Plasma Arc Cutting
Critical Evaluation of Pipe Welds
Friction Stir Welding Spherical Parts
Bonus: The American Welder

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On the cover: An apprentice at Southern Alberta Institute of Technology, Calgary, Canada, practices gas tungsten arc welding on stainless steel. (Photo courtesy of Miller Electric Mfg. Co., Appleton, Wis.)
Enforcement Procedures for Hexavalent Chromium Standards

The U.S. Occupational Safety and Health Administration (OSHA) has issued a new compliance directive for occupational exposure to hexavalent chromium (Cr(VI)) that provides guidance for enforcement of the final rule on hexavalent chromium standards. The directive, OSHA Instruction CPL 02-02-074, Inspection Procedures for the Chromium (VI) Standards, became effective Jan. 24, 2008. The Cr(VI) standards were originally published in the Feb. 28, 2006, Federal Register.

The Cr(VI) standards, which lower the permissible exposure limit for hexavalent chromium to 5 micrograms of Cr(VI) per cubic meter of air as an 8-h time-weighted average, are applicable to general industry, construction, and shipyards (Sections 29 CFR 1910.1026, 29 CFR 1926.1126, and 29 CFR 1915.102, respectively). Highlights of the new Cr(VI) directive include procedures for reviewing an employer’s air sampling records to determine exposure levels; guidance on how employers can implement effective engineering and work practice controls to reduce and maintain exposure below approved permissible exposure limits; requirements for employers to provide hygiene areas to minimize employees’ exposure to Cr(VI); guidelines requiring employers to maintain exposure and medical surveillance records; and a requirement that Compliance Safety and Health Officers (CSHOs) evaluate portland cement wherever it is being used.

The standards became effective May 30, 2006. Employers with 20 or more employees were given six months from the effective date to comply with most of the provisions. Employers with fewer than 20 employees were allowed 12 months from the effective date to come into compliance with most of the provisions. All employers were given four years from the effective date to install feasible engineering controls.

Stimulus Legislation Benefits Businesses

The Economic Stimulus Act of 2008, signed into law in early February, has two provisions that may be beneficial to businesses. First, the legislation gives companies a 50% bonus deduction on new equipment that would normally be depreciated over many years, and, second, the law increases — to $250,000 from $128,000 in 2008 — the limit on expenses that small businesses can deduct from annual income, with a total cap of $800,000.

Companies that purchase less than $800,000 of capital assets in a year now can expense (i.e., deduct currently) the first $250,000 of capital investment, effective for purchases made in 2008 (the prior limits for 2008 were $128,000 and $510,000, respectively).

The new law also includes a new 50% expensing allowance (also known as bonus or accelerated depreciation) that generally applies to capital equipment purchased and placed in service during 2008. This incentive is available to all companies, regardless of the size of their investment.

Under this provision, companies are eligible for a “bonus” first-year depreciation totaling 50% of the cost of the investment and can depreciate the remaining basis of the asset under the regular depreciation rules. Smaller companies get even more of a “bonus.” As described above, they can first take advantage of expensing and then also use the 50% expensing allowance.

Federal Regulations Recommended for Review

Small business owners and representatives have nominated more than 80 federal regulations for review and reform in response to the U.S. Small Business Administration’s (SBA) Office of Advocacy’s Regulatory Review and Reform (r3) initiative. The r3 program is designed to identify and address existing federal regulations that should be revised because they are ineffective, duplicative, or out of date. It is a tool for small business stakeholders to suggest needed reforms. The program includes the process under Section 610 of the Regulatory Flexibility Act for agencies to consider whether their current regulations are still needed, and the degree to which technology, economic conditions, or other factors have changed since their rules were first promulgated. Also, it includes a process by which interested stakeholders can nominate existing regulations for reform, and monitor the progress that agencies make toward achieving those reforms.

The SBA will transmit the Top 10 list to agencies in the spring and will work to ensure that the listed rules will be reviewed and reformed. In order to track agency progress, the recommended reforms will be posted on the SBA's Web site and an update on the status of reforms will be published twice a year. SBA will accept r3 nominations for 2009 from now until Dec. 31.

Paperwork Burden Unfairly Falls on Small Business

Recent hearings before the U.S. House Committee on Small Business concluded that the requirements of the federal Paperwork Reduction Act fall disproportionately on small businesses. In 2007, the Federal Register grew to 70,000 pages, roughly the equivalent of 39 New York City phone books. The committee estimates that the federal regulatory burden translates into approximately $8000 per employee in annual costs.

The Paperwork Reduction Act of 1980 was signed into law to clarify government communications while easing related burdens on U.S. business. The law established the Office of Information and Regulatory Affairs at the Office of Management and Budget, and charged the Small Business Administration with mitigating the impact of federal information requests. Despite this, small firms now spend 15% more time on paperwork than they did just three years ago.

Workplace Injury and Illness Rates at Record Lows

The U.S. Department of Labor reports continued declines in serious workplace injuries and illnesses. The rates for calendar year 2006 were the lowest ever reported. In calendar year 2005, the rate of fatal work injuries was 4.0 fatalities per 100,000 employees. In calendar year 2006, the rate of fatal work injuries was 3.9 fatalities per 100,000 employees. This decreased rate is the all-time low achieved since the Bureau of Labor Statistics instituted its Census of Fatal Occupational Injuries in 1992.
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AWS Names World Engineering Xchange as International Auditor

The American Welding Society (AWS), Miami, Fla., recently announced World Engineering Xchange, Ltd. (WEX), has been engaged as the Society’s international auditing agency, effective immediately.

WEX will be responsible for auditing AWS certification seminars and exams that take place outside of the United States. Additionally, the company will assist AWS’s international certification agencies with the development of strategies to improve and promote AWS interests within the international market.

“We have enjoyed a successful relationship with WEX since it became our fulfillment partner for AWS codes, standards, and other publications,” said Cassie Burrell, AWS deputy executive director. “WEX’s focus on quality, dependable service, first-class representation, and knowledge of our industry make them particularly well suited to take an additional role as AWS’s international auditor. We look forward to working with WEX in all phases of its auditing activities as we continue to expand and enhance our international certification base.”

WEX will conduct ongoing quality control and technical compliance analyses of all AWS international agencies. Also, it will help to maintain open communication streams between AWS and its international agencies while ensuring that AWS best practices and procedures are followed.

Westinghouse Subsidiary Wins Machining and Welding Services Contract

Westinghouse Electric Co. subsidiary WEC Welding and Machining has won a major contract from CalEnergy, Calipatria, Calif., a large geothermal power producer, to complete the 2507 Superduplex Pipe Replacement Project. Its Carolina Energy Solutions (CES) will provide all machining and welding services for the assignment.

Specifically, CES will provide orbital welding of 2507 superduplex stainless steel utilizing 686CPT Inconel™ filler material for the replacement of the customer’s existing carbon steel pipeline. The 14,000-ft-long pipeline will require more than 600 welds. The project will last approximately four months.

CES met the stringent weld properties established by CalEnergy for this project by repetitively producing 100% flawless welds.

Kobe Steel to Establish Welding Company in China

Kobe Steel, Ltd., plans to establish a company to produce welding materials in Qingdao, Shandong Province, China. It will make flux cored welding wire for welding carbon steel used in shipbuilding.

The joint venture, called Kobe Welding of Qingdao Co., Ltd., will be formed this month. Production is scheduled to begin in April 2009. The plant will have a capacity of 1000 metric tons per month.

The new company will employ about 90 people and be capitalized at about $29 million.

Alcoa Completes Modernization Project in Hungary

Alcoa has completed a $83 million modernization investment project at Alcoa-Köfém, its operations in Székesféhérvár, Hungary. The project began in November 2005.

The core of the investment is the modernization of Alcoa European Mill Products, involving expanding brazing sheet capability to offer a full range of gauges.

Lincoln Electric Forms Agreement with Petty Enterprises

The Lincoln Electric Co., Cleveland, Ohio, recently formed a team-supplier agreement with Petty Enterprises, a two-car team with Kyle Petty driving the #45 Marathon Dodge and Bobby Labonte driving the #43 Chevys/Betty Crocker Dodge.

Lincoln is supplying the team with a full range of welding and cutting equipment, technical training, and welding application support. The program will also help ensure the team maintains a high standard of safety, weld integrity, and performance both on the track and in the shop.
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The Hands-on Experience: Is It Losing Its Touch?

There was once a vision that we would become a paperless society. That template never quite materialized, but we have moved a lot closer to its fulfillment with many business and consumer transactions taking place electronically without a piece of paper in sight. The question that now looms is “will we become a printless society?” Will there be a time when a printed periodical is as obsolete as atomic hydrogen welding? Will there be a time when picking up the Welding Journal, flipping through its pages and resting comfortably to read what interests you will be as archaic as a 1000-lb welding machine?

Four years ago, I would have said, “You’re crazy.” Three years ago it was “Never.” Two years ago I’m thinking, “Could it really happen?” Today, I see where reading publications online is a foregone conclusion. I’m still old school enough to think that the tactile “hands-on experience” still has appeal when it comes to reading the Welding Journal. Picking it up, sensing something of substance in your hands, feeling the texture of the page and hearing it rustle as it’s turned, carrying the whole of it to wherever you want, all have an allure that is not quite dead. But, then again, I also think, “Am I kidding myself?”

For someone who has used a slide rule and has had a large chunk of his life unadulterated by personal computers, I may not be the best in gauging what a generation that has never been without the Internet might want. There is an age group that is used to getting all its information from the Web, and who see anything not accessible electronically as “old generation,” and to be avoided. Text messaging, blogs, podcasts, webinars, vlog, YouTube, all have become a common means of obtaining information in our evolving society. The pace of information access and the technology to deliver it are moving at mach speed. So it might not be so unbelievable that one day all periodicals will be read online and that printing will be obsolete.

Today, now, this minute, I still think a print publication is desirable and will be around for many years, but I am not ignorant of the multiple advantages a digital version of the Welding Journal offers. For one, it is immediate — no waiting for delivery, no uncertainty of its availability. The digital page offers instant links to related information, is searchable, archiveable, incorporates animation and video, and the list goes on and on.

That is why I am investigating new ways to offer the Welding Journal in digital form with all the unique features it affords. One of the core competencies of the American Welding Society is the dissemination of information and knowledge, and my goal is to do that with the Welding Journal in the most efficient way possible. The present printed Welding Journal will remain the stalwart member benefit, but the future is a multimedia platform of presentation.

Excuse me now while I find a nice cozy corner and a comfortable chair to sit down in and read my BlackBerry®.
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The Mobile Weld Training Center (MWTC), created by the New England School of Metalwork (NESM), can be delivered to a training site and be ready for instruction in ten minutes. In operation since October 2007, the center currently services northern New England (Maine, New Hampshire, and Massachusetts), but the school is hopeful it may be able to expand into more areas.

The school established the center because it wanted to increase the availability of weld training to its clients and introduce welding to high school and nontraditional students thinking of different career choices. Also, the NESM can promote welding by visiting schools with the center and giving hands-on demonstrations to students during career days.

“We have built a tremendous amount of flexibility into the MWTC. Our basic training includes shielded metal arc welding, gas metal arc welding, flux cored arc welding, and gas tungsten arc welding on a variety of materials. By switching power sources, instruction can incorporate such features as high frequency and pulse. Arc gouging, oxyfuel, and plasma have also been taught in the MWTC,” said Warren Swan, welding director, NESM. “In addition, the booths can be removed to demonstrate a large piece of welding or cutting equipment. The 82-kW generator that sits in the front of the trailer provides all of the power we need for any of these applications.”

The eight-booth self-contained unit is outfitted with up-to-date equipment. It further features a welding fume extraction system; heat and air conditioning; and a classroom. It also offers customized weld, safety, and gas apparatus training; welder qualification; and welding procedure specifications developed in accordance to specific code.

Approximately 350 individuals have utilized the center since it opened. So far, a large percentage has been high school students participating in career days, women exploring the welding trade as an occupation, or individuals attending trade shows promoting the welding field. The remaining percentage have been employees of companies requesting training for a specific process or application. This instruction has ranged from a two-day seminar in gas tungsten arc welding to an intensive two-week program designed for a local contractor that needed to increase the skills of its employees in welding open root pipe.

The ages represented by students of the center follow what the school has seen at its Auburn, Maine, and Hooksett, N.H., locations. Area schools are sending students during career days ranging from 14 to 19 years old, and employees sent by companies for training can be anywhere from 20 to 60 plus years old.

“The school is extremely pleased with all of the positive comments from people who have spent time with us training in the MWTC,” added Swan. For more information, contact Swan at wswan@newenglandschoolofmetalwork.com.
Weldmex Attracts a Crowd

Weldmex, the only exhibition in Latin America devoted totally to welding, is growing in popularity if the most recent show held in Mexico City Jan. 29–31 is any indication. Net exhibit space increased by 5000 sq ft from the 2007 show to a record 22,000 sq ft in 2008. The 6100 attendees who visited the 240 exhibitors were the highest number in the show’s five-year history.

American Welding Society (AWS) President Gene Lawson and Vice President John Mendoza attended the event. Lawson took part in the opening ceremony welcoming the attendees.

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The American Welding Society purchased controlling interest in the show prior to the 2008 exhibition, and the Society will be marketing it and selling exhibit space. Trade Show Consultants, the Society's partner, will manage the show for the next five years. The Society and its publications fulfillment partner WEX Ltd. both had booths at the show, and there was strong interest in AWS publications, membership, and certification products.

The next Weldmex is scheduled for June 2–4, 2009, in Monterrey, Mexico.

**Robotic Hybrid Laser-Gas Metal Arc Pipe Welding Demonstrated**

At the recent meeting of the National Shipbuilding Research Program’s SP-7 Welding Technologies Panel, held at General Dynamics (GD) NASSCO Shipyard in San Diego, Calif., a robotic hybrid laser-gas metal arc (GMA) pipe welding system was demonstrated. This capped an effort funded by the Office of Naval Research through the Center for Naval Shipbuilding Technology to develop the technology. The project team consisted of the Applied Research Laboratory, Pennsylvania State University; GD NASSCO; and Wolf Robotics.

It was the first qualification of hybrid laser-GMA welding by the American Bureau of Shipping in the United States; first demonstration of hybrid welding in a U.S. shipyard; first production components hybrid welded in a U.S. shipyard; and first hybrid welded components installed on a U.S. ship.

The hybrid process was developed for this application and qualified by the American Bureau of Shipping for a wide range of pipe schedules in this project. A system to realize this application was specified, designed, built, and implemented, and subjected to a seven-month evaluation on the production floor. Numerous production pipe spools were manufactured using the system as well.

**AWS Calls for Nominations for Sixth Annual Image of Welding Awards**

The American Welding Society (AWS), Miami, Fla., and the Welding Equipment Manufacturers Committee (WEMCO) seek
nominations for the Sixth Annual Image of Welding Awards. The winners will be announced at the Image of Welding Awards Ceremony to be held during the FABTECH International & AWS Welding Show Oct. 6–8 at the Las Vegas Convention Center in Las Vegas, Nev.

The awards categories are as follows: Individual; Section (AWS local Section); Large Business (200 or more employees); Small Business (less than 200 employees); Distributor (welding products); Educator; and Educational Facility. All individuals, organizations, and groups may be nominated for multiple categories.

WEMCO will judge the nominations. Deadline for submissions is June 15. To nominate an individual, group, or organization for an award, send a written description of the nominee’s qualifications and contact information, along with your name, phone number, e-mail, and mailing address, to Adrienne Zalkind at azalkind@aws.org, or mail to AWS Image of Welding Awards, 550 NW LeJeune Rd., Miami, FL 33126.

**Welding Metallurgy Subsidiary of Air Industries Wins Contracts**

Air Industries Group, Inc., Bay Shore, N.Y., recently announced its Welding Metallurgy subsidiary has won $1.07 million of new contracts during January.

A majority of the contracts in terms of value was received from the Boeing Co.’s Helicopter division for welding assemblies on the CH-47 Chinook, a multimission, heavy-lift transport helicopter.

The other development based on the contracts awarded is the first purchase order from Sikorsky Aircraft Corp., a subsidiary of United Technologies Corp. The company received a quality supplier approval.

**GraviKor Announces Partnership to Commercialize Military Vehicle Spaceframe Technology**

GraviKor, Inc., Madison Heights, Mich., recently announced a development and licensing agreement with southeastern Michigan-based SpaceForm, Inc., to commercialize advanced vehicle spaceframe technology for security and military markets. The multiyear agreement involves an exclusive field of use license for military vehicles to GraviKor for SpaceForm’s patented deformation resistance welding technology.

During the early product validation stages, the companies will collaborate through SpaceForm’s Detroit-based design studio with engineering and testing occurring at GraviKor locations in Madison Heights and Columbus, Ohio.

**Fleming College to Develop Welding Techniques Program**

Fleming College, Peterborough, Ont., Canada, will offer a new two-semester Welding Techniques program beginning in September. This will provide graduates with the skills needed to obtain well-paying jobs in the welding trade.

Students will learn many welding processes and gain extensive hands-on experience on shielded metal arc, gas metal arc, flux cored arc, and gas tungsten arc welding. Also, basic blueprint reading, trade math, weld symbols, metallurgy, oxyfuel, and plasma cutting will be introduced.
Aluminum lends itself to a wide variety of industrial applications, but because its chemical and physical properties set it apart from other metals, welding of aluminum requires special processes, techniques, and expertise. At this conference, a distinguished panel of aluminum-industry experts will survey the state of the art in aluminum welding technology and practice.
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The American Welding Society established the honor of Counselor to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counselor shall be based on an individual’s career of outstanding accomplishment.

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• Leadership of or within an organization that has made a substantial contribution to the welding industry. The individual’s organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities.

• Leadership of or within an organization that has made a substantial contribution to training and vocational education in the welding industry. The individual’s organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employee in industry activities.

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the Welding Journal. The deadline for submission is July 1, 2008. The committee looks forward to receiving these nominations for 2009 consideration.

Sincerely,

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Q: With the price of gold now above $900 per troy ounce, we are looking for a less-expensive brazing filler metal as a replacement. We are testing BNi-7, and would like to learn the physical properties of this material: tensile strength, yield point, ductility, coefficient of expansion vs. temperature, etc.

A: The physical properties of the brazing filler metal prior to brazing are not relevant since the brazing filler metal, as such, is not the same material found in the joint after the “diffusion brazing” process.

It should be remembered when brazing with pure-gold brazing filler metal that gold is approximately twice as heavy as nickel, and therefore, twice as much gold brazing filler metal, by weight, as nickel filler metal, will be needed to fill the same joint.

To produce high-strength nickel-brazed joints, it is necessary to employ the diffusion brazing process. This process requires holding the brazed assemblies at a suitably high brazing temperature, which allows interdiffusion of the base metal and brazing filler metal to take place. With BNi-7, I recommend 1950°F (1066°C) as the standard brazing and diffusion temperature for 60 minutes at heat.

The diffusion temperature can be decreased or increased as desired. When the brazing temperature is decreased, the time held at the brazing/diffusion temperature must be increased to produce the same results. When the brazing temperature is increased, the time held at the brazing/diffusion temperature can be decreased to produce the same results.

With normal machining and fabricating processes, the joint clearance (gap) can vary considerably. A very useful tool for determining the degree of full diffusion of various clearances (gaps) is the tapered-joint-test specimen. This specimen should be made of the base metal to be used in the final brazed assembly so the diffusion rate with desired brazing filler metal will represent the production brazed assembly.

Two strips of metal, approximately 0.5 × 0.01 × 2–3 in. long (12.7 × 0.254 × 50.8–76.2 mm), are assembled as follows. The two 0.5-in. (12.7-mm) surfaces are placed side by side then tack welded at one end with zero joint clearance, then the opposite ends are tack welded together with a clearance of 0.006 in. (0.162 mm) standard. Larger end-joint clearances may be used if additional investigation is desired.

After brazing, the variable clearance specimen is cut and polished for metallographic inspection. Normally, the zero-clearance joint end will be a single-phase amorphous structure. When moving along the tapered specimen, the single-phase amorphous structure will continue until the maximum full-diffusion (MBC) point is reached. This is the point at which the single-phase amorphous diffusion is complete, and above the center phase where some of the harder original brazing filler metal starts to appear. Continuing farther up the wider clearance, more of the center phase is apparent.

To increase the clearance at the MBC point, it will be necessary to revise the brazing cycle to allow for more diffusion time.

Is diffusion brazing always a requirement? It is definitely not necessary in many cases, and some Japanese brazing shops have demonstrated this over and over again while using vacuum and continuous belt furnaces that can braze stainless steels in 80°F (26.8°C) dew point exothermic atmosphere in continuous furnaces. This is a brazing process that can be tailored to survive many engineering service requirements.

