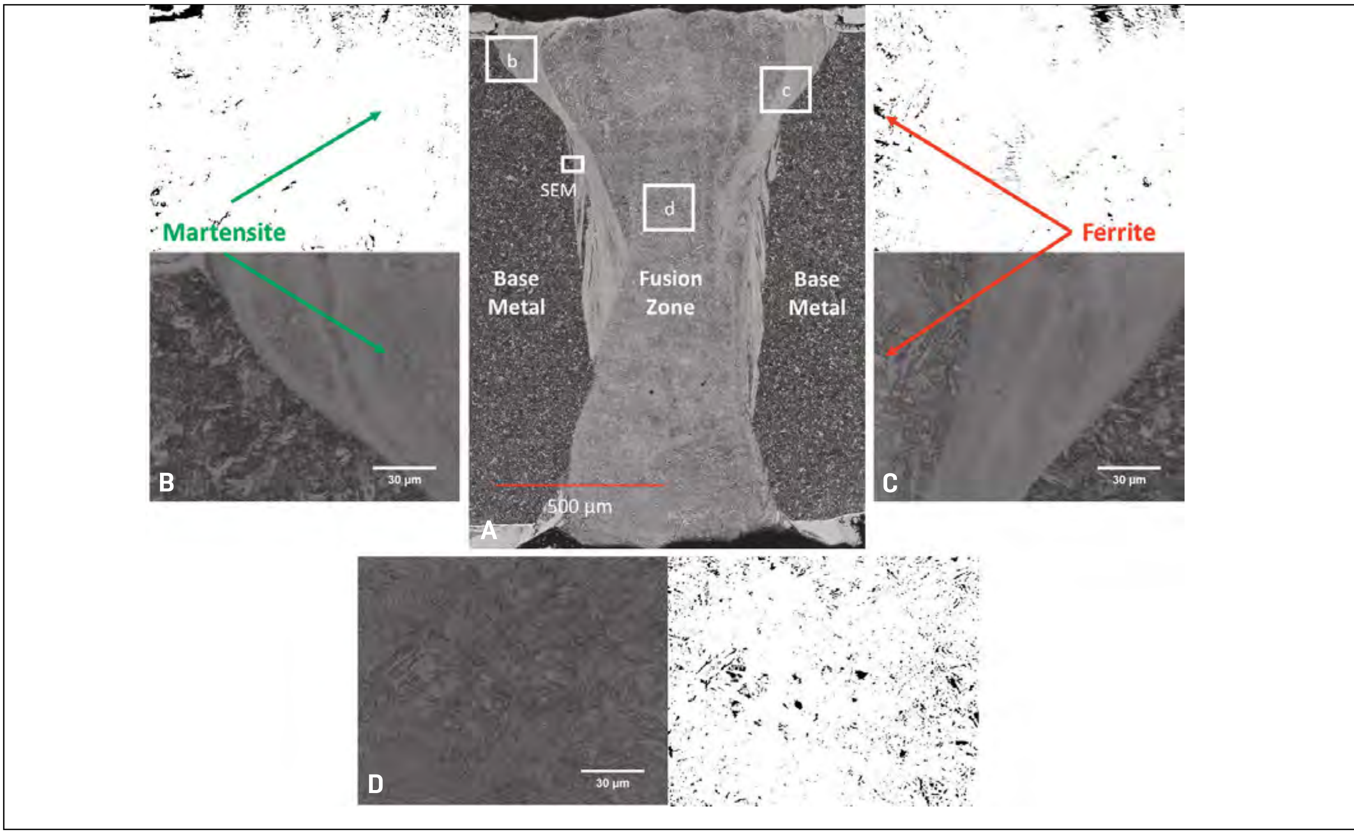

Fig. 6 — Optical micrographs of the: A — Weld microstructure with Ni coating; B — left-side fusion boundary; C — right-side fusion boundary; D — center of the fusion zone with corresponding images showing the PC of ferrite (black color) and martensite (white color).

Fig. 7 — SEM images of the: A — Fusion boundary of the WNHS condition at the location specified in Fig. 6; B — base metal showing a fully martensitic microstructure; C — martensitic fusion zone showing a combination of prior martensite characterized by the darker concave morphology and fresh martensite characterized by the lighter convex morphology.

Table 3 — Summary of the Ferrite PC Found in the ARWHS and WNHS Conditions

Sample Condition	Ferrite PC	Martensite PC
ARWHS	35.4%	bal.
WNHS	4.2%	bal.

the quenching process, and fresh martensite (FM), which formed at a later stage during quenching as shown by Fig. 7C. PM and FM were identified in the microstructure of steels containing Ni by Yao et al. (Ref. 17) who showed that PM had a lower carbon content as it formed at higher temperatures, which gives it better toughness properties compared to FM. Furthermore, they showed that the PM etched easily, was darker, and its microstructural morphology was concave similar to what is shown in Fig. 7C.