For additional information on diffusion brazing, get a copy of the new and improved AWS Brazing Handbook, 5th edition, revised by the AWS C3 Committee on Brazing and Soldering. Chapter 17 discusses diffusion brazing. One of the more interesting sections is on diffusion brazing of machined, press-fit BNi-7 joints brazed at 1950°F (1066°C). A microphotograph of the completed joints indicates that approximately 50% of the joint is solid base metal and the remaining small pools of brazing filler metal are of a new composition of interdiffusion. This again shows that the original physical properties of the brazing filler metal are not usable.

It is important to require testing of the new joint, to ensure that the brazing process variables are suitable for the intended service requirements.

An interesting paper on the subject is “High-Temperature Brazing of Stainless Steels with Nickel-Base Filler Metals BNi-2, BNi-5, and BNi-7,” published in the Welding Journal, June 1983, p. 164-s. Its authors, Erich Lugscheider and K-D Partz, University of Aachen, Germany, made good use of the tapered-joint test specimen to obtain diffusion brazing data.

Any comments and suggestions will be appreciated.

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Q: I have heard the terms “anodized” and “hardcoat anodized” used to describe the surface condition on aluminum. What exactly is this type of coating, and can you weld aluminum when it has this type of coating on it?

A: An oxide film can be grown on certain metals such as aluminum, niobium, tantalum, titanium, tungsten, and zirconium by an electrochemical process called anodizing. For each of these metals there are process conditions that promote growth of a thin, dense barrier oxide of uniform thickness. The thickness of this layer and its properties vary greatly depending on the metal. Aluminum is unique among these metals in that, in addition to the thin barrier oxide, anodizing aluminum alloys in certain acidic electrolytes produces a thick oxide coating, containing a high density of microscopic pores. This coating has diverse and important applications including architectural finishes and prevention of corrosion. When exposed to the atmosphere, aluminum naturally forms a passive oxide layer that provides moderate protection against corrosion. In its pure form aluminum self-passivates very effectively; however, aluminum that is alloyed with other elements is more prone to atmospheric corrosion and can therefore benefit from the protective quality of anodizing. Aluminum alloy parts are anodized to increase the thickness of the oxide layer in order to improve corrosion resistance, improve abrasion resistance, and/or allow for dyeing of colors — Fig. 1.

What Is Anodizing?

Anodizing is a process that produces an oxide film or coating on metals and alloys by electrolysis. The metal to be treated is made the anode in an electrolytic cell, and its surface is electrochemically oxidized. Anodization can improve certain surface properties, such as corrosion resistance, abrasion resistance, hardness, and appearance. The most common material anodized is aluminum. All of the above properties are improved when aluminum is anodized. Furthermore, since the surface film is porous after anodizing, the aluminum metal can be easily colored by the application of pigments or dyes into the pores. The most widely used anodizing specification, MIL-A-8625, defines three types of aluminum anodization: Type I (Chromic Acid Anodization), Type II (Sulfuric Acid Anodization), and Type III (Sulfuric Acid Hardcoat Anodization).

How Is It Performed?

Before anodizing, wrought aluminum is cleaned in either a hot soak cleaner or in a solvent bath and may be etched in sodium hydroxide (normally with added sodium gluconate), ammonium bifluoride, or brightened in a mix of acids. In aluminum anodization, this aluminum oxide layer is made thicker by passing a direct current through an acid solution, with the aluminum object serving as the anode (the positive electrode). The current releases hydrogen at the cathode (the negative electrode) and oxygen at the surface of the aluminum anode, creating a buildup of aluminum oxide. Anodizing at 12 V DC, a piece of aluminum with an area of one square decimeter (about 15.5 in.²) can consume roughly 1 A of current. In commercial applications, the voltage used is more normally in the region of 15 to 21 V.

Conditions such as acid concentration, solution temperature, and current must be controlled to allow the formation of a consistent oxide layer, which can be many times thicker than would otherwise be formed. This oxide layer increases both the hardness and the corrosion resistance of the aluminum surface. The oxide forms as microscopic hexagonal “pipe” crystals of amorphous alumina, each having a central hexagonal pore (which is also the reason that an anodized part can take on color in the dyeing process). The film thickness can range from under five microns on bright decorative work up to 150 microns for architectural applications.

Different Types of Anodizing

Type I — Chromic Acid Anodizing

The oldest anodizing process uses chromic acid. It is widely known as Type I because it is so designated by the MIL-A-8625 standard, but it is also covered by AMS 2470 and MIL-A-8625 Type IB. Chromic acid produces thinner (0.00002 to 0.00007 in. or 0.5 to 18 microns), more opaque films that are softer, ductile, and to a degree self-healing. They are harder to dye and may be applied as a pretreatment before painting. The method of film formation is different from using sulfuric acid in that the voltage is ramped up through the process cycle.

Type II — Sulfuric Acid Anodizing

Sulfuric acid is the most widely used solution to produce anodized coatings. Coatings of moderate thickness (0.00007 to 0.001 in. or 1.8 to 25 microns) are known as Type II. Standards for thin sulfuric acid anodizing are given by MIL-A-8625 Types I and II, and AMS 2471 (undyed), and AMS 2472 (dyed).

Type III — Hardcoat Anodizing

Also produced by using sulfuric acid anodizing, these coatings are thicker than 0.001 in. and are known as Type III. Hardcoat, or engineered anodizing. Thick coatings require more process control and are produced in a refrigerated tank near the freezing point of water with higher voltages than the thinner coatings. Hardcoat anodizing can be made between 25 and 150 microns or 0.001 to 0.006 in. thick. The increased anodizing thickness increases wear resistance, corrosion resistance, ability to retain lubricants, and electrical and thermal insulation. Standards for thick sulfuric acid anodizing are given by MIL-A-8625 Type III, AMS 2469, and the obsolete AMS 2468.

Sealing

Chromic acid and sulfuric acid
processes such as Types I, II, and III produce pores in the anodized coat. These pores can absorb dyes and retain lubricants, but are an avenue for corrosion. When lubrication properties are not critical, these pores are usually sealed after dyeing. Long immersion in boiling-hot deionized water is the simplest sealing process, although it is not completely effective and reduces abrasion resistance by 20%. Teflon®, nickel acetate, cobalt acetate, and hot sodium or potassium dichromate seals are common. MIL-A-8625 requires sealing for thin coatings (Types I and II) and allows it as an option for thick ones (Type III).

**Welding on Anodized Aluminum**

Anodized coatings have a much lower thermal conductivity and coefficient of linear expansion than aluminum. As a result, they have a tendency to crack when exposed to temperatures above 80°C (176°F), although they do not peel. The melting point of an anodized coating is 2050°C (3722°F), and the melting point of pure aluminum is 658°C (1216°F). The anodized coating on the surface of aluminum acts as an electrical insulator. If we did manage to break through the anodized surface and attempt to arc weld, we would expect to have many problems in stabilizing an arc and would typically produce a weld of very poor quality containing numerous discontinuities. For these reasons, it is not recommended to weld on aluminum that has been anodized without first removing the anodized surface in the area to be welded. The AWS D1.2, Structural Welding Code — Aluminum, stipulates in the fabrication section, under preparation of base metals, that all surfaces to be welded shall be free from thick aluminum oxide. Consequently, if aluminum that has been anodized is to be welded, the anodized surfaces in the area to be welded must be removed before welding. Removal can be performed by mechanical means such as grinding.

One other area of concern relating to the anodizing process is the effect of anodizing on material that has already been welded. The weld area will always be visible, having at least a slightly different appearance than the adjacent aluminum. Because the anodic oxide layer is translucent, the differing substrates will be visible and may in fact be accentuated. If you want the best color match after postweld anodizing, 4043 is not a good choice of filler metal because it will typically turn dark gray in color after the anodizing process, and the weld will become very visible in contrast to the base alloy. The 5356 filler metal will provide a much closer color match after anodizing, particularly on the 6xxx series base alloys.

**References**

I would like to thank the Aluminum Anodizing Council (AAC) for providing me information for this article and strongly recommend that anyone requiring further information about the metal finishing process of aluminum anodizing and its many inherent performance qualities, including corrosion resistance and decorative options for coloring aluminum, contact the AAC at www.anodizing.org or (847) 526-2010.

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Electrode Life: A Measure of System Performance in Plasma Cutting

Provided are descriptions for assorted electrode wear mechanisms

BY NAKHLEH HUSSARY AND THIERRY RENAULT

Plasma cutting has become a major tool in the fabricating industry due to its high productivity on both ferrous and non-ferrous materials. Its performance has seen drastic improvements in the last 20 years from cut quality and speed to consumable life. Consumable life is in excess of 1500 starts, 11-s arc on-time, at 200 A with oxygen plasma-forming gas while maintaining a high cut quality.

The longevity of the consumables depends, among other factors, on the erosion rate of the electrode (cathode) — the one component in the plasma cutting torch that is most stressed by the plasma arc. It is, therefore, essential to understand the electrode wear mechanisms in order to push forward the cutting system performance.

Erosion of the electrode is influenced by many factors including, but not limited to, arc current, cathode material, temperature and cooling method, arc chamber geometry and pressure, plasma-forming gas composition, arc root motion, and gas dynamics. This wide range of variables leads to a large variety of designs as shown in Fig. 1.

This discussion presents a brief overview of the various electrode wear mechanisms.

**Examining the Plasma Cutting Arc**

**Cathode Region, Arc Column, and Anode Region**

The plasma cutting arc is divided into three main regions as follows: cathode region in front of the cathode; arc column, which stretches from the cathode region through the arc chamber and the nozzle to the workpiece; and the anode region, which is adjacent to the workpiece (anode) as shown in Fig. 2. A typical electrode used in plasma cutting is made with a refractory material insert, often tungsten or hafnium, embedded in a water-cooled copper holder. Refractory material cathodes provide the arc with the electrons through a thermionic emission mechanism. This mechanism comes into play when the surface temperature of the cathode is in excess of 3000 K (values are material dependent). It is worth noting that thorium oxide is added to tungsten in order to enhance its thermionic properties.

Intuitively, the main cause of wear of the cathode is due to the excessive heat flux to the emissive element from the cathode arc root. Therefore, properly understanding and describing this flux as well as the arc root physics will greatly help in improving the life of these cathodes.

One might reason that the transition from the cathode surface to the plasma arc column does not happen abruptly. A transition region, i.e., a near cathode plasma, exists between the cathode surface and the bulk plasma. A simplified form of the currently accepted description, starting from the cathode surface, is made of a first sublayer (presheath) dominated by a net positive space charge and high electric field, followed by a second layer, which is quasineutral, where the needed ionization occurs to sustain the plasma arc — Fig. 2.
In steady-state operation, the cathode surface is hot enough to enable thermionic emission of electrons to the space charge layer. This space charge layer is assumed collisionless (i.e., no collisions between electrons and ions), resulting in no net energy exchange. The electrons are accelerated through this space charge layer into the ionization layer. The ions, on the other hand, are accelerated from the ionization layer through the space charge layer to the cathode surface. Some electrons in the ionization layer with sufficient energy to overcome the electric field of the space charge layer will diffuse back to the surface of the cathode. The ions bombarding the surface and the back diffusing electrons form a large component of the total energy flux deposited on the cathode surface. This input energy flux in the cathode is balanced by the energy losses due to the emission of electrons, conduction, radiation, and vaporization of the cathode material.

One might also consider the radiated energy from the arc to the cathode (which is geometry dependent), Joule heating in the cathode, convective effects due to plasma-forming gas flow around the electrode, condensation of neutral atoms on the electrode, ejection of emissive material droplets, and others.

Theoretical models and simulation built on such description estimate the temperature of the cathode under the arc root can reach temperatures above 3000 K (Refs. 1, 2). This is higher than the melting point of the emissive insert material; hence, the cathode under the arc root is molten. In fact, this is experimentally observed on the cathode of the plasma cutting process.

**Choosing Tungsten vs. Hafnium**

Plasma cutting employs two emissive element materials depending on the nature of the plasma forming gas. Tungsten is used with nonoxidizing and inert gases (N₂, Ar, Ar-H₂), while hafnium is preferred when using oxidizing gases (O₂ and air). The wear mechanisms of these two electrodes using tungsten or hafnium are different because of the thermal, chemical, and electrical properties of the materials (Table 1). In the case of tungsten, it is experimentally observed that a crater forms under the arc root that expands with use at a constant rate. The arc root occupies a small portion of the total surface area of the tungsten (given a large enough surface). The tungsten is locally molten under the arc root. The material is both evaporated and ejected due to arc root instability. The ejected tungsten droplets are deposited on the arc chamber walls and the nozzle. Since there is a little amount of molten tungsten, the ejected mass is low and the electrode life is long when compared with hafnium — Fig. 3A, B.

Hafnium, on the other hand, has a lower melting point compared to tungsten, and the whole surface of the emissive insert is molten (as shown in Fig. 3B) leading to higher wear rate and higher wear depth as observed in Fig. 3B.
sensitivity to arc root motion, fluid dynamics, and electrode cooling.

At ignition, the arc root is located at the edge of the hafnium insert (i.e., hafnium/copper interface) and starts heating the metal/oxide surface. Because the surface temperature is low, the electron emission mechanism is a combination of field and explosive emission. As the temperature of the surface increases, the thermionic emission mechanism takes over. The transition from room temperature to the melting point, over a time period on the order of 100 ms, induces large thermal shock that may result in further electrode erosion. Other droplet ejection occurs during the transition from the starting gas (less oxidizing) to the cutting gas (oxidizing).

During the steady-state operation, all of the surface of the hafnium insert is molten. Evaporation of the molten material is the dominant wear mechanisms in this state. However, any instabilities in the arc can cause additional wear.

One of the main electrode wear mechanisms is a significant ejection of liquid hafnium droplets at shutdown. This is due to the swirling plasma-forming gas drag force on the liquid metal at arc extinction. Effectively, when the arc turns off, the liquid hafnium solidifies in about 5 to 10 ms, while the plasma arc extinguishes in about 1 ms (Ref. 3). The absence of the arc increases the effective exit orifice area leading to rapid depletion of the gas from the arc chamber. The rapid increase in gas flow momentum increases the drag force on the liquid hafnium. This force is sufficient to pull away the liquid hafnium.

Therefore, thermal management of the emissive element is key in maintaining a low wear rate on both tungsten and hafnium. Such management entails liquid cooling of the electrode, use of high thermal diffusivity holder materials, and minimization of contact resistance between the emissive insert and the electrode holder. Because the emissive material is in the molten state, both the flow dynamics around the electrode front end and the arc root stability are critical. The effect of higher pressure in the arc chamber acts in two ways — 1) it increases the ion flux bombarding the surface and therefore increases the energy input, and 2) a higher ion pressure increases the displacement of the liquid metal (Refs. 3, 4).

**Aiming for Advances**

It is interesting to note that improving the properties of the emissive insert material (use of new refractory metal alloys) has yet to yield significant results.

Plasma cutting system manufacturers continuously pursue research and development in order to improve electrode life, an issue that is central to many plasma processing applications.

**References**

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A growing demand for gas and oil has energy firms searching in places they never have before. As a result, the tentacles of global pipelines are extending deeper into remote regions of the world.

A new wave of long-distance natural gas lines has sparked a renewed interest in construction-cost scrutiny, as energy firms look for ways to increase productivity. But in the high-standard industry of pipeline construction, quality cannot be compromised. However, unnecessary repairs of small, innocuous weld discontinuities result in added cost, delays, and can actually compromise weld integrity.

Traditional acceptance standards for pipeline girth welds (such as API 1104) have been based on what is defined as “good workmanship.” This vague, yet generally accepted standard is defined as “what a reasonably competent pipeline welder can achieve using cellulosic SMAW electrodes.”

The API 1104 standard prescribes that discontinuities that do not meet this “good workmanship” criteria, as detected by radiography, are repaired. Ultrasonic testing is now commonly used, and it reveals considerably more resolution to better characterize weld discontinuities. Specially trained experts are increasingly analyzing this additional information and questioning the need to rework many imperfections deemed innocuous.

In a scientific process called Engineering Critical Assessment (ECA), imperfections are evaluated based on fracture mechanics, where the driving force (design loads) and the resistance force (material toughness) are evaluated. Imperfections below the determined critical defect size are safe and may remain untouched inside the finished weld.

This higher level of understanding is increasing productivity substantially, especially on longer pipeline projects throughout North America. Many projects in other parts of the world, however, have yet to take advantage of this method, which is growing in acceptance.

KENNETH Y. LEE is pipeline welding engineer, The Lincoln Electric Co., Cleveland, Ohio.
Understanding the difference between what is acceptable and what is not means a gain in productivity

for natural gas transmission lines, allowing for thinner walls and higher operating gas pressure. These steels have microalloy additions and are lower in carbon, which improves weldability.

While the main section of API 1104 places primary importance on flaw length, Appendix A allows an evaluation of flaw length and height.

Conventional radiography detects the length and density of weld imperfections, not the height. Ultrasonic testing offers greater resolution and the ability to discern microalloy and characterize height along the length of a defect.

ECA alternative defect acceptance criteria for pipeline construction are detailed in the codes API 1104 Appendix A and CSA Z662 Appendix K. Also, the ECA method is used to determine if an existing structure is fit for service and detailed in BS 7910 and API 579.

Under API 1104 Appendix A, ECA allows experts to determine the maximum size of planar imperfections that remain stable under designed service conditions. These flaws can, in fact, safely remain in the completed weld, understanding that they do not compromise the structural integrity when the pipeline is operated under the designed service conditions.

This evaluation process requires additional qualification tests, CTOD testing of the weld and heat-affected zone (HAZ), stress analysis, and additional inspection, but it is only applicable in certain conditions. For instance, ECA can only be used in circumferential welds between pipes of equal nominal wall thickness. It excludes welds in pump or compressor stations, as well as fittings, weld repairs, and valves in the main line.

Higher-Strength Pipe Steel

Line pipe steels have steadily increased in strength, incorporating microalloy additions such as niobium, vanadium, and titanium, and more sophisticated pipe mill rolling and cooling techniques. This new generation of steel offers lower carbon and carbon equivalent levels, making it easier to weld.

Higher strength also allows increased operating pressures, which improves operational efficiencies. The advancements in pipeline steel have ushered in new electrode technology that optimizes alloy chemistry and minimizes diffusible hydrogen. It was discovered that standard cel-lulose electrodes did not work well on new high-strength steel.

With that, welding consumable manufacturers are designing specialized electrodes, such as the Pipeliner™ series from Lincoln Electric, which is manufactured under lot control, with each lot welded tested and certified for consistency.

These new consumables are designed for greater fracture toughness — a metal’s ability to resist extension of a crack. This is often a greater concern when welding stronger steels, which are more highly strength and more sensitive to notches and imperfections.

Testing ECA Methods

The ECA method was studied on girth welds made on high-strength X120 (120 ksi min yield strength) pipe by a group of researchers and was presented at the 2004 International Conference on Pipeline Technology in Ostend, Belgium (Ref. 1).

Over the range of discontinuities examined, the study found that API 1104 Appendix A (as well as BS 7910 and CSA Z662) resulted in conservative ECA limits compared to the fracture behavior of X120 welds in curved wide plate tests. They observed no cases of failure in curved wide plate specimens with stress levels lower than allowed by the three ECA methods.

The study noted that improved ECA methods are required to minimize unnecessary and expensive weld repairs, while ensuring safety. This is even more critical for modern higher-strength steels and larger stress demands, where the challenge is to obtain higher toughness and higher weld strength.

ECA methods intended for conventional stress-based applications, however, may not be suitable for strain-based applications, where high-applied strains might enlarge weld imperfections.

As emphasis for weld quality and weld strength overmatch is being placed on strain-based design applications, where the pipe could experience longitudinal strains greater than 0.5%. This is often associated with soil displacement from seismic activity, slope instability, and frost heave.

Automated Ultrasonic Testing

Many pipeline projects are using automated ultrasonic testing (Fig. 1) for main-line weld inspection. The benefits include high speed, safety in the absence of radiation, higher resolution, and improved sizing of weld imperfections.

The margin for error in automatic ultrasonic testing, however, for imperfection height is important when using an ECA. If the error is too large, allowable imperfection sizes could be too restrictive to render ECA beneficial.

Also, actual weld imperfections are often difficult to describe through the use of a few simple parameters, such as length, height, and depth. In actual girth welds, imperfections are rarely rectangular, as discontinuity heights can vary along its length. This, of course, raises the need for better sizing and the categorization of imperfections for an accurate assessment.