Martin et al. confirmed that aluminum is a strong ferrite stabilizer that reduces the size of the single-phase austenite region in the Fe-Al phase diagram (Ref. 10). It was clearly seen that the addition of Ni into the FZ stabilized the austenite phase by expanding the size of the single-phase austenite region as compared to the size of the single-phase

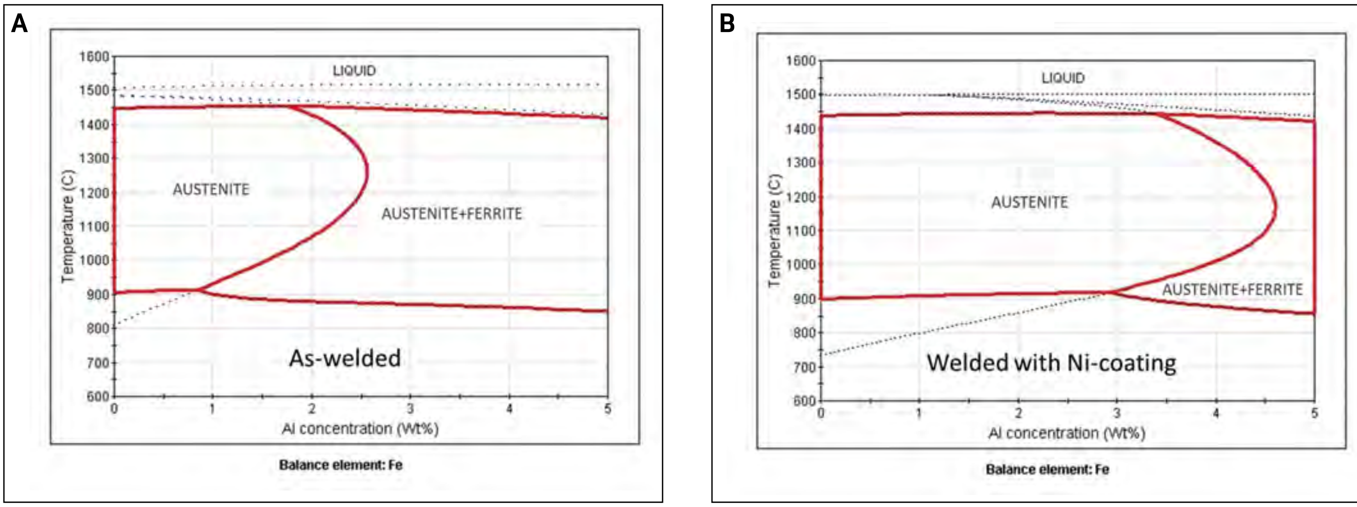

Fig. 8 — Fe-Al phase diagrams generated using JMatPro (v. 11.2) for: A — The ARWHS FZ composition in which there is no Ni, and the arrow is showing that at the austenitization temperature of 930°C, the FZ microstructure is composed of austenite and ferrite; B — the WNHS FZ composition showing the addition of Ni stabilizes the single-phase austenite region thereby increasing the PC of the martensite at the end of the hot stamping process, and the arrow is showing that the FZ microstructure at 930°C is fully austenitic.