Conclusion

The Engineering Critical Assessment method for pipeline construction has been proven to be safe and beneficial for the construction of pipelines throughout North America. Much of the rest of the world has yet to take advantage of the process. The ECA method has found acceptance in other industries as well, such as evaluating bridges and pressure vessels, and even the high-standard nuclear power industry.

Advanced technology in the past 20 years has played a critical role in pipeline welding. Nearly 15 years ago, Lincoln Electric developed the STT process — a controlled-current GMAW process that uses high-frequency inverter technology and waveform control. It has been successful for onshore and offshore pipelines to perform root pass welding much faster than GTAW.

But as the world, and especially fast-growing economies like China and India, continues to increase its demand for oil and gas, pipelines will grow longer into the far corners of the earth in quest to tap into distant reserves. As that happens, new technologies will be developed to find ways to make it more cost effective.

Reference

Plasma Cutting Systems Combine Versatility with Efficiency

Many people know that a plasma system can cut, but far fewer know that it can gouge, or that plasma can cut any type of electrically conductive metal, that it can be used on a track system, or that it can be used to efficiently cut metal up to 1½ in. thick. But, in fact, plasma can do all this and more, and this versatility helps make plasma a truly valuable productivity tool.

When you use a tool more you better leverage your investment, making the tool a greater value. And when that tool helps you avoid having to switch back and forth among various tools, or rely on others to execute certain tasks, versatility translates into greater productivity.

American Fire Training Systems is an example of one company enjoying the versatility of plasma. The company makes some of the largest steel fire training structures in the United States. Its projects, which can range in size from a single story 3200-sq-ft unit to a six-story complex, are used to train firefighters around the country. American Fire Training Systems switched from oxyfuel to plasma five years ago and hasn’t looked back.

Reed Steffek, the company’s production manager, said oxyfuel is used for certain things, but plasma arc cutting machines “are definitely the tool of choice around here. There’s really no beating the productivity we get from plasma. Plasma definitely cuts quicker, cleaner, and allows us to do more.”

The Measures of Versatility

Plasma versatility can be measured in many ways.

Processes

Plasma is best known as a cutting tool, but even within cutting, plasma is more versatile than many people realize. With specialized consumables, plasma systems can be used for drag cutting, cutting with a standoff (particularly useful when cutting odd-shaped pieces or when trying to access a tight location), or even for getting high-quality, very narrow cuts on thin materials.

In addition to cutting, many owners are now starting to leverage plasma’s gouging capabilities. Specialized gouging consumables are now available for many brands of plasma systems. Plasma gouging can be used in place of carbon arc gouging and is an effective method of removing metal for weld preparation or for gouging out worn or cracked parts for repair or replacement.

Plasma is also an effective piercing tool, whether by hand or on a cutting table. Compared to oxyfuel, which requires pre-

heating before cutting or piercing, plasma is particularly productive because it requires no preheating of the workpiece.

**Material Types**

One of plasma’s biggest advantages over other thermal cutting processes is that it can be used on any electrically conductive metal, including mild steel, stainless steel, galvanized steel, copper, cast iron, and others. This capability is especially attractive to users who may encounter many different types of metals, including farmers, scrapyards, metal fabricators/job shops, facility maintenance professionals, and others.

Plasma’s effectiveness on painted, rusted, or dirty metals is also attractive to these and other users.

The ability to cut multiple metal types is a frequently cited reason why plasma owners make their initial plasma purchase. Whether owning a plasma system enables them to avoid wasting time and money subcontracting out certain parts of a project, or whether it simply enables them to avoid wasting time switching from one tool to another, plasma’s material type versatility is a clear productivity enhancer.

**Material Forms and Thicknesses**

In addition to cutting any type of electrically conductive metal, plasma can also efficiently cut many material forms: plate, rod, pipe, beam, and even grating — with no preheating required.

Air plasma is an effective tool for cutting thicknesses from gauge to 1½ in. Judging a plasma system’s true capacity is not always easy given the lack of consistency among various manufacturers in how they rate their systems. There is, however, a common relationship between cut speed, cut quality, and cut capacity: there is an optimal speed for achieving the desired cut quality on a given metal thickness. In many cases, the speed advantage of plasma over other cutting methods, such as oxyfuel cutting, is dramatic. Oxyfuel

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**What Is Plasma Cutting?**

Plasma cutting is a high-speed thermal process that utilizes an accurately controlled electric arc to cut most common metals. The plasma process uses a small nozzle orifice and high-velocity gas flow to generate a very high-temperature, high-energy-density arc. Plasma cutting and gouging requires a process gas, such as air or nitrogen, a DC power source, and consumables, including an electrode and nozzle. Plasma arc cutting systems provide the following:

- Fast cutting speeds
- Application versatility
- High productivity
- Cost-effective operation
cutting is, however, generally regarded as the superior method for cutting materials more than 1½ in. thick.

The versatility of plasma also makes the job easier for American Fire Training Systems because workers can use the same plasma cutting machine for just about anything they’re cutting.

“We use our Powermax1000’s to cut through different types of steel and aluminum whether painted, unpainted, or rusted,” Steffek said. “And we’re able to cut through a wide range of sizes — from ½-in.-thick tube, to ¼-in.-thick quarter-tons steel to thin 14-gauge sheets.”

Location

At a macro level, plasma can be used in any number of locations, indoors and out, from a garage to a shop, and from a factory to a job site. A plasma cutting and gouging system can be used almost anywhere that a process gas (compressed air or sometimes nitrogen) and energy source are available. When hooked to a portable motor-generator and a portable compressor or gas cylinder, a plasma system is truly mobile, making it appropriate for use in the field, on a construction site, and in many other locations. Unlike oxyfuel cutting, which requires a flammable process gas such as acetylene, propylene, or propane, plasma systems may even be used in some more highly regulated environments where flammable gases aren’t permitted.

American Fire Training Systems cited this ability to easily move from location to location as another reason why it depends on plasma.

“We do as much as we can at our plant, but a lot of time the final cutting and assembly has to take place at a job site. Our work would definitely be a lot harder without plasma.”

Certain plasma systems, especially those utilizing inverter technology, are even more portable, and can be easily carried up a ladder, taken on board a ship, or used in other tight quarters, and can easily be moved from point to point, whether in a facility or in the field. Recent engineering developments also contribute to the versatility of plasma.

“The incorporation of Auto-Voltage™ and Boost Conditioner™ technologies into our Powermax brand of plasma systems really gives users much greater flexibility,” said Dennis Borowy, a principal engineer at Hypertherm. The first-mentioned technology allows people to use a wide variety of input voltages with no manual linking of any kind, while the second technology makes it possible for the system to extract the maximum amount of power from any given line.

With Auto-Voltage™, operators can start a job in their shop, plugged into their regular power source, and finish it in the field, hooked up to a completely different power source. Up until about seven years ago, this wasn’t possible. People moving from site to site had to either make sure the same voltage levels were available at all of their locations, or go through the time-consuming process of manually rewiring their system to match the available voltage.

Boost Conditioner™ technology enables better, more consistent performance regardless of fluctuations in input voltage. This is especially beneficial for operators in areas with unreliable or low line power. The technology also compensates for weak or varying voltage on motor-generators, providing improved performance for users in the field.

Since this technology is fairly new, not all systems have it. Therefore, if your particular situation requires lots of moving around, you may want to check with your distributor to find a plasma cutting machine with these features.

Applications

With a simple change of the torch and/or consumables, a plasma system can switch between manual and automated cutting or gouging. With a straight machine torch, a plasma system can easily be connected to an X-Y cutting table. Plasma systems can also be used on robotic arms or, more commonly, with a track system for effective long, straight cuts. Many plasma systems are used in conjunction with pipe bevellers or with hole-cutting tools. Plasma systems can also be used with metal templates or guides for efficient replication of cuts.

Conclusion

Plasma systems are highly versatile, highly productive cutting and gouging tools. The plasma process’s ability to perform various processes and applications, to operate in various locations, and to work on various metal types, forms, and thicknesses gives it distinct advantages over competitive cutting technologies. If you already own a plasma system, chances are you can derive greater value out of your investment simply by expanding your usage occasions. And if you do not yet own a plasma system, you may find that you can get more done, in less time, at lower cost by investing in this powerfully versatile tool.◆
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Friction stir welding has been successfully demonstrated to produce near full-strength welds in many high-strength Al alloys (Refs. 1, 2). Lawrence Livermore National Laboratory and Advanced Joining Technologies, Inc., formed a team for the design, development, and manufacturing of polymer-matrix composite overwrapped Al alloy pressure vessels intended for the containment of dynamic loads. Preliminary analyses showed that near yield-stress loads would be developed in vessels consisting of a spherical section with two cylindrical nozzles. Past experiences with fusion welded Al alloy pressure vessels overwrapped with polymer-matrix composites had shown that the defects inherent in fusion welds in these alloys compromised the performance of otherwise useful developmental vessels (Ref. 3). Consideration of the advantages of friction stir welding, such as freedom from solidification-induced effects, improved fatigue resistance over fusion-welded joints, good corrosion resistance, and less distortion than for fusion-welded joints, was balanced against some drawbacks, such as difficulties in making out-of-position welds and a lack of information on completing welds that close on themselves.

After extensive discussions with organizations involved in friction stir welding in the U.S. and the UK, it was decided to work with Advanced Joining Technologies, Inc., to develop the process information, nondestructive examination (NDE) methods, and mechanical property data that would support the use of friction stir welding for joining the two hemispheres of the vessel.

Design and Material

Based on previous experience and extensive analyses, the shape of the vessel had evolved into that of a sphere with an inside diameter of about 1 m and a wall-thickness of 3.81 cm. This basic shape was modified by the addition of cylindrical nozzles at the top and bottom of the sphere for access to the interior of the vessel. Consultation with various Al alloy fabricators resulted in selection of the two modified spherical forgings (Fig. 1) that would be joined at their large open ends by a single-pass friction stir weld. Given the need for relatively high strength at and near the weld, as well as some reservations about the availability of friction stir welding shop jobs, it was decided to use an Al alloy that was capable of being joined by the usual fusion welding methods, should joining of thick (3.81 cm.) Al alloy forgings in the configuration shown in Fig. 1 prove difficult. The alloy chosen was Alloy 2219, with a nominal composition of 5.8–6.8% Cu, 0.2–0.4% Mn, 0.10–0.25% Zr, with trace amounts of Ti, Si, Fe, Mg, and Zn. As forged and heat treated to the artificially aged or "-T62" condition, minimum room-temperature tensile properties are ultimate tensile strength of 400 MPa, 0.2% offset yield strength of 276 MPa and an elongation in 5.08 cm of 6%, per Ref. 4.

Because there was no readily available mechanical property information on the properties of the friction stir welds in Alloy 2219, the forgings were purchased in the annealed condition, so that any combination of friction stir welding and heat treatment could be used, once development work was done.

Friction Stir Welding Development

The challenge in friction stir welding (FSW) of circumferential parts is providing a backing support for the part. For single-sided FSW, the forces are in the range of 6000 kg for this alloy and thickness. The force has to be reacted from the back of the weld, making assembly and disassembly difficult. To back up the weld from inside the vessel, several options were considered. The approach chosen was the bobbin tool or self-reacting tool (SKT). The SKT uses a second FSW shoulder on the backside of the weld to react to the loads. This eliminates the need for...
internal tooling. The SRT uses a scrolled shoulder for normal-to-the-surface welding allowing for the second shoulder to be used on the backside of the weld. The SRT was selected for welding of the firing vessel. The FSW machine used has a rotary device for circumferential welding. This device was used with the SRT machine to weld the vessels.

Initial welding development was done on 2.54-cm-thick 2219-O and 2219-T651 material. When the 3.8-cm-thick material became available, efforts were shifted to install a planetary gear reducer in line to achieve more rotary power. Upon completion of the gear reducer installation, a successful circumferential demonstration was performed.

Advanced Joining Technologies performed circumferential weld demonstrations on 2.5-cm-thick rolled plate. The plate was rolled to 102 cm outer diameter and was 122 cm in length. The demonstration was used to test the modified rotary drive mechanism. It was necessary to install a planetary gear reducer in line to achieve more rotary power. Upon completion of the gear reducer installation, a successful circumferential demonstration was performed.

Closing Out the Circumferential Friction Stir Weld

Once friction stir welding is completed, a keyhole is present due to tool retraction. Trimming off the keyhole is not an option in circumferential friction stir welding. A closure method needed to be identified. Examples of closure methods are a run off wedge, retractable pin tool (RPT), friction plug welding, and fusion fill. The most viable keyhole closure method for self-reacting friction stir welding is friction plug welding, which maintains the solid-state structure of the friction stir weld.

An inertia welding machine was used to develop process parameters for the friction plug welded closeout. Advanced Joining Technologies designed a plug and hole configuration that allowed the entire welding cycle to be completed in a single operation. Initial friction plug welding trials resulted in the 2219 Al alloy plug shearing halfway through the thickness of the friction stir weld. The plug was 2219-O to match that of the friction stir welded vessel. The shearing of the plug caused the bottom half of the plug to stop rotating, creating a poorly bonded interface. It was decided that a 2219-T6 plug was the next option to be evaluated. Weld plug trials showed promise, but the upper portion of the weld was not bonded due to the hard tool condition of the plug. The welding parameters were adjusted to allow for some softening of the plug at the topside. This resulted in sound plug welds being made into flat plate — Fig. 2.

![Fig. 1 — Alloy 2219 aluminum forgings.](image1)

Mechanical Properties of the Friction Stir Welds

**Tensile Properties**

The room-temperature tensile properties of friction stir welded 2219 Al alloy plate with various combinations of welding parameters and heat treatments are summarized in Figs. 3–5.

Room-temperature tensile and elastic-plastic fracture toughness properties of friction stir welds that were solution-treated, quenched, and artificially aged to the T62 condition after welding were determined. Tensile samples, with a 0.635-cm diameter and 2.54-cm gauge length, were removed from the top, center, and bottom thirds of the welds, with the samples oriented in the longitudinal (along the weld axis) and long transverse (normal to the weld axis) directions. Tensile tests were conducted per Ref. 5.

Tensile properties of friction stir welds made in fully aged (-T62) 2219 Al alloy, followed by testing in the as-welded condition (actually after natural aging for 2–3 weeks), are presented as a function of welding speed in Fig. 3. The ductility, expressed in terms of the total elongation in a 5-cm gauge length, is between 10.5 and 13%, and does not vary systematically with increasing welding speed. The 0.2% offset yield strength values ranged from about 145 to 155 MPa as the welding speed was increased from 7.5 to 15 cm/min. Ultimate tensile strength values increased from about 280 to 305 MPa as the welding speed increased from 7.5 to 15 cm/min.

Using the base metal minimum yield-strength of 276 MPa results in joint efficiency values based on the ratio of as-welded yield strength to minimum forging yield strength of 52 to 56%. In a similar manner, i.e., using the minimum base metal ultimate tensile strength of 400 MPa, the joint efficiency based on ultimate tensile strength ranged from 70 to 76%. These joint efficiency values were inadequate for the intended application. The low joint efficiencies of welds in the naturally aged (-T4) condition led to extensive weld parameter exploration followed by a complete solution treatment (995°±10°F), a water quench, and artificial aging heat treatment of 375°±10°F for 36 hours, which is the heat treatment cycle recommended for the base material (Ref. 4).
Tensile properties of friction stir welds made in the annealed (-O) condition, followed by the previously described heat treatment, which rendered the weld in the fully aged (-T62) condition, are presented in Fig. 4 as functions of welding speed. The ductility, expressed in terms of the total elongation in a 5-cm gauge length, varied between 0.5% at lower welding speeds (5 to 7.5 cm/min) to as high as 6.6% at a maximum welding speed of 15 cm/min. The 0.2% offset yield strength values ranged from about 293 to about 267 MPa as the welding speed increased from 4 to 15 cm/min.

Ultimate tensile strength values varied widely at lower welding speeds (from 4 to 6 cm/min), with values ranging from 280 to about 371 MPa. At a welding speed of 7.5 cm/min, the ultimate tensile strength went through a minimum of about 259 MPa. At higher welding speeds (10 to 15 cm/min), the ultimate tensile strength values decreased with increasing welding speed from about 354 to 323 MPa. As before, using the base metal minimum yield strength value of 276 MPa, the corresponding joint efficiencies ranged from about 93% at a welding speed of 4 cm/min to about 80.8% at a welding speed of 15 cm/min.

After review of the weld process development and tensile test results, LLNL and AJT selected a set of weld process parameters that yielded the following mean tensile properties when using a welding speed of 5.75 cm/min: ultimate tensile strength, 370 MPa; 0.2% offset yield strength, 293 MPa; and total elongation, 5.2%. These strength values corresponded to a joint efficiency of 92.5%, based on minimum ultimate tensile strength of the base metal, and a joint efficiency of 106%, based on the minimum yield strength of the base metal.

Ductile Fracture Toughness

Compact tension samples (0.5 T, Ref. 6) were removed from the top, center, and bottom thirds of welds made with the optimized process parameters. The notch and precrack were located along the weld-axis and running from the face to the root of the weld (so-called TL orientation) per Ref. 7, or with the notch and precrack located normal to the weld axis and running from the face toward the root of the weld (so-called LT orientation per Ref. 7). Also tested were several 0.5T fracture toughness samples removed from drop-offs from one of the forgings. All fracture-toughness samples were heat treated to the fully aged (-T62) condition before machining of the notch and precracking.

Testing was done at room temperature per Ref. 6, and the data analyzed to determine both ductile fracture toughness (J_{IC}) and linear-elastic (K_{IC}) values per Ref. 6. All samples yielded valid J_{IC} values that ranged from 21.36 kJ/M to 37.73 kJ/M. K_{IC} results, converted from the J_{IC} values by the method described in Ref. 8, for the forgings and friction stir welds, are compared with published values from friction stir welded Al alloys (Ref. 9) in Fig. 5, in the form of a plot of K_{IC} vs. 0.2% offset yield strength. Note that the individual values for the heat-treated friction stir welded 2219 Al alloy mostly are above the least-squares trend line for the other Al alloys, indicating the good fracture resistance of the heat-treated 2219 friction-stir welds. No consistent difference was seen in the K_{IC} results for friction stir welds with the crack oriented in the TL vs. LT orientation. The fracture toughness values of the heat-treated 2219 forging samples fell somewhat below the least-squares trend line for the other alloys.
Macrostructure and Microstructure of Friction Stir Welded 2219 Aluminum Alloy

Plates welded in the annealed condition had abnormal grain growth in the FSW nugget due to weld-induced solution heat treatment — Fig. 6. The large grain growth in the nugget resulted in decreased ductility and transgranular fracture. The large grains in the nugget cause a slight decrease in ultimate tensile strength. Plates welded in the -T62 condition had much greater elongation than those described above. However, the welding-induced heating caused significant decreases in both yield strength and ultimate tensile strength due to precipitate coarsening in the heat-affected and thermomechanically affected zones. Tensile specimens displayed microvoid coalescence fractures in the heat-affected zone, with less than 75% joint efficiencies based on tensile yield strength.

Microstructures of heat-treated welds are shown in Fig. 7. Note the swirled structure in the weld-region (Fig. 7, feature A), as well as the large grains growing across the weld region. Contrast the coarse-grained weld region (Fig. 7, features A and C) with the fine-grained thermomechanically affected zone (Fig. 7, feature B). The same grain growth phenomenon occurred in the self-reacting tool (SRT) welds and in the single-sided welds. Initial SRT weld tensile specimens failed by the same transgranular mechanism. Later SRT weld tensile specimens displayed increasing amounts of a microvoid coalescence failure mode due to improved welding parameters and tool geometry.

Once a set of weld parameters was found that yielded acceptable tensile test results to both LLNL and AJT, two welded panels were made with these SRT weld parameters.

One of these welds was cut into two pieces, and these pieces were used as control samples for vessel heat treatment. Tensile and ductile fracture toughness samples were removed from these heat-treatment witness plates, and tested as described above. The results are presented in Figs. 4 and 5.

**Welding of the Vessels**

**Tack Welding**

The vessel halves were tack welded together using a single-sided friction stir welding tool. The tool created a tack weld that was 1.02 cm deep. Once tack welding was completed, the clamping mechanism was disassembled. The tack weld supported the full weight of the free half-vessel.

**Vessel Self-Reacting Tool Friction Stir Welding**

Vessel B was the first to be welded. With the clamping mechanism disassembled, a through-hole was drilled at a slight angle toward the retreating side of the weld. This was done to compensate for deflection seen in the tack welding and in the circumferential demonstration plates. Since the joint was within the pin diameter path and was favoring the retreating side of the weld, the alignment was acceptable. The self-reacting tool was assembled on the outside of the part. The pin was fed through the drilled hole and the lower shoulder was attached. The entire clamping mechanism was reassembled and the circumferential weld was made.

Vessel A was prepared in the same manner as vessel B. The hole was drilled favoring the retreating side of the weld. Again the machine saw minimal deflection. Both inside and outside weld surfaces were satisfactory.
Vessel Friction Plug Welding

Both vessels were welded using the friction plug welding process developed on flat plate. Friction plug weld tooling and the inertial welding machine performed as expected. Ultrasonic inspection of the friction plug welds revealed minor indications, most of which were within 0.64 cm of the face surfaces of the welds. These indications were removed by subsequent finish machining of both vessels. Nondestructive examination of the friction stir welds and the friction plug welds was performed using a combination of straight-beam ultrasonic examination and phased-array ultrasonic examination (Fig. 8, Ref. 10).

Ultrasonic inspection performed on the circumferential weld on vessel B revealed a small continuous channel defect located in the bottom half of the weld. It is likely that the defect was due to the compound curvature of the spherical vessel. The circumferential weld had been made using process parameters that were based on results obtained with the same weld parameters used in flat plate and cylindrical plate welding. Repairs were accomplished by rewelding the vessel with increased pressure and increased travel speed to eliminate the channel defect. The vessel was rewelded using the procedure described above. Ultrasonic inspection revealed only minor indications (less than 0.14 cm² by 0.635 cm long) in the start and overlap areas of this weld. Phased-array ultrasonic examination of the circumferential weld in vessel A revealed no indications.

Preliminary Fracture Analysis

Some preliminary static fracture mechanics analyses have been performed. It was assumed that an undetected semieliptical flaw, 0.25 cm deep by 0.635 cm long, was located close to the external or tension surface of the vessel. Tensile stresses close to the yield strength of the weld, or about 276 MPa, were obtained from stress analyses performed during design of the vessel. The minimum linear-elastic fracture toughness, converted in the usual manner (Ref. 8) from the elastic-plastic fracture toughness values for 2219 friction stir welds (Fig. 6) was used. The results indicate that at stresses of 276 MPa, the calculated stress intensity for the assumed flaw is about half that expected for an aluminum alloy with a yield strength of 276 MPa. Additional fracture mechanics analyses, for both static and fatigue loading, will be carried out once the results of fatigue crack growth testing of the 2219 friction stir welds is completed.

Conclusions

1. Bobbin tool friction stir welding produced satisfactory joints in 3.8-cm-thick 2219 aluminum alloy.
2. Friction plug welding produced satisfactory closeout welds in the circumferential welds.
3. Postweld solution treatment, quenching, and artificial aging were necessary to restore the welds to near base metal strength, ductility, and toughness.
4. A combination of straight-beam and phased-array ultrasonic examination found a few defects of about 0.14 cm² by 0.64 cm in length in the welds.
5. Satisfactory repair welds were made by friction stir welding over the defective region in the original weld.
6. Preliminary fracture mechanics analyses indicated that the welds are fit for the intended service.

Acknowledgments

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References

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♦ Automatic Welding Conf. May 13, 14, New Orleans, La. This conference covers new technologies in automatic controls, training, and management innovations, and automation breakthroughs for the latest welding processes, including fiber and disk lasers, friction and thermal stir welding, hot-wire tungsten arc, laser/GMA hybrid welding, as well as automation technologies for traditional processes. Contact American Welding Society (800/305) 443-9353, ext. 455, or visit www.aws.org/conferences.


♦ Sheet Metal Welding Conf. XIII. May 14–16, VirTaTech Center, Livonia, Mich. Sponsored by the AWS Detroit Section. Call (586) 466-7070, or visit www.awsdetroit.org for program information.


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Coatings for Africa 2008. Aug. 19–21, Champagne Sports Resort, Central Drakensberg, Kwazulu-Natal, South Africa. E-mail rosalie@coa.co.za, or visit www.coatingsforafrica.org.za.


For info go to www.aws.org/ad-index


♦ FABTECH International & AWS Welding Show. Oct. 6–8, Las Vegas Convention Center, Las Vegas, Nev. This show is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, welding equipment, and technology. Contact: American Welding Society, (800/305) 443-9353, ext. 455; or visit www.aws.org.


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Liquid Penetrant & Magnetic Particle Inspection
Aug 18-22 • Nov 10-14

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Apr 28-May 9 • Jun 2-13 • Jul 14-25 • Sep 8-19 • Oct 20-31

Prep for AWS Certified Welding Supervisor Exam
Jun 23-27 • Aug 25-29 • Nov 17-21

1-800-332-9448
or visit us at www.welding.org
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WELDING JOURNAL 51
### AWS Certification Schedule

**Certification Seminars, Code Clinics and Examinations**

Application deadlines are six weeks before the scheduled seminar or exam. Late applications will be assessed a $250 Fast Track fee.

#### Certified Welding Inspector (CWI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oklahoma City, OK</td>
<td>May 18-23</td>
<td>May 24</td>
</tr>
<tr>
<td>Birmingham, AL</td>
<td>May 18-23</td>
<td>May 24</td>
</tr>
<tr>
<td>Long Beach, CA</td>
<td>EXAM ONLY</td>
<td>May 31</td>
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<tr>
<td>Hartford, CT</td>
<td>Jun. 1-7</td>
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</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>Jun. 1-6</td>
<td>Jun. 7</td>
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<tr>
<td>Fargo, ND</td>
<td>Jun. 1-6</td>
<td>Jun. 7</td>
</tr>
<tr>
<td>New Orleans, LA</td>
<td>Jun. 1-6</td>
<td>Jun. 7</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>Jun. 8-13</td>
<td>Jun. 14</td>
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<td>Kansas City, MO</td>
<td>Jun. 8-13</td>
<td>Jun. 14</td>
</tr>
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<td>Miami, FL</td>
<td>EXAM ONLY</td>
<td>Jun. 19</td>
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<td>Phoenix, AZ</td>
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<td>Los Angeles, CA</td>
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<tr>
<td>Louisville, KY</td>
<td>Jul. 13-18</td>
<td>Jul. 19</td>
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<td>Corpus Christi, TX</td>
<td>EXAM ONLY</td>
<td>Jul. 19</td>
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<tr>
<td>Beaumont, TX</td>
<td>Jul. 20-25</td>
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<td>Milwaukee, WI</td>
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<tr>
<td>Cleveland, OH</td>
<td>Jul 27-Aug. 1</td>
<td>Aug. 2</td>
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<td>Denver, CO</td>
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<td>Jul 27-Aug. 1</td>
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<td>Miami, FL</td>
<td>Aug. 3-8</td>
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<tr>
<td>San Diego, CA</td>
<td>Aug. 3-8</td>
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<tr>
<td>Charlotte, NC</td>
<td>Aug. 10-15</td>
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<td>San Antonio, TX</td>
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<td>Roswell, NM</td>
<td>EXAM ONLY</td>
<td>Aug. 16</td>
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<tr>
<td>Bakersfield, CA</td>
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<td>Portland, ME</td>
<td>Aug. 17-22</td>
<td>Aug. 23</td>
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<tr>
<td>Salt Lake City, UT</td>
<td>Aug. 17-22</td>
<td>Aug. 23</td>
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<tr>
<td>Houston, TX</td>
<td>Sept. 7-12</td>
<td>Sept. 13</td>
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<td>Pittsburgh, PA</td>
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<td>Las Vegas, NV</td>
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<td>Minneapolis, MN</td>
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<td>Sept 14-19</td>
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<td>Anchorage, AK</td>
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<td>Miami, FL</td>
<td>Oct. 19-24</td>
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<td>Tulsa, OK</td>
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<tr>
<td>Long Beach, CA</td>
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<td>Newark, NJ</td>
<td>Oct. 26-31</td>
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<td>Portland, OR</td>
<td>Oct. 26-31</td>
<td>Nov. 1</td>
</tr>
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<td>Cleveland, OH</td>
<td>Nov. 2-7</td>
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<td>Atlanta, GA</td>
<td>Nov. 16-21</td>
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<td>Nov. 22</td>
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<td>Sacramento, CA</td>
<td>Nov. 30-Dec. 5</td>
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<td>Spokane, WA</td>
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<td>Syracuse, NY</td>
<td>Nov. 30-Dec. 5</td>
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<tr>
<td>Miami, FL</td>
<td>EXAM ONLY</td>
<td>Dec. 13</td>
</tr>
<tr>
<td>Reno, NV</td>
<td>Dec. 7-12</td>
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#### 9-Year Recertification Seminar for CWI/SCWI

<table>
<thead>
<tr>
<th>Location</th>
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<th>Exam Date</th>
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<tr>
<td>Pittsburgh, PA</td>
<td>May 19-24</td>
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<td>San Diego, CA</td>
<td>Jun. 9-14</td>
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<td>Dallas, TX</td>
<td>Oct. 20-25</td>
<td>NO EXAM</td>
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<tr>
<td>Miami, FL</td>
<td>Dec. 1-6</td>
<td>NO EXAM</td>
</tr>
</tbody>
</table>

For current CWIs and SCWIs needing to meet education requirements without taking the exam. If needed, recertification exam can be taken at any site listed under Certified Welding Inspector.

#### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbus, OH</td>
<td>May 19-23</td>
<td>May 24</td>
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<tr>
<td>Minneapolis, MN</td>
<td>Jun. 23-27</td>
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<td>Atlanta, GA</td>
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<td>Philadelphia, PA</td>
<td>Aug. 18-22</td>
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<td>Tulsa, OK</td>
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<td>Atlanta, GA</td>
<td>Nov. 17-21</td>
<td>Nov. 22</td>
</tr>
<tr>
<td>Long Beach, CA</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
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</tbody>
</table>

CWS exams are also given at all CWI exam sites.

#### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
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</thead>
<tbody>
<tr>
<td>Nashville, TN</td>
<td>May 19-23</td>
<td>May 24</td>
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<td>Manchester, NH</td>
<td>Jun. 9-13</td>
<td>Jun. 14</td>
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<tr>
<td>St. Louis, MO</td>
<td>Aug. 18-22</td>
<td>Aug. 23</td>
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<td>Denver, CO</td>
<td>Sept. 15-19</td>
<td>Sept. 20</td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>Nov. 17-21</td>
<td>Nov. 22</td>
</tr>
<tr>
<td>Jacksonville, FL</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
</tr>
</tbody>
</table>

Radiographic Interpreter certification can be a stand-alone credential or can exempt you from your next 9-Year Recertification.

#### Certified Welding Educator (CWE)

Seminars 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 first two days).

#### Senior Certified Welding Inspector (SCWI)

Exam can be taken at any site listed under Certified Welding Inspector. No preparatory seminar is offered.

#### Code Clinics & Individual Prep Courses

The following workshops are offered at all sites where the CWI seminar is offered (code books not included with individual prep course): Welding Inspection Technology (general knowledge and prep course for CWI Exam-Part C); Visual Inspection Workshop (prep course for CWI Exam-Part B); and D1.1 and API-1104 prep course for CWI Exam-Part A); Visual Inspection Workshop (prep course for CWI Exam-Part B); and D1.1 and API-1104 Code Clinics (prep courses for CWI Exam-Part C). On-site Training and Examination

On-site training is available for larger groups or for programs customized to meet specific needs of a company. Call ext. 219 for more information.

#### International CWI Courses and Exams

Please contact international seminar & testing locations directly.

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico City, Mexico</td>
<td>EXAM ONLY</td>
<td>Jul. 4</td>
</tr>
<tr>
<td>Mexico City, Mexico</td>
<td>EXAM ONLY</td>
<td>Nov. 7</td>
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<tr>
<td>Monterrey, Mexico</td>
<td>Jul. 7-11</td>
<td>Jul. 12</td>
</tr>
<tr>
<td>Monterrey, Mexico</td>
<td>Nov. 3-7</td>
<td>Nov. 8</td>
</tr>
<tr>
<td>Sao Paulo, Brazil</td>
<td>EXAM ONLY</td>
<td>Sept. 6</td>
</tr>
</tbody>
</table>

* Contact info@omcs.org.mx
** Contact info@dalus.com
*** Contact d.almeida@abs-soldagem.org.br

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For information on any of our seminars and certification programs, visit our website at [www.aws.org/certification](http://www.aws.org/certification) or contact AWS at (800/305-443-9353, Ext. 273 for Certification and Ext. 455 for Seminars). Please apply early to save Fast Track fees. This schedule is subject to change without notice. Please verify your course status before making final travel plans.
Annual Officers Transition Ceremony Held in Miami

BY KRISTIN CAMPBELL

Gene E. Lawson was officially introduced as AWS president for 2008 at the transition ceremony held February 8 at AWS headquarters in Miami, Fla. — Fig. 1. Lawson spoke of the business travel he has already undertaken as part of his new role. “We have been home a total of a week since the first of the year,” he said, referring to how busy he and his wife, Bette, have been. So far, they have traveled to Chennai, India, for Weld India 2008; Longboat Key, Fla., for the 12th annual Welding Equipment Manufacturers Committee (WEMCO) meeting; and Mexico City for the AWS-sponsored Weldmex show.

Lawson said, “We’ve been overwhelmed with the love that people show for the visiting dignitary from the American Welding Society. It’s humbling.”

Gerald Uttrachi, outgoing AWS president, spoke about his time served as president. “Ultimately, when I added it up, I delivered 20 domestic talks, including a couple hours at Ohio State, and in nine countries. My wife Christine and I were never treated better than we were internationally,” he said. Included among their travels were venues in Peru, South Korea, and China.

Ray Shook, AWS executive director, and Gerald Uttrachi presented the Michael A. Rowland Employee of the Year Award to Osvaldo (Ozzie) Rodriguez — Fig. 2. The award recognizes an AWS employee who demonstrates exceptional service or makes outstanding contributions to the Society, as nominated by his/her peers. Rodriguez, who joined the AWS staff in 1980, was cited as “a very important part of AWS operations. He strives to keep 98+ people comfortable in their work environment.” Originally hired as a warehouse shipping helper, he has evolved over the years into a building maintenance superman extraordinaire. Rodriguez fixes broken chairs, lights, and flat tires; runs errands; sets up and breaks down the classroom; hangs pictures; paints; fixes plumbing; rearranges offices (etc., etc., etc.). Shook said, “On behalf of the employees and our volunteers, we congratulate you on this prestigious award. We’ve gotten pretty spoiled here at AWS, and we would be lost without Ozzie.”

As part of his award, Rodriguez received $1000; a gift certificate for dinner for two at an area restaurant; a designated parking space; and a commemorative engraved clock.

John L. Mendoza, attending with his wife, Nora, was formally installed for his first term as an AWS vice president — Fig. 3. Wayne Carter, representing Miami-Dade County Mayor Carlos Alvarez, presented a proclamation declaring February 8 as American Welding Society Day in the county — Fig. 4.

Carter said, “I would like to congratulate the Society for the pioneering ef-
fort that they have consistently done over the years. The principles, the work ethic that they have embraced, and they have endured and persevered with, have obviously been a success for them. I urge you to continue embracing those principles. We thank you for the contributions that you have made not just here in Miami-Dade County but to industry worldwide.”

Attending were Ron Pierce, Foundation chair; William Rice, vice president-elect; Damian Kotecki, past president; Earl Lipphardt, treasurer; Victor Matthews and John Bruskotter, vice presidents; Neal Chapman, District 6 director; Mace Harris, District 15 director; Dean Wilson, director-at-large; and the AWS staff members.

Well-known economist Alan Beaulieu presented his popular and entertaining Economic Forecast at the Welding Equipment Manufacturers Committee (WEMCO) annual meeting. Beaulieu is with the Institute for Trend Research, Concord, N.H.

Economist Addresses WEMCO Meeting

Fig. 3 — John Mendoza (right) is introduced by Executive Director Ray Shook on beginning his first term as an AWS vice president.

Fig. 4 — Wayne Carter (left) presents President Lawson with a proclamation designating February 8 as American Welding Society Day.

Fig. 4 — Wayne Carter (left) presents President Lawson with a proclamation designating February 8 as American Welding Society Day.

Tech Topics

Highlights of the Duplex Stainless Steel Pipe Welding Guide

BY RICHARD E. AVERY AND BARBARA K. HENON

The AWS D10Y Subcommittee on Duplex Pipe Welding has completed its work on the Guide for Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing, and has recently released it for publication.

The duplex stainless steels are finding increased use in industry where their good corrosion resistance and high mechanical strength properties can offer advantages over the alternate alloys. However, the metallurgy of the duplex stainless steels is significantly different from the more commonly used austenitic chromium-nickel stainless steels, and these differences must be considered in order to make quality pipe and tube welds. The Guide explains these metallurgical differences and modifications needed to develop successful welding procedures.

A high-quality root pass weld in duplex stainless steels is essential for ensuring structural strength and corrosion resistance. The Guide gives considerable attention to automatic and orbital root pass welding to provide defect-free welds with the desired dimensional requirements. Typical joint designs for various wall thickness are included. The importance of heat input control of the root and hot pass on corrosion resistance is also illustrated and suggested guides offered.

The important need to maintain a proper ferrite-austenite balance in the weldment and measures to control this balance through methods such as shielding gas composition are covered.

The correct weld ferrite-austenite balance can also be achieved by using a nickel-enriched filler metal. The new Guide includes a list of commonly used duplex filler metals.

The heat from welding may generate detrimental phases, such as sigma, that in turn can reduce the corrosion-resistance and mechanical properties. Measures to reduce sigma are addressed in the Guide. The importance of heat input control of the root and hot pass on corrosion resistance are illustrated, and suggested control guides offered. Corrosion tests of duplex welds are often a requirement and specimen preparation can be a critical factor. This area and corrosion test parameters are also presented.

Individuals interested in welding ferritic/austenitic duplex stainless steel piping and tubing will find this Guide most helpful and should consider adding it to their technical libraries.

RICHARD E. AVERY (richardea@aol.com) is D10Y Subcommittee chairman and consultant to the Nickel Institute; and BARBARA K. HENON, PhD, is manager technical publications at Arc Machines, Inc.
New Standards Projects

Development work has begun on the following two revised standards. Persons affected by these standards are invited to contribute to their development. Contact the staff engineer listed with the document. Participation on AWS technical committees and subcommittees is open to all persons.

B2.1-200X, Standard Welding Procedure Specification for Gas Tungsten Arc Welding of Aluminum (M/P/S 22 to M/P/S 22), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing. This standard contains the essential welding variables for aluminum in the thickness range of 10- through 18-gauge using manual GTAW. It cites the base metals and operating conditions necessary to make the weldment, the filler metal specifications, and the allowable joint designs for fillet welds and groove welds. Stakeholders are welders and shops. Contact Stephen Borrero, ext. 313.

C3.3:200X, Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components. This standard lists the necessary steps to ensure the suitability of brazed components for critical applications. Although such applications vary widely, they have certain common considerations with respect to materials, design, manufacture, and inspection. It is the intent of this document to identify and explain these common considerations and the best techniques for dealing with them. It is beyond the scope of this document to provide specific details on these techniques that the user must adapt to fit each particular application. Stakeholders are brazing engineers, educators, general interest groups, etc. Contact Stephen Borrero, ext. 334.

ISO/DIS 5173, Destructive tests on welds in metallic materials — Bend tests.


New Standard Approved by ANSI


Technical Committee Meetings

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should contact the staff secretary shown. Call (800/305) 443-9353, ext. 466, adavis@aws.org.

Standards for Public Review

AWS was approved as an accredited standards developing 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. The five revised standards listed have been submitted for public review. Draft copies may be obtained from Rosalinda O’Neill, (800/305) 443-9353, ext. 451, ronell@aws.org.


ISO Standards for Public Review

Copies of the following two draft international standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., Fourth Floor, New York, NY, 10036; (212) 642-4900. Send any comments regarding these documents to your national standards body.

In the United States, if you wish to participate in the development of international standards for welding, contact Andrew Davis, (305) 443-9353, ext. 466, adavis@aws.org.

J1 Committee: Resistance Welding

Share your expertise by contributing to the development of AWS standards. Volunteers are needed by the J1 Committee on Resistance Welding Equipment to help prepare Welding standards related to RW consumables, components, and machinery. Contact Annette Alonso, (800) 443-9353, ext. 472; gayler@aws.org.