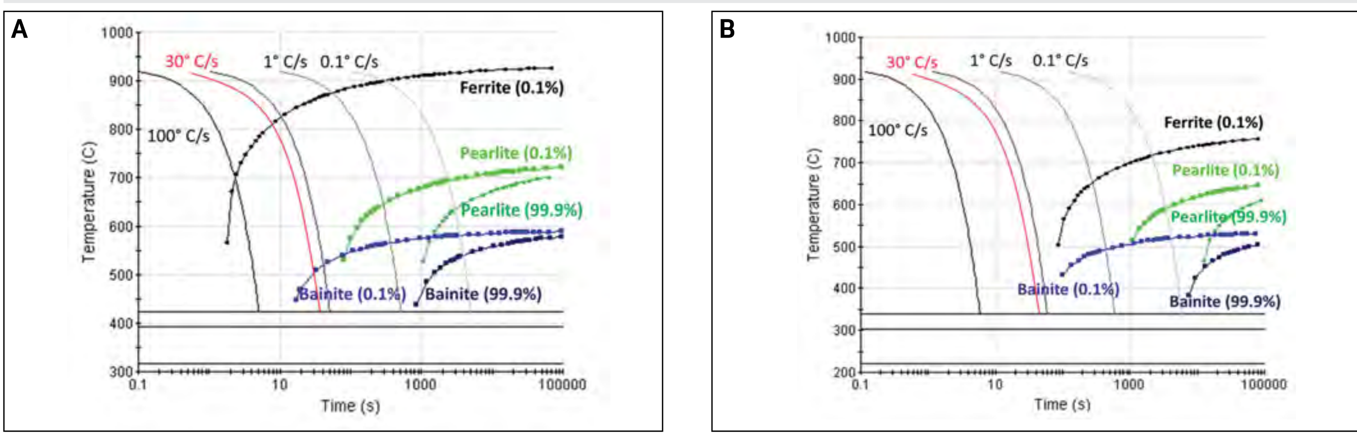

Fig. 9 — Predictive CCT diagrams for: A — ARWHS FZ composition showing that at a 30°C/s cooling rate, the weld microstructure is expected to be a combination of ferrite and martensite; B — WNHS FZ composition showing that the weld microstructure is expected to be purely martensitic at a 30°C/s cooling rate.

austenite region in the Fe-Al phase diagram generated using JMatPro (v. 11.2) for the ARWHS FZ composition as shown in Fig. 8. The increase in the size of the single-phase austenite region ensures that during austenitization at a temperature of 930°C, the FZ microstructure was completely austenitic in the welded with Ni coating condition compared to the dual-phase ferritic and austenitic microstructure observed in the ARW condition, as shown in Fig. 8A. Therefore, it can be said that the addition of Ni into the FZ stabilizes the austenite phase leading to a direct reduction in α-ferrite PC that is observed in the weldment.

CCT curves generated using JMatPro (v. 11.2) predicted that at a cooling rate of about 30°C/s, the microstructure of the FZ in the ARWHS condition would be a mixture of ferrite and martensite as shown in Fig. 9A, which agrees with the PC results shown in Tables 3 and 4. Conversely, the CCT diagram for the FZ of the WNHS condition predicted that the weld should have a fully martensitic microstructure, as shown in Fig. 9B. However, the ferrite PC of the FZ in the WNHS condition was shown to be about 3-4% with the remainder being made up of martensite. The small disagreement between the ferrite PC observed in the

Table 4 — Summary of the Ferrite PC Found in the ARWHS and WNHS Conditions Measured Using Image Analysis for Three Distinct Regions of Interest at High Magnification

Sample Condition	Ferrite PC Region b	Ferrite PC Region c	Ferrite PC Region d	Average Ferrite PC	Martensite PC
ARWHS	43.3%	49.5%	21.5%	38.1%	bal.
WNHS	2.2%	2.1%	4.8%	3.0%	bal.

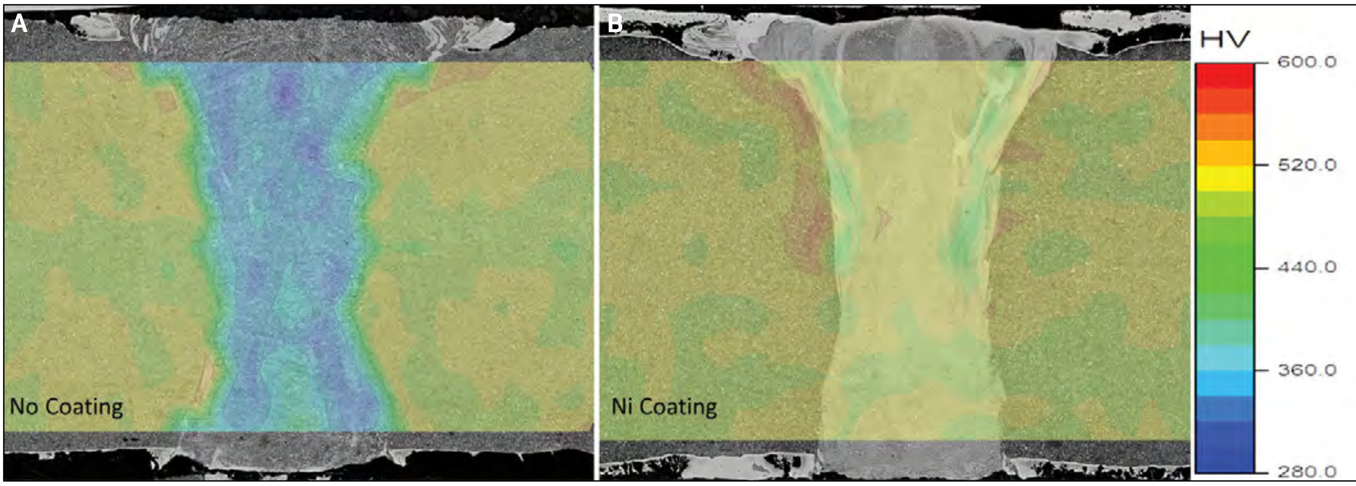

Fig. 10 — Hardness maps for: A — BM and FZ of the ARWHS condition showing a significantly softer FZ as compared to the BM; B — BM and FZ of the WNHS condition showing that the average FZ hardness is the same as that of the BM.