Tech Want Ads

C5 Committee: Arc Welding and Cutting

The AWS C5 Committee on Arc Welding and Cutting seeks volunteers to assist in the preparation of recommended practices for all of the widely used arc welding and cutting processes. Much of the content of the AWS Welding Handbook on arc welding and cutting processes is taken from these C5 recommended practices. To learn more about this committee’s work, contact John Gayler, (800) 443-9353, ext. 472; gayler@aws.org.

D11 Subcommittee: Reinforcing Bars

Volunteers are sought to serve on the D11 Subcommittee on Reinforcing Bars. This subcommittee is currently revising D1.4, Structural Welding Code — Reinforcing Steel. To learn more about this committee’s work, contact Selvis Morales, (800) 443-9353, ext. 313; smorales@aws.org.

Errata A5.22

AWS A5.22-95 (R2005), Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding.

The following errata have been identified and corrected in current reprints of this document. Page 2, Table 1: Change content of “N” from “0.08–2.0” to “0.08–0.20” for AWS Classification “E2209T0-X.”

WELDING JOURNAL 55
Member-Get-A-Member Campaign

Listed are the members participating in the 2007–2008 AWS Member-Get-A-Member Campaign for the period between June 1, 2007, and May 31, 2008. For campaign rules and a prize list, see page 67 of this Welding Journal. Standings are as of 2/18/2008. If you have any questions regarding your member proposer points, call the Membership Department, (800) 443-9353, ext. 480.

Winners’ Circle

Members who have sponsored 20 or more new Individual Members, per year, since June 1, 1999. The superscript indicates the number of times the member has achieved Winner’s Circle status.

J. Compton, San Fernando Valley7
E. Ezell, Mobile5
J. Merzthal, Peru2
G. Taylor, Pascagoula2
B. Mikeska, Houston1
R. Peaslee, Detroit1
W. Shreve, Fox Valley1
M. Karagoulis, Detroit1
S. McGill, NE Tennessee1
L. Taylor, Pascagoula1
T. Weaver, Johnstown-Altoona1
G. Woomer, Johnstown-Altoona1
R. Wray, Nebraska1
M. Haggard, Inland Empire1

President’s Club

AWS Members sponsoring 3–8 new Individual Members.

L. Taylor, Pascagoula — 9
E. Ezell, Mobile — 20

President’s Honor Roll

AWS Members sponsoring 1 or 2 new Individual Members. Only those sponsoring 2 AWS Individual Members are listed.

M. Beato, Mobile — 3
J. Compton, San Fernando Valley
D. Daugherty, Indiana
R. Gaffney, Tulsa
W. Galvry Jr., Long Beach/Or. County
H. Jackson, L.A./Inland Empire
C. Johnson, Northern Plains
J. Johnson, Northern Plains
D. Landon, Iowa
S. Leighton, Louisville
J. McCarty, St. Louis
T. Moffitt, Tulsa
J. Nieto, Corpus Christi
F. Schmidt, Niagara Frontier
T. Snider, Michigan
A. Sumal, British Columbia
J. Truitt, San Diego
R. Wright, San Antonio
P. Zammit, Spokane

Student Member Sponsors

Members sponsoring 3 or more new AWS Student Members.

S. Siwiski, Milwaukee — 45
D. Berger, New Orleans — 38
M. Reiter, Columbus — 36
G. Euliano, Northwestern Pa. — 34
R. Evans, Siouxland — 34
T. Zablocki, Pittsburgh — 28
M. Anderson, Indiana — 26
G. Carl, Michigan — 21
G. Smith, Lehigh Valley — 20
J. Daugherty, Louisville — 19
G. Seese, Johnstown-Altoona — 19
B. Harrison, York-Central Pa. — 19
J. Kacir, Detroit — 18
C. Kipp, Kipp — 18
J. Carver, Indiana — 18
M. Reiter, Columbus — 18

President’s Guild

Members sponsoring 20 or more new Individual Members.

L. Taylor, Pascagoula — 94
E. Ezell, Mobile — 20

President’s Roundtable

AWS Members sponsoring 9–19 new Individual Members.

J. Sanchez, Cuautitlan Izcalli — 9

Student Member Sponsors

Members sponsoring 3 or more new AWS Student Members.

S. Siwiski, Milwaukee — 45
D. Berger, New Orleans — 38
M. Reiter, Columbus — 36
G. Euliano, Northwestern Pa. — 34
R. Evans, Siouxland — 34
T. Zablocki, Pittsburgh — 28
M. Anderson, Indiana — 26
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G. Smith, Lehigh Valley — 20
J. Daugherty, Louisville — 19
G. Seese, Johnstown-Altoona — 19
B. Harrison, York-Central Pa. — 19
J. Kacir, Detroit — 18
C. Kipp, Kipp — 18
J. Carver, Indiana — 18
M. Reiter, Columbus — 18

Nominees Sought for Robotic Arc Welding Awards

Nominations are solicited for the 2009 Robotic and Automatic Arc Welding Award. December 31 is the deadline for submitting nominations. The nomination packet should include a summary statement of the candidate’s accomplishments, interests, educational background, professional experience, publications, honors, and awards. Send your nomination package to Wendy Sue Reeve, awards coordinator, 550 NW LeJeune Rd., Miami, FL 33126. For more information, contact Wendy Sue Reeve at wreere@aws.org or call (800/305) 443-9353, ext. 293.

In 2004, the AWS D16 Robotic and Automatic Arc Welding Committee, with the approval of the AWS Board of Directors, established the Robotic and Automatic Arc Welding Award. The award was created to recognize individuals for their significant achievements in the area of robotic arc welding. This work can include the introduction of new technologies, establishment of the proper infrastructure (training, service, etc.) to enable success, and any other activity having significantly improved the state of a company and/or industry. The Robotic Arc Welding Award is funded by private contributions. This award is presented during the FABTECH International & AWS Welding Show held each fall.

R. Bridell, St. Louis — 14
H. Browne, New Jersey — 14
T. Geisler, Pittsburgh — 14
C. Overfelt, SW Virginia — 14
A. Stute, Madison-Beloit — 14
A. Wyatt, Holston Valley — 13
R. Munns, Utah — 12
T. Buchanan, Mid-Ohio Valley — 11
M. Rotary, Detroit — 11
J. Compton, San Fernando Valley — 10
D. Lynn, Ozark — 10
R. Tully, San Francisco — 10
P. Bedel, Indiana — 9
R. Hutchins, Long Beach/Or. Cty. — 9
D. Williams, North Texas — 9
A. Badeaux, Washington D.C. — 8
W. Komlos, Utah — 8
D. Kowalski, Pittsburgh — 8
M. Legel, Maine — 8
J. McCarty, St. Louis — 8
C. Schiner, Wyoming Section — 8
T. Smith, Utah — 8
J. Boyer, Lancaster — 7
H. Hughes, Mahoning Valley — 7
L. Smeglia, Cleveland — 7
T. Strickland, Arizona — 7
W. Troutman, Cleveland — 7
D. Vranich, North Florida — 7
D. Zabel, SE Nebraska — 7
J. Boyer, Lancaster — 6
J. Cox, Spokane — 6
B. Hallila, New Orleans — 6
E. Norman, Ozark — 6
T. Shirk, Tidewater — 6
B. Wenzel, San Francisco — 6
P. Carney Jr., Lehigh Valley — 5
B. Hardin, San Francisco — 5
R. Hilty, Pittsburgh — 5
L. Taylor, Pascagoula — 5
J. Angelo, El Paso — 4
J. Craiger, Indiana — 4
G. Eillar, Detroit — 4
S. Hansen, SE Nebraska — 4
R. Ledford Jr., Birmingham — 4
R. Olesky, Pittsburgh — 4
R. Richwine, Indiana — 4
S. Robeson, Cumberland Valley — 4
C. Rossi, Washington, D.C. — 4
C. Yager, Northeastern Carolina — 4
N. Carlson, Idaho/Montana — 3
J. Crosby, Altanta — 3
A. Kitchens, Olympic Section — 3
W. Galvry Jr., Long Beach/Or. Cty. — 3
J. Geesey, Pittsburgh — 3
R. Purvis, Sacramento — 3
R. Wahrman, Triangle — 3

Northern Plains
C. Yaeger, Northeastern Carolina — 4
J. Ciaramitaro, N. Central Florida — 4
M. Arand, Louisville — 16
D. Ketler, Willamette Valley — 17
M. Arand, Louisville — 16
J. Ciaramitaro, N. Central Florida — 16
C. Donnell, Northwest Ohio — 15
J. Kacir, Detroit — 18
C. Overfelt, SW Virginia — 14
A. Stute, Madison-Beloit — 14
A. Wyatt, Holston Valley — 13
R. Munns, Utah — 12
District 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
January 28
Activity: The Section’s executive board met at Artisan Industries in Waltham, Mass. In attendance were District 1 Director Russ Norris, Chairman Tom Ferri, Laurie Jones, Carl Richardson, Rick Moody, Jack Paige, Gary Hyland, Jim Reid, Bob Lavoie, and Jim Shore.

GREEN & WHITE MOUNTAINS
January 17
Activity: The Section hosted its first vendors’ night at River Valley Technical Center in Springfield, Vt. Rich Fuller, head welding instructor, hosted the event. Participating vendors included Arc One, Hypertherm, Lincoln, Miller, Thermal Dynamics, and J. Walter. The Section plans to make vendors’ night an annual event.

February 14
Activity: The Green & White Mountains Section members and CWI Geoff Putnam judged the test pieces welded by Vermont students in preparation for their SkillsUSA trials. Larry Kirchoff was presented the District Educator Award by Russ Norris, District 1 director.

MAINE
January 24
Activity: The Section hosted its third annual vendors’ night program at Southern Maine Community College in South Portland.

Shown at the Green & White Mountains Section vendors’ night program are (from left) Jerry Ouellette, Ernie Plumb, Jim Reid, Adam Fallon, Gary Buckley, John Steel, Bill McKone, Geoff Putnam, Chair Ray Henderson, Dean Donovan, Chris Bremer, Chuck Sarcia, Joe DeCosta, Phil Wittman, Ken Albert, instructor Rich Fuller, Gordon Snyder, John Erasseur, and Tom Ferri, Boston Section chairman.

Shown at the Boston Section board meeting are (seated, from left) Laurie Jones, Carl Richardson, and Rick Moody; (back row, from left) Jack Paige, Gary Hyland, Jim Reid, Chair Tom Ferri, Bob Lavoie, and Jim Shore.

Ray Henderson (left) receives his chairman’s pin from Russ Norris, District 1 director, at the January Green & White Mountains Section program.

Larry Kirchoff (left) receives the District Educator Award from Russ Norris, District 1 director, at the February meeting of the Green & White Mountains Section.
Mark Legel, head instructor, coordinated the program and conducted a tour of his metal fabrication shop. Arthur S. Gallant received his Silver Membership Certificate for 25 years of service to the Society. The vendors exhibiting their wares included Advantage Gases, Bosch Tools, Hobart, Miller Electric, Pacific Laser Systems, Smith Cutting Equipment, Thermadyne, and Bremer Sales.

February 7
Activity: The Maine Section members met with District 1 Director Russ Norris to plan for the Maine State SkillsUSA tests to be held in Bangor. Vice Chair Tom Cormier and Jeff Fields, Maine SkillsUSA test co-chairmen, discussed the project then assigned jobs to each attendee to be completed by March 13. The meeting was held at Verrillos Restaurant in Portland, Maine.

Nominees Solicited for Prof. Koichi Masubuchi Award

November 3, 2008, is the deadline for submitting nominations for the 2009 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology. It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development. The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an AWS member. The nominations should be prepared by someone familiar with the research background of the candidate. Include a resume listing background, experience, publications, honors, awards, plus a least three letters of recommendation from researchers.

This award was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures.

Submit your nominations to Prof. John DuPont at jnd@lehigh.edu.
Shown at the February New Jersey Section program are award winners (from left) Steve Dagnall, Al Fleury, Don Smith, George Sheehan, Sean Bradley, and Sean Mitchell.

Speaker Ben Schiavone (left) chats with Philadelphia Section Chair John DiSantis.

Frank Babish (left) receives a speaker appreciation gift from Bob Petrone, New Jersey Section awards chairman.

Harry Ebert was the featured speaker at the New Jersey Section program in February.

FEBRUARY 19
Speaker: Harry Ebert, consultant, welding engineer
Topic: Discussion of welding terminology
Activity: This New Jersey Section awards-presentation meeting honored Steve Dagnall, Section Appreciation Award; Al Fleury, Section Meritorious Award; Don Smith, District Educator Award; George Sheehan, Section Educator of the Year Award; Sean Bradley, Section Meritorious Award; and Sean Mitchell, District Private Sector Award.

PHILADELPHIA
FEBRUARY 6
Speaker: Ben Schiavone, president
Affiliation: Schiavone Electronics Labs
Topic: NASCAR welding and NDE
Activity: The program was held in Essington, Pa., at Ramada Inn.

District 3
Director: Alan J. Badeaux Sr.
Phone: (301) 753-1759

LEHIGH VALLEY
JANUARY 23
Activity: The Section hosted its 38th annual student welding competition at Bethlehem Area Vocational Technical School in Bethlehem, Pa. Seven area schools each provided two students for the event. The competitors were Amir

Shown at the joint York-Central Pennsylvania and Lancaster Sections’ program are (from left) Ed Calaman, York-Central Pa. Section Chairman Dave Herr, speaker Matt Reiff, Dean Whitmer, and Mike Bunnell.

Shown are the students who participated in the Lehigh Valley Section’s 38th annual welding competition.
Shown are the attendees at the joint York-Central Pennsylvania and Lancaster Sections program held at Precision Custom Components.

Several Student Chapter members are shown with their instructor Josh Seitzer and presenters Tom Murphy and Dave Muro at the York-Central Pennsylvania Section meeting.


Shown at the York-Central Pennsylvania Section program in February are Chairman Dave Herr (center), with presenters Tom Murphy (left) and Dave Muro.

Dave Averyt displayed his blacksmithing skills for the Atlanta Section members.

YORK-CENTRAL PA./LANCASTER
JANUARY 10
Speaker: Matt Reiff, welding engineer
Affiliation: Welding Alloys USA
Topic: Metal cored stainless steel subarc welding wires
Activity: This joint meeting with members of the Lancaster Section was held at Precision Custom Components LLC in York, Pa.

SOUTHWEST VIRGINIA
JANUARY 30
Speaker: Bill Wallace, senior account representative
Affiliation: 3M Occupational Health and Environmental Safety division
Topic: Hexavalent chromium safety standards affecting the welding industry
Activity: The program was held in Roanoke, Va.

TIDEWATER
April 17: Golf outing, Ron Davis, organizer.
May 15: Fish fry at Ft. Monroe, shelter 5.
Sept. 11: Fall kickoff picnic.
Oct. 9: Scott Nelson, speaker.
Contact: Jon Cookson, chair, (757) 865-3122; cooksonj@tncc.edu

ATLANTA
DECEMBER 15
Activity: The Section members observed Dave Averyt, senior blacksmith, use forge welding to create a variety of objects. He presented his techniques in a step-by-step process to give a better understanding of his art. The meeting was held at Lanier Technical College in Winder, Ga.

FLORIDA WEST COAST
FEBRUARY 13
Activity: Twenty-five Section members and guests toured Lazzara Yachts fabrication facility in Tampa, Fla. All phases of yacht building were studied, high-
lighted by a visit to a $6-million yacht in Tampa Bay. Michael Schenk, general manager, conducted the program.

SOUTH CAROLINA
JANUARY 17
Activity: The Section members toured the ESAB Welding & Cutting Systems facilities in Florence, S.C. Tim Mayhan, plant manager, conducted the tour and demonstrations of aluminum friction stir welding, robotic arc welding, aluminum gas tungsten arc, and pulse on pulse aluminum gas metal arc welding. Gerald Uttrachi, past AWS president, attended the program.

NIAGARA FRONTIER
JANUARY 22
Activity: The Section members toured the Flying Bisons Brewery in Buffalo, held at Mill Road Restaurant & Tavern in Latham, N.Y., was attended by 52 members and guests.

NORTHERN NEW YORK
FEBRUARY 5
Speaker: Jeff Bernath, welding research engineer
Affiliation: Edison Welding Institute
Topic: Fundamentals of friction stir welding and applications in production
Activity: This was a joint meeting with members of the Eastern New York Chapter of ASM International. The program,

DISTRICT 6
Director: Neal A. Chapman
Phone: (315) 349-6960

DISTRICT 7
Director: Don Howard
Phone: (814) 269-2895
Activity: The Section members toured the Applied Research Laboratory at Penn State University in State College, Pa. Richard P. Martukanitz, head of the Laser Processing Division, made a presentation and guided the tour.

DECEMBER 11
Speaker: Dale Anderson, metallurgical engineer
Affiliation: Concurrent Technologies Corp.
Topic: Pattern welding
Activity: The event was held in Johnstown, Pa.

CHATTANOOGA
JANUARY 22
Speaker: George Mendez, welding and robotics field service engineer
Affiliation: Panasonic Factory Solutions Co. of America, Buffalo Grove, Ill.
Topic: Robotic digital controls and tandem wire gas metal arc welding
Activity: Fifty-two Section members and guests met at Komatsu America Corp. in Chattanooga, Tenn. Following the talk, Don Russell presented background information about Komatsu, then Mendez discussed robotic arc welding and expectations for its applications in the future. The highlight of the program was a demonstration of the tandem wire gas metal arc welding process.

HOLSTON VALLEY
FEBRUARY 5
Speaker: Denny Davis, technical representative
Affiliation: The Lincoln Electric Co.
Topic: Latest developments in welding technology and equipment
Activity: The membership determined regular meetings will be planned for the first Tuesday night of each month. The tour of American Water Heater Co. was canceled and will be rescheduled. The meeting was held at Golden Corral Restaurant in Johnson City, Tenn.
Shown at the February New Orleans Section program are (from left) District 9 Director George Fairbanks, AWS President Gene Lawson, AWS Vice President John Bruskotter, and Chairman Travis Moore.

**District 9**

**Director:** George D. Fairbanks  
**Phone:** (225) 673-6600

**MOBILE**

**FEBRUARY 14**

**Speaker:** Gene Lawson, AWS president  
**Affiliation:** ESAB Welding & Cutting  
**Topic:** AWS updates and developments in FCAW  
**Activity:** In attendance were District 9 Director George Fairbanks and AWS Vice President John Bruskotter. The program was held at Saucy Q Restaurant in Mobile, Ala.

**NEW ORLEANS**

**JANUARY 15**

**Speaker:** Gerard Riche  
**Affiliation:** Airgas  
**Topic:** Compressed gases  
**Activity:** Rick Myer was presented the sponsor plaque in appreciation for Airgas’s support for the Section’s activities. The lucky 50/50 raffle winner was Rene DeShotel. Eighty members and guests attended the program.

**FEBRUARY 12**

**Speaker:** Gene Lawson, AWS president  
**Affiliation:** ESAB Welding & Cutting  
**Topic:** Proposed solutions to the shortage of welders in the United States  
**Activity:** Rodney Dufour from Inspection Specialists, Inc., was presented a sponsor appreciation plaque for his company’s support of the Section’s activities. About 80 people attended this program held at Inspection Specialists in New Orleans, La.

**District 10**

**Director:** Richard A. Harris  
**Phone:** (440) 338-5921

**NEW ORLEANS**

**JANUARY 15**

**Speaker:** Bruce Hallila  
**Affiliation:** Airgas  
**Activity:** Travis Moore, New Orleans Section chair, at the February program.

**FEBRUARY 12**

**Speaker:** Rodney Dufour (center) receives a sponsor appreciation award from District 9 Director George Fairbanks (left) and Travis Moore, New Orleans Section chair, at the February program.

**MOBILE**

**FEBRUARY 14**

**Speaker:** Denny Davis (left) is shown with Dale Hicks, a welding instructor at Tennessee Technology Center, during the Holston Valley Section program.

**NEW ORLEANS**

**JANUARY 15**

**Speaker:** District 9 Director George Fairbanks, AWS President Gene Lawson, AWS Vice President John Bruskotter, and Chairman Travis Moore.

**District 9 Director:** George D. Fairbanks  
**Phone:** (225) 673-6600  
**Affiliation:** ESAB Welding & Cutting  
**Activity:** In attendance were District 9 Director George Fairbanks and AWS Vice President John Bruskotter.

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**District 10**

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**MOBILE**

**FEBRUARY 14**

**Speaker:** Denny Davis (left) is shown with Dale Hicks, a welding instructor at Tennessee Technology Center, during the Holston Valley Section program.
Gordon Carlson discussed welding alloys for the Drake Well Section members.

Emcees for the Detroit Section’s ladies’ night event were Vice Chair Michael Karagoulis and his wife, Lynne.

The Indiana Section’s welding contest committee members are shown at their January planning meeting.

Speaker: Dean Phillips, manager, welding engineering
Affiliation: Hobart Brothers Co.
Topic: WPS/PQR and filler metal testing requirements
Activity: Chuck Moore received the District Meritorious Award. Leon Stitt was presented the Section Meritorious Award, and Chairman Huck Hughes received the District Educator Award. District 10 Director Rich Harris made the presentations. The program was held at Manor Restaurant in Austintown, Ohio.

**District 11**
Director: Efthiios Siradakis
Phone: (989) 894-4101

**DETROIT**
FEBRUARY 8
Activity: The Section held its 68th annual ladies’ night party at Atheneum International Banquet Center in Detroit, Mich. Vice Chair Michael Karagoulis and his wife, Lynne, hosted the event. Ladies’ night has been an important activity for the Detroit Section for nearly 70 years. It is an opportunity for the welding community to come together for camaraderie and celebration. Most importantly, funds raised from the evening are used to support the Section’s scholarship program. Since its inception, the Detroit Section has raised more than $750,000 to fund scholarships for students pursuing careers in welding. The event attracted 350 attendees.

**District 12**
Director: Sean P. Moran
Phone: (920) 954-3828

**District 13**
Director: W. Richard Polanin
Phone: (309) 694-5404

**District 14**
Director: Tully C. Parker
Phone: (618) 667-7744

**INDIANA**
JANUARY 23
Activity: The Section’s welding contest committee members met to finalize plans for three upcoming projects. Plans were set for the SkillsUSA regional contests, the Section-sponsored Annual Mid-West Team Welding Tournament, and the SkillsUSA Indiana state welding contest. The meeting was held at Jonathan Byrd’s Cafeteria in Greenwood, Ind.
District 15
Director: Mace V. Harris
Phone: (952) 925-1222

SASKATOON
DECEMBER 4
Activity: The Section members participated in a graduate student seminar at the University of Saskatchewan in Saskatoon, Canada. Coordinated by Qiaoqin Yang and Fang Xiang Wu, the six-hour program included papers presented by Songlan Yang, Heather Huenison, Williams Uju, Yang Lin, Jeffrey King, Wenwen Yi, Nahshon Bawolin, Chris Zhang, Srinivasan Sethuraman, and Minggan Li. The event concluded with a holiday party hosted by the Department of Mechanical Engineering.

District 16
Director: David Landon
Phone: (641) 621-7476

IOWA
JANUARY 22
Activity: The Section members toured the ALMACO facilities in Nevada, Iowa, to study the manufacture of custom-made harvesters and planters for the seed corn and soybean industry. District 16 Director David Landon attended the program.

KANSAS CITY
FEBRUARY 7
Speaker: Mike Ross
Affiliation: Fanuc Robotics
Topic: Advancements in robotics
Activity: The meeting was held at Masterpiece Barbeque in Kansas City, Mo.

NEBRASKA
JANUARY 19
Activity: The Section hosted its second annual bowling tournament fund-raising and scholarship awards-presentation program at Maplewood Lanes in Omaha, Neb. Seventeen teams competed in a Scotch doubles nine-pin, no tap contest. More than $900 was raised for the Section’s scholarship program from entry fees, lane sponsorships, and a silent auction. The Jeff Rodgers and Gary Barnes team from Praxair took first-place honors. Kelsey Orendach, a senior at Westside High School, was presented the post-secondary education scholarship for $1000. Three $250 secondary education scholarships were awarded to Noah Banks, Anthony Caniglia, and Andy Smith. The lane sponsors for the event were Davis Erection Co., Ironworkers Local 21, Linweld, Metro Community College, Olsson Associates, Praxair Distribution, and TSA Manufacturing Co.

District 17
Director: J. J. Jones
Phone: (940) 368-3130

NORTH TEXAS
JANUARY 15
Speaker: Ron Weisz
Affiliation: 3M Corp.
Topic: Welding fumes and use of respirators
Activity: Among the 69 attendees at the program were welding students from local schools. ATI student Joseph Heck won a power grinder, and Tarrent County College student Angela Joldin won a set of welding leathers.

FEBRUARY 19
Speaker: Gene Lawson, AWS president
Student Angela Joldin shows off the set of leathers she won at the North Texas Section program.

Welding student Joseph Heck won a power grinder at the North Texas Section meeting.

Shown at the Nebraska Section bowling tournament are (from left) Monty Rodgers, Vice Chair Jason Hill, Secretary Nick Weidenbach, first-place team winners Jeff Rodgers and Gary Barnes, Chairman Rick Hanny, and Treasurer Karl Fogleman.

Shown at the Nebraska Section program are (from left) Vice Chair Jason Hill, Monty Rodgers, scholarship winner Kelsey Orendach, Chairman Rick Hanny, Secretary Nick Weidenbach, and Treasurer Karl Fogleman.

North Texas Section Chair Robert Tessier (left) presents a speaker gift to Ron Weisz.
Robert Tessier (left) receives the District Meritorious Award from J. Jones, District 17 director, at the North Texas program in February.

**OZARKS**

**JANUARY 17**

Activity: The Section members toured the newly refurbished welding show at Southwest Area Career Center in Monett, Mo. Ed Norman, instructor and education director, conducted the program. The Section received an appreciation award from the Joplin Chapter of the Society of Manufacturing Engineers for its contributions to the society’s scholarship program.

**TULSA**

**JANUARY 22**

Speaker: Mike Ross, district account manager, arc welding and lasers

Affiliation: Fanuc Robotics America

Topic: Robotics for welding

Activity: The program was held at the Lincoln Electric district sales office in Tulsa, Okla.
District 18
Director: John Bray
Phone: (281) 997-7273

HOUSTON
JANUARY 16
Speaker: John Lecour, contractor
Affiliation: NASA
Topic: The U.S. manned space program
Activity: The Section presented Gold Membership Award certificates for 50 years of service to the Society to V. C. Reed, past AWS President John Bartley, and Robert Anderson. Recognized were past Section chairs Ron Theiss, Dennis Eck, Ron van Arsdale, Larry Wilmesmeier, and Roy Morton; John Bartley, Robert Anderson, Robert Hunt, Christopher Bloch, Asif Latif, and John Bray, District 18 director.

SAN ANTONIO
FEBRUARY 13
Speaker: John Bray, District 18 director
Affiliation: Affiliated Machinery, Inc., president
Topic: District 18 activities and a report on the recent Weldmex Show
Activity: The program was held at The Spaghetti Warehouse in San Antonio, Tex.

District 19
Director: Neil Shannon
Phone: (503) 201-5142

SPokane
NOVEMBER 16
Activity: The Section members toured ASC Machine Tools, Inc., in Spokane, Wash. Rick Eiffert, fabrication supervisor, discussed the history and evolution of the company, then conducted a tour of the facility.

JANUARY 16
Activity: The Spokane Section members toured the Local Ironworkers Appren-
More than 160 students and teachers from local schools attended the Spokane Section program in January.

Rick Eiffert conducted the Spokane Section members on a tour of ASC Machine Tools in November.

Phil Zammit, a past District 19 director, spoke at the Spokane Section program in January.

Spokane Section Chairman Art Sabiston (right) and Vice Chair Terry Sanchez introduced the speakers at the January 16 program held at the Local Ironworkers Apprenticeship Training Center.

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The Albuquerque Section members pose for a group shot during their tour of Speed of Light².

Tim McJunkin (left) receives the District Director Certificate Award from Paul Tremblay, chairman of the Idaho/Montana Section.

San Francisco Section Chair Tom Smeltzer (left) chats with speaker David L. Norris.

Ed Dalder (left) receives his Gold Membership certificate from Tom Smeltzer, San Francisco Section chairman.

Shown at the Idaho/Montana Section awards-presentation program are (from left) Norma and Scott Jensen, Ofilia and Chair Paul Tremblay, Stephanie Eaton, speaker Larry Zirker, and Tim McJunkin.

District 22
Director: Dale Flood
Phone: (916) 933-5844

SAN FRANCISCO
February 6
Speaker: David L. Norris, CWI
Affiliation: ES Geotechnologies
Topic: Case studies where following the rules ended up in disaster
Activity: Gold Membership certificates for 50 years of AWS membership were presented to C. E. Witherrell and E. N. Dalder. Life Membership certificates were awarded to Alan Demmons and Ronald Yonekawa for 35 years of service to the Society. Byron May and Steven Nekimken received Silver Membership certificates for 25 years of membership.

The program was held at Spenger’s Restaurant in Berkeley, Calif.
New Sustaining Companies

Irwin Industries, Inc.
1580 W. Carson St.
Long Beach, CA 90810
(310) 233-3000; www.irwinindustries.com
Representative: John D. Cotton Jr.
Irwin Industries, Inc., is a leading industrial construction, maintenance, and engineering service provider offering self-performed civil, structural, and mechanical construction on a firm-price and time-and-materials basis. Founded in Long Beach, Calif., in 1922, the company serves the onshore and offshore oil and gas, petrochemical, power-generation, and other heavy industries nationwide.

Olsson Associates
8720 S. 114th St., Ste. 107
La Vista, NE 68128
(402) 827-7220; www.oaconsulting.com
Representative: Eric J. Nordhues
Since 1956, Olsson Associates has been providing its clients with comprehensive design and consulting engineering services. It offers expertise in many disciplines, including transportation, structural, water and waste water, mechanical, geotechnical, materials testing, and inspections. The company specializes in structural steel inspection and testing employing certified welding inspectors and nondestructive testing personnel and equipment. It also provides written procedures for procedure qualification test records, welding procedure specifications, and welder qualification test records for fabricators and erectors for AWS, AME, API, and other codes.

The Tiberti Co.
4975 Roger St.
Las Vegas, NV 89118
(702) 382-7070; www.tiberti.com
Representative: Jerry Tanner
The Tiberti Fence Co. is a full-phase general contracting company with an AB Unlimited License. The company specializes in chain-link fencing, ornamental iron, playground equipment, gate operators, and custom-built iron. As the largest chain-link fence contractor in Nevada, it is a full-service provider from manufacturing to installation with the most reputable warranty on the West Coast.

New Affiliate Companies

Carolina Industrial Services of Sumter, Inc.
PO Box 10
Sumter, SC 29150

Integrated Welding Systems, Inc.
34314 Oak Knoll Rd.
Burlington, WI 53105

Lake Champlain Transportation
King St. Dock
Burlington, VT 05401

Maccabee Industrial, Inc.
113 Water St.
Belle Vernon, PA 15012

Quality Industries, Inc.
PO Box 7016, 130 Jones Blvd.
La Vergne, TN 37086

Sphere Drilling Supplies
3112 80th Ave. SE
Calgary AB T2C 1J3, Canada

Supreme Welding Inc.
202 2nd Ave. S.
Clearlake, SD 57226

Tower Elevator Systems, Inc.
900 RR 620 S., Ste. C-206
Lakeway, TX 78734

Wyatt Resources, Inc.
PO Box 744
Fulshear, TX 77441

Supporting Companies

Astec Underground
9600 Corporate Park Dr.
London, TX 37774

Ameritech Machine Mfg., Inc.
350 SW Industrial Way
Bend, OR 97702

Cast-Fab Technologies
3040 Forrer St.
Cincinnati, OH 45209

Ernest-Spencer Metals, Inc.
3323 E. 82nd St.
Meriden, KS 60512

Kriton Weld Equipments Pvt.
Plot #406, GIDC Estate, Makarpura,
Vadodara, Gujarat 390010, India

Pendarvis Mfg., Inc.
1808 N. American St.
Anaheim, CA 92801

Southwest Ironwork, Inc.
12312 Horseshoe Tr. SE
Albuquerque, NM 87123

Membership Counts

<table>
<thead>
<tr>
<th>Category</th>
<th>As of Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustaining</td>
<td>3/1/08</td>
</tr>
<tr>
<td>Supporting</td>
<td></td>
</tr>
<tr>
<td>Educational</td>
<td></td>
</tr>
<tr>
<td>Affiliate</td>
<td></td>
</tr>
<tr>
<td>Welding distributor</td>
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<tr>
<td>Total corporate members</td>
<td>1,700</td>
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<tr>
<td>Individual members</td>
<td>47,880</td>
</tr>
<tr>
<td>Student + transitional members</td>
<td>5,019</td>
</tr>
<tr>
<td>Total members</td>
<td>52,899</td>
</tr>
</tbody>
</table>

New AWS Supporters

Irwin Industries, Inc.
4151 W. State Rte. 18
Tiffin, OH 44883

Tradesmen International
1791 Tribute Rd., Ste. 6
Sacramento, CA 95815

Educational Institutions

Crest High School
2006 S. Ankeny Blvd.
Ankeny, IA 50023

Flint Hills Technical College
3301 W. 18th St.
Emporia, KS 66801

Lilama Technical & Technology College
Km. 32 Nat. Rd. 51, Long Phuor
Long Than, Dong Nai, Vietnam

Putnam Career and Technical Center
101 Roosevelt Blvd., Rte. 62
PO Box 640, Eleanor, WV 25070

Southwest Alaska Vocational and Education Center, Bldg. 647 KSAFB
King Salmon, AK 99613

The Center of Industry & Technology
A division of Colltech Training Institute
4801 Fulton Industrial Rd.
Atlanta, GA 30336

Welding 101 LLC
218 S. Maple St.
Lebanon, TN 37087

Wenatchee Valley College
1300 Fifth St.
Wenatchee, WA 98801
Nominees for National Office

Only Sustaining Members, Members, Honorary Members, Life Members, or Retired Members who have been members for a period of at least three years shall be eligible for election as a director or national officer.

It is the duty of the National Nominating Committee to nominate candidates for national office. The committee shall hold an open meeting, preferably at the Annual Meeting, at which members may appear to present and discuss the eligibility of all candidates.

To be considered a candidate for the positions of president, vice president, treasurer, or director-at-large, the following qualifications and conditions apply:

President: To be eligible to hold the office of president, an individual must have served as a vice president for at least one year.

Vice President: To be eligible to hold the office of vice president, an individual must have served at least one year as a director, other than executive director and secretary.

Treasurer: To be eligible to hold the office of treasurer, an individual must be a member of the Society, other than Student Member, must be frequently available to the national office, and should be of executive status in business or industry with experience in financial affairs.

Director-at-Large: To be eligible for election as a director-at-large, an individual shall previously have held office as chairman of a Section; as chairman or vice chairman of a standing, technical, or special committee of the Society; or as District director.

Interested persons should submit a letter stating which office they seek, including a statement of qualifications, willingness and ability to serve if nominated and elected, and a biographical sketch.

E-mail the letter to Gricelda Manalich, gricelda@aws.org, c/o Gerald D. Uttrachi, chair, National Nominating Committee.

The next meeting of the National Nominating Committee is scheduled for October 2008. The terms of office for candidates nominated at this meeting will commence January 1, 2010.

Honorary Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These awards are presented during the FABTECH International & AWS Welding Show held each fall. The deadline for submissions is December 31 prior to the year of awards presentations. Send candidate materials to Wendy Sue Reeve, secretary, Honorary Meritorious Awards Committee, wreeve@aws.org; 550 NW LeJeune Rd., Miami, FL 33126. Descriptions of the awards follow.

National Meritorious Certificate Award: This award is given in recognition of the candidate’s counsel, loyalty, and devotion to the affairs of the Society, assistance in promoting cordial relations with industry and other organizations, and for the contribution of time and effort on behalf of the Society.

William Irrgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irrgang. It is awarded each year to the individual who has done the most over the past five years to enhance the American Welding Society’s goal of advancing the science and technology of welding.

George E. Willis Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor George E. Willis. It is awarded each year to an individual for promoting the advancement of welding internationally by fostering cooperative participation in areas such as technology transfer, standards rationalization, and promotion of industrial goodwill.

International Meritorious Certificate Award: This award is given in recognition of the recipient’s significant contributions to the worldwide welding industry. This award reflects “Service to the International Welding Community” in the broadest terms. The awardee is not required to be a member of the American Welding Society. Multiple awards can be given per year as the situation dictates. The award consists of a certificate to be presented at the awards luncheon or at another time as appropriate in conjunction with the AWS president’s travel itinerary, and, if appropriate, a one-year membership in the American Welding Society.

Honorary Membership Award: An Honorary Member shall be a person of acknowledged eminence in the welding profession, or who is accredited with exceptional accomplishments in the development of the welding art, upon whom the American Welding Society sees fit to confer an honorary distinction. An Honorary Member shall have full rights of membership.

AWS Publications Sales

Purchase AWS standards, books, and other publications from 
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orders@awspubs.com; www.awspubs.com
Toll-free (888) 925-3464 (U.S., Canada)
(305) 824-1177; FAX (305) 826-6195

Welding Journal Reprints

Copies of Welding Journal articles may be purchased from Ruben Lara.
(800/305) 443-9353, ext. 208; ralau@aws.org

Custom reprints of Welding Journal articles, in quantities of 100 or more, may be purchased from FosteReprints
Toll-free (866) 879-9144, ext. 121
sales@fosteprints.com

AWS Foundation

The AWS Foundation, Inc., is a not-for-profit corporation established to provide support for educational and scientific endeavors of the American Welding Society.

Information on gift-giving programs is available upon request.

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Executive Director, AWS
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Executive Director, Foundation
Sam Gentry, ext. 331, gentry@aws.org

Corporate Director, SOS
Monica Pfarr, ext. 461, mpfarr@aws.org

550 NW LeJeune Rd., Miami, FL 33126
(305) 445-6628; (800) 443-9353, ext. 293
general information:
(800) 443-9353, ext. 689; spiok@aws.org

AWS Mission Statement

The mission of the American Welding Society is to advance the science, technology, and application of welding and allied processes, including joining, brazing, soldering, cutting, and thermal spraying.

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gene E. Lawson, as listed on the previous page.
CALL FOR PAPERS

4th International Brazing & Soldering Conference (IBSC)

Conference dates: April 27-29, 2009

Abstract Deadline: April 30, 2008   Manuscripts Due: July 31, 2008

The American Welding Society and ASM International® are again organizing its world recognized International Brazing & Soldering Conference (IBSC). This four-day event will begin with Short Courses offered on Sunday, followed by a three-day Technical Program Monday-Wednesday. IBSC brings together scientists, engineers and technical personnel from around the globe involved in the research, development, and application of brazing and soldering. Parallel sessions allow us to present the latest advances in these joining technologies and will be organized to permit interaction between the two disciplines.

IBSC 2009 Program Organizers invite you to submit your work for consideration of inclusion in the technical program. They are accepting 150-200-word abstracts describing original, previously unpublished work. The work may pertain to current research, actual or potential applications, or new developments. Whereas commercialism must be avoided to maintain the high level of technical quality and integrity of the IBSC conferences, the new brazing applications and case histories are most welcome.

The technical program will include a special half day session focused on practical and innovative applications of brazing and soldering. The Tabletop Exhibit will provide a forum for commercial presentations and demonstrations of state-of-the-art brazing and soldering materials, processes and equipment. Check our website for details. The Poster Session will allow yet another opportunity to present the interesting developments in brazing and soldering technologies.

A Conference Proceedings containing only full manuscripts of the accepted research papers will be published to capture these high-quality technical presentations for later reference. Presentations focused on practical applications of brazing and soldering will also be included in the conference proceedings.

Below are some of the topical areas covered at IBSC

<table>
<thead>
<tr>
<th>Aircraft and Aerospace</th>
<th>Furnace / Vacuum Brazing</th>
<th>Power and Electrical Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive and Transportation</td>
<td>Joint Design and Reliability</td>
<td>Sensors / Micro-Electronics</td>
</tr>
<tr>
<td>Brazing and Soldering Standards</td>
<td>Lead Free Solders</td>
<td>Solder Joining Methods</td>
</tr>
<tr>
<td>Ceramic / Glass to Metal Joining</td>
<td>Light Metals</td>
<td>Special / Advanced Brazing Processes</td>
</tr>
<tr>
<td>Chemical and Petroleum Production</td>
<td>Materials and Process Design / Control</td>
<td>Structural Solder Applications</td>
</tr>
<tr>
<td>Composite Materials</td>
<td>Medical / Dental</td>
<td>Test Methods and Evaluation</td>
</tr>
<tr>
<td>Electronic Packaging / Sensors</td>
<td>Mining &amp; Heavy Equipment</td>
<td>Thermal Management</td>
</tr>
<tr>
<td>Filler Metal Properties</td>
<td>Modeling and Process Control</td>
<td>Vacuum Brazing</td>
</tr>
<tr>
<td>Fluxes and Atmospheres</td>
<td>Consumer Products</td>
<td>Gasses and Plumbing</td>
</tr>
<tr>
<td>Fixtures and Design and use</td>
<td>Factory Automation</td>
<td>LEAN Brazing Processes</td>
</tr>
<tr>
<td>Musical Instruments</td>
<td>Job-Shop &amp; Process Customization</td>
<td>Low Volume Critical Components</td>
</tr>
</tbody>
</table>

To submit your work for consideration, visit our website at www.aws.org/ibsc then follow the instructions at “Click here to submit your abstract.” All abstract submissions must be completed by close-of-business on Wednesday, April 30, 2008. Before submitting your abstract, we ask that you carefully consider your ability to present your work at the conference. Speakers are required to pay a (reduced) conference registration fee, and are totally responsible for their travel, housing and any related expenses.