image analysis results and the CCT diagram can be explained by recognizing that the CCT diagram has been generated for a fixed bulk material chemical composition while, in reality, the local chemical composition in certain parts of the FZ may be different than the bulk chemical composition. For this reason, very small amounts of ferrite may still be found in the FZ. The CCT diagrams can be used in conjunction with the Fe-Al phase diagrams to confirm that as the Ni content in the weld increases, the α-ferrite PC decreases, leading to an almost fully martensitic microstructure in the FZ upon cooling.

Mechanical Properties

As the α-ferrite content in the weldment significantly lower in the WNHS condition compared to the ARWHS condition as determined by the image analysis, the difference leads to an observable effect on the mechanical properties of the weld. To generate hardness maps as shown in Fig. 10, 299 microhardness indents were made in the BM and FZ of the ARWHS and WNHS conditions. The BM hardness was measured at about 500 HV, which falls within the range reported in previous research (Refs. 9, 13, 18). The average FZ hardness for the ARWHS condition was measured at about 350 HV, which was significantly lower than the BM hardness as shown in Fig. 10A, which agrees with the data reported in the literature and showed that the difference in hardness was due to the presence of α-ferrite (Refs. 13, 21). However, due to the reduced ferrite PC in the FZ of the WNHS condition, the average hardness was measured to be around 500 HV, which is the same as the BM hardness.

Due to the high-ferrite PC present in the FZ and the relatively lower hardness, the weld strength in the ARWHS condition was measured at about 1276 ± 11 MPa and sudden fracture was observed in the FZ, which agrees with the literature (Refs. 3, 8, 9, 13). However, due to the reduction in ferrite PC and the subsequent improvement in FZ hardness, the UTS for the WNHS condition matched that of the BM at around 1562 ± 5 MPa and failure in these samples occurred in the BM with the crack propagating on an angle showing the plane of maximum shear stress as shown in Fig. 11.

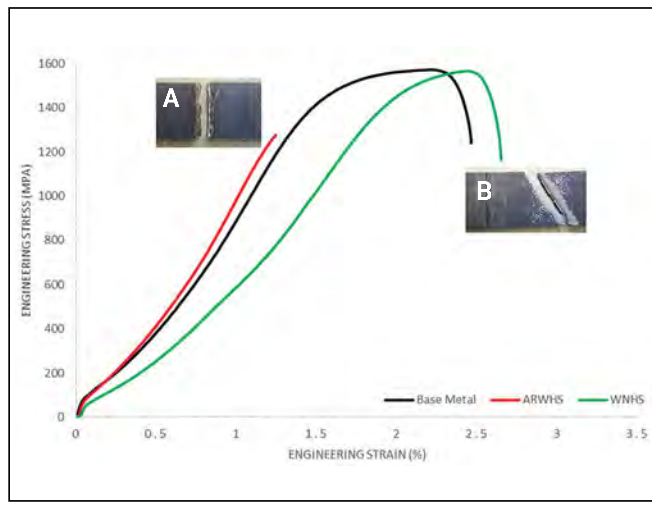

Fig. 11 — Flow curves for the hot-stamped BM, ARWHS condition, and WNHS condition with inserts showing: A — The failure location of the ARWHS samples along the FB due to the high PC of α-ferrite present in the FZ; B — the failure location of the WNHS samples in the BM.

Conclusion

By welding an Al-Si coated 22MnB5 PHS through a pure Ni coating followed by a hot stamping process, the strength of the welds was increased to that of the hot-stamped BM, and the failure location was shifted from the FZ to the BM. Prior to welding, a 50-µm Ni shim was applied using an adhesive to 1.5-mm-thick Al-Si coated 22MnB5 steel, and fiber laser welds were then made through the Ni coating. This condition was compared to that in which welds were made with no Ni coating applied as well as the nonwelded BM and all the samples were hot stamped using identical conditions. It was found that by welding Al-Si coated 22MnB5 steel through a Ni coating, the Ni content in the weld can be increased, which suppresses the formation of α-ferrite. This improved the hardness and the UTS of the FZ to match that of the BM.

Therefore, it can be concluded that the aforementioned method can be used to improve the mechanical properties of Al-Si coated TWBs without requiring the prior removal of the Al-Si coating by mechanical, chemical, or laser ablation methods which can be costly and time consuming.

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