This premiere event is truly one that anyone involved in the brazing and soldering community should plan to attend.

Mark your calendar now, and if you are interested in presenting your work at the conference, submit your abstract no later than April 30, 2008.

Endorsing Sponsors:
Guide to Laser Application Resources Online

The 44-page, full-color PDF, Laser Application Resource Guide, can be downloaded from the company’s Web site. It is intended to help laser end users learn how to profit from using laser technology and how to tap into the institute’s corporate members’ expertise on all topics relating to laser technology. The index headings include beam delivery, job shop, laser manufacturers, research and development, system integrators, plus an extensive glossary of laser-related terms. Twelve pages detail laser safety information with diagrams of the human eye and its absorption characteristics for visible, ultraviolet, and mid-infrared radiations.

Laser Institute of America
www.laserinstitute.org/laserguide
(800) 345-2737

Abrasive Products Catalog Updated with New Items

The Rex-Cut® 2008–2009 Specialty Abrasive Products Catalog features the company’s complete lines of products for grinding, blending, and finishing stainless steel, aluminum, mild steel, exotic alloys, fiberglass, and composites. The catalog is intended for use by the welding, aerospace, aircraft, automotive, casting, metal-finishing, tool and die, tank fabrication, and jewelry industries. Included are mounted points and wheels, Type 1 straight wheels, Type 27 depressed-center wheels made from various materials, flap discs, cotton-fiber quick-change discs, stainless steel cutoff wheels, hand-held finishing sticks, accessories, and several...

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application-specific kits. Call to request a copy of the literature.

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www.rexcut.com
(800) 225-8182

Brochure Details Welding High-Nickel Alloys

A 16-page brochure provides information on high-nickel alloys and offers detailed descriptions of the company’s lines of covered electrodes and bare wires. Included are the classifications, approvals, diameters, typical mechanical properties, and chemical compositions. Also specified are the broad range of welding applications for these products in petrochemical plants, offshore and marine environments, chemical processing plants, pipelines, pressure vessels, furnace equipment, nuclear power-generation facilities, and automotive exhaust systems.

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www.arcos.us
(800) 233-8460

Nicrobraz® 31 Brazing Filler Metal Described

A new 2-page data sheet No. 2.1.7.1 provides complete information on Nicrobraz® 31 brazing filler metal. Data are provided on burst strength, composition, brazing range, oxidation resistance, and application methods. The filler metal is recommended for use in many products including heat exchangers, exhaust gas recirculator coolers, honeycomb structures, and oil coolers. Call for a copy or download from the company’s Web site.

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For info go to www.aws.org/ad-index
New Text Features Al-Alloy Fatigue Data

The text, Properties of Aluminum Alloys: Fatigue Data and Effects of Temperature, Product Form, and Process Variables, edited by J. G. Kaufman, includes more than 1100 fatigue data curves, all drawn to consistent formats conveniently arranged by alloy and temper. Included are rotating beam reverse bending fatigue, flexural fatigue, axial-stress fatigue, torsional fatigue, and modified Goodman diagrams. The first part of the book explains the origin of the data, fatigue testing and data analysis procedures, and provides guidelines for the use and interpretation of the data. Detailed discussions are presented on the effect of temperature, production process variables, shape, orientation, and joining and finishing technologies on aluminum-alloy fatigue. The list price is $220, $176 to ASM International members.

ASM International
www.asm.org
(440) 338-5151, ext. 0

Brady Lockout Guide Helps with OSHA Compliance

The 16-page Complete LOTO Solutions handbook is a how-to guide that lays out a straightforward “4 Steps to Compliance” plan for creating an effective energy control program. Each step includes an explanation of OSHA’s basic requirements and provides information on the related resources that the company offers for successful implementation of corporate lockout/tagout programs.

Brady Corp.
(414) 438-6904

Spanish Editions of Welding Specs Offered

The company now offers Spanish language editions of all of its welding product specification sheets. The Spanish editions correlate directly to the English specification sheets, allowing direct correlations of the two documents. The specification sheets include the company’s gas metal arc welding guns, Centerfire™ consumables, replacement necks, liners, and direct plug kits, as well as manual welding products and parts. All of the specification sheets may be downloaded free of charge from the company’s Web site as PDFs.

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Phone: (570) 339-5200 • Fax: (570) 339-5206

For Info go to www.aws.org/ad-index
ABB Names Division Heads

ABB, Norwalk, Conn., has appointed Greg Scheu region division manager of the Power Products division; Rick Hepperla region division manager of the Automation Products division, ABB North America; and Aaron Aleithe vice president and general manager of low-voltage drives. Previously, Scheu served as senior vice president of the company’s Automation Products division in North America. Hepperla previously served as local business unit manager of ABB’s North American low-voltage drives unit based in New Berlin, Wis. Aleithe, with the company since 2005, most recently served as vice president and general manager for the medium-voltage drives business in North America.

Product Manager Spot Filled at Jergens

Jergens, Inc., Cleveland, Ohio, has appointed Jeff Martin as product manager for Kwik-Lok™ pins, inserts, and spring-loaded devices in the company’s Tooling Components division. Previously, Martin operated his own business related to the machine tool industry. He replaces Matthew Schron who earlier had been appointed general manager of Jergens Industrial Supply.

CMW Fills Two Key Posts

CMW, Inc., Indianapolis, Ind., a supplier of highly engineered metal alloys and composites, has named Cecil Taylor an engineering laboratory specialist, and appointed Sharonda Flowers Griffin its human resources manager. Taylor is a recent graduate of the Purdue University chemical engineering program. Prior to joining the company, Griffin worked eight years for International Truck and Engine Corp. in several positions, including production supervisor, quality manager, and human resources generalist.
AWS Names Certification Operations Director

The American Welding Society, Miami, Fla., has appointed John Filippi managing director, certification operations. Prior to joining the Society, Filippi, who has 20 years of experience in the field, served as operations manager at Ikon Office Solutions, Inc., based in Miami, Fla.

Lincoln Electric Makes Four Staff Changes

Lincoln Electric Holdings, Inc., has announced the promotions of Vincent K. Petrella, senior VP and CFO, and George Blankenship, senior VP, Global Engineering and U.S. Operations, to expanded roles within the company. Petrella has been given the additional responsibility for The Lincoln Electric Co. of Canada. Blankenship has been promoted to the newly created position of president, Lincoln Cleveland, responsible for the Euclid and Mentor, Ohio, plants. The Lincoln Electric Co., Cleveland, Ohio, has appointed Scott Funderburk global business segment director — pipelines. He has been with the company since 1996. Prior to this time, Funderburk led the Applications Engineering team that focused on productivity improvements and sharing of technology and welding procedures on a global scale. Michael S. Mintun has been elected vice president, sales, North America. With the company since 1984, Mintun previously served as sales manager, North America.
ProMotion Controls Signs on Marketing VP

ProMotion Controls, Inc., Medina, Ohio, has appointed Todd H. Critoph vice president, sales and marketing, for North, Central, and South America. Critoph previously served more than 20 years in engineering management at Koike Aronson, a supplier of thermal cutting machinery.

Specialty Gas Manager Appointed at ILMO

ILMO Products Co., Jacksonville, Ill., has named Travis Nelson specialty gas marketing manager. Prior to joining the company, Nelson worked as an analytical chemist for Scott Specialty Gases.

EWI Names Vice Chair

Edison Welding Institute (EWI), Columbus, Ohio, has elected Richard Rogovin vice chairman of the company’s board of directors. Prior to joining the company, Rogovin practiced corporate and international law in the law firm of Frost Brown Todd, LLC.

Atema Fills Quality Spot

Atema, Inc., Chicago, Ill., has named Michael J. Mauris quality systems specialist. Mauris, an AWS Certified Welding Inspector and Certified Welding Educator, has more than 30 years of experience in the structural steel industry and most recently as an auditor for the AISC Certified Fabricator program.

Obituaries

Charles Burnham

Charles Burnham, 87, died December 25 at his home in Essex Junction, Vt. Born in Eving, Mass., Burnham served in the Army Air Corps in the India and Burma theater from 1942 to 1945. Following discharge from service, he worked as a salesman for Rod’s Auto Electric in Gardner, Mass. He studied mechanical engineering at Worcester Junior College. In 1953, he joined General Electric Co., in Cincinnati, Ohio, as a specifications engineer. While there, he worked extensively with various community theatre groups, directing 16 plays. In 1974, Burnham transferred to General Electric in Burlington, Vt., where he began service as chairman of the AWS A2 Committee on Definitions and Symbols. Retiring in 1984, he spent many years caring for his ailing wife, Eleanor, who died in 2004. After her death, Burnham became active in community events including volunteer work as a reader and tutor at the Hiawatha Elementary School in Essex Junction. He is survived by his children Michael and Deborah Lupia.

Chauncy C. Hart

Chauncy C. Hart, 92, died January 12 in Helena, Mont. He was a Life Member of the American Welding Society, joining in 1944. He was affiliated with the Milwaukee Section where he served many officer positions including chairman, and served on several AWS and ASME technical committees. He is a coauthor of History of Fabricating and Welding of Armor Vehicles, written for the U.S. Army Ordnance, and the ASME Welding Handbook. Hart majored in engineering at Riverside Junior College and Milwaukee School of Engineering. He started his career as a production welder at Harstichfer Corp. for eight years before serving as chairman of The Heil Co. He later served as manager of welding engineering. He later served as manager of welding engineering at Pressed Steel Tank Co., before serving as general manager at Wagner Iron Works. From 1954 to 1961, Hart served as manager of manufacturing for the Body and Hoist division, and manager of welding and welding research at The Heil Co.

G. J. (Joe) Daumeyer

G. J. (Joe) Daumeyer, 45, of Fishers, Ind., died February 20 in an automobile accident. An AWS member for 23 years, he was technical representative and a past chair of the Indiana Section. Daumeyer was owner of Athena Plus in Anderson, Ind., and president of Resistance Welding Equipment and Supply Co. in Indianapolis. A welding engineering graduate of The Ohio State University (OSU), he was an active member of the Resistance Welding Manufacturing Alliance (RWMA) and served on numerous AWS technical committees, including the Committee on Resistance Welding, Educators Committee, Subcommittee on Automotive Resistance Welding, Handbook Chapter Committee on Projection Welding, and the Subcommittee on Certification of Resistance Welding Technicians. Donations in his name may be made to the OSU College of Engineering Scholarship Fund. Daumeyer is survived by his wife, Chris, his parents, a son, two daughters, two sisters, and three brothers.

Lloyd J. (Joe) Cole

Lloyd J. (Joe) Cole, 85, an AWS Life Member associated with the New Orleans Section, died February 9. Cole worked for more than 40 years as an applications specialist for Air Reduction Co. and later with AIRCO. He provided welding distributor support through KOBE Welding Wire Co., where he served as regional representative until his retirement. He also was a representative for B.M.S. Corp. and Union Industrial Gas. During the early days of World War II, he welded ships at Avondale and Delta Shipyards, then served on a ship in the U.S. Navy. Cole remained a highly skilled welding consultant until his death.

John E. Postle

John E. Postle, 84, died January 20. Born in Buffalo, N.Y., he moved to Cleveland, Ohio, in 1947. From 1954 to 1967, he worked for Eutectic Welding Corp. He started his own business in 1969 where he worked until his retirement in 1990. Postle is survived by his wife, Phyllis, three children, six grandchildren, and five great-grandchildren.
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Friends and Colleagues:

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 Fellows. In particular, I would make a special request that you look to the most senior members of your Section or District in considering members for nomination. 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 take the extra effort required to make sure that those truly worthy are not overlooked because no obvious individual was available to start the nomination process.

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form in this issue of the Welding Journal. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2008. The Committee looks forward to receiving numerous Fellow nominations for 2009 consideration.

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee
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While no one can provide the definitive answer, one thing is certain: the shortage of welders—more than 200,000 by 20101—could limit the growth and productivity of many industries. While U.S. federal and state government agencies don’t seem to be able to articulate a clear policy on the skilled trades, Canada, and particularly the province of Alberta, has. The extraction of oil and other natural resources has created a boom that makes Alberta the “Texas of the North.” You can hardly pick up a newspaper in Alberta and not see headlines like “skilled worker shortage” or “labor shortage.”

To meet demand, the province aggressively recruits young people for trade positions and is investing heavily in its technical schools.

BY MYLES LANGIER AND SCOTT MacKAY

The shortage of welders, some argue, is due to an overall declining interest in the skilled trades. Others believe welding is simply a dirty job. Some say secondary schools discourage young people from going into the trade, or that many young people have no knowledge of the career options available.

NAIT operates the province’s largest welding program; SAIT operates the second largest. Of the more than 8000 apprentices requiring training this year, 1725 will attend NAIT and 1372 will attend SAIT. NAIT increased its enrollment by 60% after opening a new $15.2 million facility in 2006 (Fig. 1), and it increased staff by 63% over an 18-month period beginning in January 2005. With 51 instructors, NAIT comes close to its goal of a 10:1 student-to-instructor ratio. SAIT has doubled its staff from 10 years ago to 40 instructors (to maintain its 14:1 student-to-instructor ratio), increased enrollment by nearly 1000 students, and totally refurbished five welding labs.

**Welding Canadian Style**

In the United States, anyone with a power source can hang up a sign and run a welding business (assuming any applicable codes and standards are

1. More details regarding the welder shortage are available from the American Welding Society at www.aws.org/pr/shortagefactsheet.pdf.
met). Not so in Alberta. To start, working in a trade is governed by the Alberta Apprenticeship and Industry Training, informally called the apprentice board orAIT. (Visit www.tradesecrets.org for details.) There are 51 designated trades, including welding.

Alberta divides welding into two branches: wire process operators and welders — Fig. 2. Basically, wire process operators use gas metal arc welding (GMAW), flux cored arc welding (FCAW), submerged arc welding (SAW), and other wire welding processes. Welders use those processes, plus shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), oxyacetylene welding/brazing/cutting, and resistance welding.

To work in Alberta, a welder or wire process operator must be one of the following:
• A registered apprentice
• A certified journeyperson
• Someone who holds a recognized trade certificate

To become an apprentice, a person must have at least an Alberta Grade 9 education or equivalent (or pass an entrance exam) and find a suitable employer who is willing to hire and train an apprentice.

The term of apprenticeship for welders is three years (three 12-month periods), which includes a minimum of 1500 hours of on-the-job training and eight weeks (240 hours) of technical training each year. For wire process operators, the term is two years (two 12-month periods), including a minimum of 1500 hours of on-the-job training and eight weeks of technical training in the first year and 1800 hours of on-the-job training in the second year.

Becoming an apprentice involves a legal contract between the student, employer, and provincial government. The student isn’t bound to stick with one employer, but a student needs a sponsor. The sponsor promises to provide on-the-job training and pay the apprentice a percentage of the journeyperson wage rate (60% for first-year apprentices, 75% for second year, and 90% for third year). The average journeyperson’s yearly salary was $58,200 according to the 2005 Alberta Wage and Salary Survey.

To encourage people to enter the skilled trades, the Alberta government subsidizes training by paying the technical institutions on a per-student basis. This keeps tuition and material costs to less than $800 for an eight-week course. Considering the taxes a worker will pay on a $58,200 salary, it’s a good long-term investment.

The goal of many apprentices is not just to become a journeyperson, but also to obtain their “Red Seal.” The Interprovincial Standards (Red Seal) program allows qualified tradespersons to pass an examination that permits them to practice their trade in any province or territory in Canada (except Quebec) where the trade is designated, without having to “write” (or take) further examinations.

**Apprenticeship Program**

In Alberta, ten institutions provide apprentice training for welders and wire process operators, including NAIT and SAIT. Working in partnership with industry and these institutions, the apprenticeship board (AIT) determines how many apprentices will train each year. In this manner, AIT manages the process so that supply will meet or catch up with demand.

A single “year” of training consists of an eight-week period at one of these institutions.

For those on a welder path, first-year students typically receive one week of oxyfuel cutting and brazing, three weeks of GMAW and FCAW training, and four weeks of SMAW training — Fig. 3. They’ll also complete a 32-hour math component. Second-year training consists of two weeks of FCAW and GMAW; two weeks of GTAW on carbon steel, stainless steel, and aluminum; and four weeks of SMAW. Students also complete a 16-hour estimating block and a 32-hour block on pattern development, layout, and theory.

Third-year training starts off with two weeks of SMAW followed by two weeks of GTAW. While in GTAW, students perform root, intermediate, and cover passes on pipe and in various positions. Students go back to SMAW for week five, with week six being designated for training on 6-in. Schedule 80 pipe. This provides pretraining for students wishing to obtain a “B Pressure” certification (welding pressure vessels and pipe) after they have completed their apprenticeship. They also learn how to read blueprints.

In the last two weeks of training, third-year apprentices weld coupons to get their journeyperson certification. At this point, the Alberta government sends out its test people to administer the journeyperson tests. Students write their journeyperson exam in the morning and have the opportunity to write their Red Seal exam in the afternoon of the same day.

Dan MacKinnon, chair of NAIT’s welding program, said, “The government
mandate for us to train generalists has worked very well for the Alberta economy because of our diversity. Everyone knows us for the oil and gas work in the tar sands, but there’s welding work in agricultural, transportation, mining, forest, aerospace, and aluminum boat building industries, too.” That said, training heavily emphasizes the SMAW process because so much of the work in the petrochemical industry revolves around pressure vessel welding and field welding — Fig. 4.

“Once you get your journeyperson’s ticket, that’s your license to learn. It gets you on the job, and then you can go for your Canadian Welding Bureau ticket if you want to do structural work. If you want to go into the pressure and oil and gas transmission lines, you need to get your “B Pressure” ticket, and this will open up another door,” explained Bob Clark, associate chair of NAIT’s welding program.

Out with the Old

As noted, AIT asks just ten institutions to meet training demands. Shouldering this load required some institutions to take in five new groups of students each year. The need to share equipment among so many students required teaching on triple shifts: 7:15 a.m. until 2:30 p.m., 9:15 a.m. to 4:30 p.m., and 11:00 p.m. to 6:15 a.m.

George Rhodes, SAIT’s academic coordinator for welding/NDT and manufacturing and automation, said, “We trained 728 students in 2006 and told AIT we were at capacity. This year, AIT asked us to train an additional 200 students. The only way we were going to be able to accommodate that was by upgrading our welding labs and welding equipment.”

Until 2006, NAIT and SAIT predominately trained students on a hodgepodge of old (sometimes ancient) CC- and CV-only equipment. This bulky equipment took up so much space that only one machine fit in a welding booth. In addition, teaching students on old equipment doesn’t do them any favors when they get on the job.

“As a technical institute, we can never let ourselves get behind industry,” said Clark. “We have to be technology leaders. If you’re teaching, you want to be on that leading edge and must have the right equipment.”

For training students on SMAW, DC-GTAW, GMAW, FCAW, and air carbon arc gouging, NAIT recently installed 203 CC/CV multiprocess inverters with a 350-A output at 100% duty cycle. Complementing these power sources are 66 dual wire feeders with digital meters and digital controls for dual schedule control, adjustable weld sequence control, weld process range control, and weld program setup and storage.

For training students on AC/DC GTAW and SMAW, NAIT selected 72 inverter-based, 350-A welding machines with GTAW controls for high-speed pulsed DC-GTAW (up to 5000 pulses per second) and AC-GTAW controls for independent EN and EP amperage control, extended balance control (30 to 99% EN), AC frequency adjustment (20–400 Hz), and four AC waveform outputs (advanced squarewave, soft squarewave, sine wave, and triangular wave) — Fig. 5.

“Digital controls help students,” said Clark. “After we demonstrate a weld procedure, students can go back to their booths, set the same parameters their instructor used, and feel a lot more confident about getting good results.”

To teach AC/DC GTAW and SMAW, SAIT opted for 60 compact 200-A GTAW inverters that feature AC-GTAW controls for extended balance control (30 to 99% EN), AC frequency adjustment (20–250 Hz), and controls for pulsing at up to 500 pulses per second — Fig. 6. To make best use of welding booth space, SAIT created a platform to mount these 45-lb GTAW inverters on the wall — Fig. 7.

“Physical space is always a big problem. Now, because of space-saving inverters,
what we used to teach in three shops [with our large older equipment] we now teach in one shop,” said Rhodes. “By making all five of our weld shop multiprocess, we can accommodate more students and have flexibility when scheduling class locations.”

SAIT also upgraded to CC/CV multiprocess inverters with a 350-A output, pairing each of its 90 power sources with a dual wire feeder with digital meters. One side of the feeder runs solid wire for GMAW while the other runs tubular wire for FCAW. These processes parallel pipeline and pressure vessel industry needs that require a GMAW root and FCAW intermediate and cover passes — Figs. 8, 9.

“Our can meet the needs of industry because SAIT management has invested more than $1 million in welding and manufacturing equipment,” said Rhodes. “Without that support, our enrollment would be limited and students would train on old technology. You can’t train students on vintage equipment and expect them to understand the benefits of the advanced arc controls found on today’s inverters.”

Fig. 6 — New CC/CV inverters and dual wire digital feeders keep SAIT on the leading edge of technology. Shown (from left) are SAIT personnel Mike Hildebrand, welding instructor and team leader; George Rhodes, academic coordinator for welding/NDT and manufacturing and automation; and Jan Nielsen, welding instructor and team leader.

Table 1 — Average Hourly Wages in Canada for Various Professions in 2004 (according to www.livingin-canada.com) (The average wage for a journeyperson welder is about $30/h.)

<table>
<thead>
<tr>
<th>Profession</th>
<th>Average Wage</th>
</tr>
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<tbody>
<tr>
<td>Accounting Clerk</td>
<td>$16</td>
</tr>
<tr>
<td>Architect</td>
<td>$26</td>
</tr>
<tr>
<td>Bookkeeper</td>
<td>$16</td>
</tr>
<tr>
<td>Carpenter</td>
<td>$19</td>
</tr>
<tr>
<td>Computer Engineer (not software)</td>
<td>$29</td>
</tr>
<tr>
<td>Computer/Info Systems Manager</td>
<td>$37</td>
</tr>
<tr>
<td>Data Entry Clerk</td>
<td>$13</td>
</tr>
<tr>
<td>Dentist</td>
<td>$40</td>
</tr>
<tr>
<td>Electrician</td>
<td>$20</td>
</tr>
<tr>
<td>Engineering Manager</td>
<td>$35</td>
</tr>
<tr>
<td>Executive Assistant</td>
<td>$20</td>
</tr>
<tr>
<td>Lawyer</td>
<td>$40</td>
</tr>
<tr>
<td>Physiotherapist</td>
<td>$27</td>
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<tr>
<td>Plumber</td>
<td>$19</td>
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<tr>
<td>Registered Nurse</td>
<td>$27</td>
</tr>
<tr>
<td>Retail Sales/Clerk</td>
<td>$12</td>
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<tr>
<td>Social Worker</td>
<td>$24</td>
</tr>
<tr>
<td>Truck Driver</td>
<td>$19</td>
</tr>
</tbody>
</table>

‘‘Standardizing on just a few pieces of equipment makes our stocking easier and cheaper to manage, as does using equipment that’s energy efficient. In fact, new inverters use less than half the power of our old rectifiers,’’ MacKinnon said.

Clark noted that because all the new inverters can use three-phase, 575 VAC primary power, “We eliminated the need to make major electrical upgrades to accommodate the GTAW equipment. Rather than spend $160,000 on outlets and switching boxes, it’s more feasible to spend that money on new machinery.”

Rhodes notes that old equipment costs a lot to maintain, saying, “We spent close to $18,000 last year strictly on maintenance to keep 30 old GTAW units running.”

**Filling the Pipeline**

Canada’s tar sands may get more than $48 billion of investment by 2012, according to Canada’s National Energy Board. This is double the amount spent in the decade ending in 2003. The tar sands in Alberta hold 175 billion barrels of recoverable oil, which rivals Saudi Arabia’s 240 billion barrels. Tar sands are deposits of bitumen, or viscous oil. About two tons of tar sands have to be dug up, heated, and processed on location to make a single 42-gallon barrel of oil.

The tar sands have profoundly changed Alberta society, as more people recognize that skilled trades are the engine that runs the province’s economic success.

“It’s no longer an insult to be a tradesman,” remarked Clark. “If you look around Edmonton, a city of 700,000+ people, there isn’t a corner that doesn’t have construction. People finally recognize that buildings don’t go up, and oil doesn’t get extracted and processed without skilled trades — and we have a shortage.”

Attracting young people (most students range from 19 to 25) into a skilled trade is easier than it used to be: just dangle the dollar signs.

As noted, the average journeyman earns about $58,000. For welders who specialize in GTAW, pipeline or pressure vessel welding, salaries can range from $120,000 to $150,000 per year.

“...If a young person is ambitious and...”
wants to run a portable welding truck," Clark said, “they’ll have to outlay about $80,000 to set it up, but the average rig welder makes $330,000 a year right now.”

Mike Hildebrand, a welding instructor and team leader at SAIT, said, “Well-paid welders work hard for every penny they make. They don’t work eight to five. They work 12-hour days, six days a week. It’s pretty common for a rig welder to work hard eight months out of the year, then shut down and go fishing, golfing, or hunting for four months.”

Unlike those who attend university, tradespersons don’t carry a heavy tuition-related debt load for ten years after graduating. Instead, they have lots of ready cash.

“There’s almost no limit to how much money a young person can make,” said Clark. “Like most young people, they want nice toys: a truck, motorcycle, ATV, boat, or snowmobile. The difference is, welders can afford anything and everything, especially because young people aren’t thinking about a family or a house.”

One common misconception all the educators want to dispel is the myth of “once a tradesperson, always a tradesperson.” For example, SAIT offers a two-year welding engineering technology program accredited by the American Society of Engineering Technology. Graduates tend to follow career paths in welding inspection, quality assurance, welding department supervision, R&D, or technical sales support.

“There is always work for someone that just wants to burn rod, but even that job requires a lot more academic skill nowadays because of the code-type work the petrochemical industry requires,” MacKinnon said. “You have to have a good academic background to make a good tradesperson. Then, for those who have the aptitude, they want to become a supervisor, and those supervisors with an entrepreneurial spirit may go on to start their own company.”

To help those in designated trades grow skills beyond their technical capabilities, Alberta offers an Achievement in Business Competencies (“Blue Seal”) program. As NAIT’s Web site notes, “If you are a certified Alberta journeyperson in a designated trade or occupation, earning a Blue Seal proves that you not only meet Alberta’s high industry standards, but you also have the drive to develop your business skills and succeed in business.”

Tradespeople can earn their Blue Seal by completing 150 hours of study in the following areas: accounting, administration, business law, operations management, human resource management, industrial relations, leadership, economics, entrepreneurship, project management, public administration, finance, management, and marketing.

What’s Wrong with Kids These Days?

Like many people with a touch of gray in their hair, the educators at the two schools have a thing or two to say about today’s generation of teenagers and twenty-somethings.

“I think we should start training people at a younger age in the practicalities of work,” Clark said. “I find that work ethics are almost nonexistent nowadays.” From the time they were small, the parents of these educators gave them responsibilities around the house or farm. As teenagers, they worked a paper route, bagged groceries, pumped gas, and more. Kids today turn 18 and realize that society expects them to work hard, yet they have zero work experience.

According to Hildebrand, “A good tradesperson has a great work ethic. Most of our students — 75 to 80% — will find and hold a good job. Those who fail to hold a job almost always fail because of poor work ethics. The hardest thing for kids who slack on the job to realize is that they’re not going to get pushed through a system like they did in school. There are consequences: They won’t have a job.”

In addition to ethics, Rhodes believes that society (schools, parents, and peers) needs to change its attitude about personal growth.

“There is no shame in failing,” he said. “Nobody wants to hold little Johnny back because his classmates are going to go on without him. Parents want to make it easier on themselves and their kids, but that’s not right. Everybody learns at a different rate of speed, everybody matures at a different level, and everybody learns differently. Parents and teachers should teach children to understand these differences at an early age. If it takes 13 or 14 years to get an honest
grade 12 education, that’s acceptable.”

Clark says what’s not acceptable is a society that puts out students who, “are supposed to have a Grade 10 education yet can’t read a tape measure. Canadian blueprints will be in millimeters, but you often need to order materials in imperial. The people coming out of high school need to have practical, applied math skills to convert between metric and imperial. It seems like kids nowadays think they can make a million dollars sitting in front of a TV screen with a video game.”

**What’s Wrong with Schools?**

Historically, parents created the stigma against going into a skilled trade. Today, vocational educators like Rhodes and Hildebrand believe that the education system is now the bottleneck.

“High school and junior high school counselors don’t realize the careers available in the skilled trades,” Hildebrand said. “We’re a huge industry, but it’s amazing when you talk to counselors at the junior high and high school level and find out that they don’t even know what welding is. I think school systems first have to realize that any trade is valuable. Then, counselors have to advise kids that—if they have a good work ethic—they can make a better living as a tradesperson than some people with a university degree” (Table 1).

“What bothers me,” Rhodes added, “is that secondary school systems poured millions of dollars into funding computer labs starting in the late 1990s. But now you go to these schools and find out that all the funding was diverted from their trade-related labs. School boards don’t fund machine shops, motor vehicle shops, carpentry shops, and welding labs any more. The money is there, but some school boards still look down on the trades because they don’t see the value of a tradesperson.”

One tactic for generating interest in the trades at all levels is explaining what the skilled trades are and how an apprenticeship works.

“We’ve even gone to elementary schools and, at their request, sent an instructor out to explain the welding trade and the careers available,” Rhodes said.

To encourage high school students to enter the skilled trades, AIT created the Registered Apprenticeship Program (RAP). RAP enables high school students to earn a high school diploma at the same time they earn credits toward apprenticeship training, thereby gaining some real-world work experience. Students are required to finish core subjects through grade 12. Upon graduation, the prospective employer will sponsor their apprenticeship. But if students quit high school, the employer is not allowed to hire them.

“The RAP program,” Rhodes said, “has been extremely successful in promoting trades to the high schools and the general public. It gives kids an incentive to stay in school. It instills a work ethic, responsibility, and teaches kids that actions have consequences, and it’s producing the welders Alberta desperately needs.”

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Young ‘Veteran Welder’ Tells How Welding Changed His Life

BY HOWARD M. WOODWARD

Not yet 20 years old, Jason Niewiadomski is already fired-up to tell the world what welding has done for him and vice versa. The past few years for him have been complicated by personal problems that, fortunately, have been since overcome by cleaning up his life and learning a profitable trade in welding.

“I have experienced so much in the last three and a half years,” Jason exclaimed. “I was taking a metal shop class at Riverside High School (Painesville, Ohio) and was enjoying learning something new and working with my hands.” He said, “I could enjoy doing this work all day long.”

One fateful day, Jason shared his enthusiasm for his newfound creative shop skills with a friend who was enrolled in the welding class at nearby Auburn Career Center. He was excited about what he was learning and was confident that Jason would like studying welding, too. Jason did have a little experience assisting in the assembly of a racecar. He said that work “taught me a few things about fitting and welding and how to get things to fit and work.” Jason’s interest was aroused, and he took his friend’s suggestion to see his counselor to discuss transferring to Auburn Career Center so he could study welding.

Auburn Career Center offers a two-year program with the option to choose your own trade for the junior and senior years. Jason signed up for the welding class taught by Ryan Eubank. Before teaching at the Center, Eubank worked for The Lincoln Electric Co. in Cleveland.

“I thought I knew something about welding, but soon realized that I knew just about nothing,” Jason said. “The first year Eubank taught me the basics of gas metal arc, shielded metal arc, gas tungsten arc, and flux cored arc welding; oxyfuel and plasma arc cutting; plus mill and lathe work. He taught me about the welding positions: 1G, 2G, 3G, 4G, and 1F, 2F, 3F, and 4F.

“I was really excited when I heard about the SkillsUSA welding competition. I wanted to be the best at welding so I could compete and win that competition. “When I told Eubank that I was interested in competing in SkillsUSA all he said was, ‘Get to work.’

“I met many good people at Auburn who helped me expand my knowledge in the world of welding,” Jason said. “I got a lot of encouragement from people I met from Lincoln Electric in Cleveland. They are Dennis Klingman, Carl Peters, Joe Kalasa, Bill West, and many others. They all took me under their wing to help me get better and better at welding.”

The start of the senior year went more in depth with welding. “We started welding pipe and started working on assigned projects — projects like snow plows for the local road department, and farm equipment like tractors and equipment for tractors,” Jason explained.

Eubank decided the class should build a catwalk for its senior work project. The catwalk was to be 22.5 ft long and about 16 ft in the air. That turned out to be a real learning experience for Jason. He said, “The class members engineered the project led by Phil Henry, and I was to be the main welder on the job. I’ll never forget building that.” All this experience helped Jason get ready for the welding competitions to follow.

“We had a local competition throughout the class and I took first place in that. Then I entered the regional welding competition and took first place in that competition, too.” Jason said thoughts of making it all the way to the regional competition gave him butterflies, but after winning the regional competition he couldn’t wait to enter the state competition.” Finally, when that opportunity arrived, what Jason kept saying to himself was, “Let’s do this.”

Jason recalled, “The two-day competi-
tion went great for me. Winning made it all the more important to him to prepare himself even more. “All I knew was that I better get ready because I will be competing with the best welders from every state from the east coast to the west coast.”

Jason was overwhelmed by the SkillsUSA national competition. He said, “I thought the state competition was huge; just wait until you go to Kansas City, Missouri. When I saw where we were going to compete my jaw dropped. The building is equivalent to 16 football fields and has three floors. We would be using all brand-new equipment — half Lincoln, half Miller. The competition,” he added, “lasted days, and was one of the best experiences of my life.”

In addition to his welding experiences, Jason said, “I met all sorts of people from different places and different cultures. During the postsecondary competition, which was the high school competition, the secondary competition was going on. One welder was from Australia, others from Great Britain and Germany, and two were from the U.S. They were all practicing for the international competition. It is an experience that you have to go see and experience.

Jason concluded, “The outcome of the national competition was very close. The difference between the first- and third-place scores was only 200 points — I took third place.” His prizes included two gas metal arc welding machines, a torch outfit, welding consumables, and two $10,000 scholarships.

His welding education went a long way in turning Jason’s life around. Inspired by his successes, he said, “I can’t stress it enough how much you will get out of hard work, patience, and the will to be the best. I worked two jobs while going to school. It was hard but I made it through.”

Jason recently landed his first career job through Ronny Vanscoy, a recruiter for the International Boilermakers Union. “I started as a Boilermaker in August 2007,” he said. “I have worked in Chattanooga, Tennessee; Wheeling, West Virginia; Maysville, Kentucky; and Conesville, Ohio, so far. I like to travel and that’s what this job is all about. I have met and worked with people from all over the U.S.” Jason noted that, “As an NTL Boilermaker what I do is build tanks. They call us ‘tankies.’ I build holding tanks, scrubbers, and other projects. In just four months I earned $30,000. I just bought a brand-new 2008 Chevy Silverado 3500 Duramax diesel, fully loaded, I love it. The only reason I was able to do that is by having a good job making good money.”

But Jason realizes that there’s more to life. “To me,” he said, “money isn’t everything. I’ve got to be happy with what I do, and I can see myself doing this (welding) for the next 30 years.”

Jason wants to thank his family, Ryan Eubank, Dennis Klingman, Ronny Vanscoy, and the others who taught him, encouraged him, and made it possible for him to succeed. His advice to young readers is to get into the field of welding “if you like to work with your hands and build things. So one day you can drive down the road and say, ‘Hey, I built that!’”

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North Georgia Technical College Offers a Variety of Welder Training Options

BY HOWARD M. WOODWARD

Located in the mountains in the northeast corner of the state, North Georgia Technical College (NGTC), Clarkesville Campus, offers a variety of programs for students studying for welding-related careers.

NGTC Welding Programs

The college offers a two-year Associate of Applied Science Degree with a Concentration in Welding; a one-year Welding and Joining Technology diploma; and a number of 10- to 20-week-long Technical Certificate programs specifically for gas tungsten arc, flat shielded metal arc, overhead shielded metal arc, gas metal arc, and pipe welding. Other courses within this program include blueprint reading, mathematics, computers, employability skills, and language arts.

Upon completion of the program, graduates receive the Welding and Joining Technology diploma. They are fully prepared to take qualification tests for positions of welding and joining technician. Many NGTC students choose to pursue the diploma in Welding and Joining Technology because it also develops academic, technical, and professional knowledge, and the skills necessary for job retention and advancement. This program emphasizes welding theory and the practical applications that are necessary for successful employment.

The Welding Staff

Heading the teaching staff are Ronnie Ayers and Jason Smith.

Ayers is an AWS Certified Welding Inspector and Educator (CWI/CWE) with 12 years of work experience. He started teaching part time in 1996 and became a full-time instructor in 2000. Ayers graduated from the NGTC welding program in 1989 and its machine tool program in 1991. In 2000, he received his AAS degree from Truett-McConnell and is currently pursuing his BAS at Gainesville State College. One of Ayers's more adventurous students, Tyler Fisher (see sidebar story), credits Ayers with helping him achieve a most rewarding career in pipe welding.

“Last fall quarter,” Ayers said, “we had 60 students in the welding program. It was our largest enrollment to date.”

Jason Smith joined the teaching staff about a year ago. He graduated from NGTC with an AAT degree with a Concentration in Welding in 2003, then worked for three years in the welding industry before taking his present post.

Graduates’ Job Placements

Graduates of the Welding and Joining program were offered immediate job placements last year with starting salaries ranging from $12 to $14 per hour for local manufacturing positions, and up to $25 per hour for construction jobs involving travel.

Tuition and Fees

Tuition for Georgia residents is $432 per quarter for a full-time student, or $36 per credit hour for part-time. Out-of-state student tuition is $864 per quarter. The boarding fee is $900 per quarter for a semiprivate room or $975 for a private room. Other fees include a $25 student activity fee, $4 fee for accident insurance coverage, $26 registration fee, and a $35 instructional/technology support fee each quarter. The cost of books and supplies for the full program is approximately $350 and the graduation fee is $35. Qualified Georgia residents may receive the Hope Grant that pays for all tuition and most of the fees. Also available are Pell Grants, student incentive grants, work study grants, and various scholarships.

Student Services

The college offers a career-placement service to assist students as they complete

HOWARD M. WOODWARD (woodward@aws.org) is associate editor of the Welding Journal.
their training. The college maintains communication with employers and with the Georgia State Employment Service to provide a wide range of employment opportunities for the students. Employers also send representatives to the school for personal interviews with graduating students. The college is an Internet “access zone” to America’s Job Bank through the U.S. Department of Labor that provides information on job openings locally and nationally.

The Career Discovery Center offers job search software, résumé-building software, online application to North Georgia Technical College, links to newspapers, career scope software for interest and aptitude testing, an enhanced job analyzer for career exploration, and more than 100 links to career sites. Assessment services provide career guidance and planning by means of individual and group testing at various locations using computerized and standardized testing instruments. These services include career exploration, interest inventories, aptitude testing, and basic skills testing.

**The President’s Word**

Dr. Ruth Nichols, NGTC president, said, “Our welding program is without a doubt one of the top programs in the state and throughout the nation. Graduates are always coming back and telling us how thankful they are that they chose NGTC to help them get started in their first career, find a new career, or learn new skills for their current career.”

---

**Globetrotting NGTC Student Fulfills His Dream Welding Career**

Just six years ago, after graduating from high school, Tyler Fisher enrolled in the Industrial Systems Technology program at North Georgia Technical College, Clarkesville, Ga., where he studied welding at night with CWI/CWE Ronnie Ayers. It wasn’t long before he realized he had a true liking and talent for metal joining, especially pipe welding. He graduated from Ayers’s class well prepared, energized, and ready to go to work.

Ayers helped Fisher search for a pipe welding job in the nationwide want ads, where they found an interesting position posted for a paper mill in Maine. Fisher drove to Maine to take the company’s welding test. He passed the test, got the job, and thus was launched on his career as a professional welder.

Always looking for more interesting and better-paying jobs, Fisher left the paper mill to work at several nuclear power plants where he continued to hone his pipe-welding skills. While working at Surrey Nuclear Power Station he learned about high-paying job opportunities overseas for skilled pipe welders. Eager to explore these jobs, Fisher applied to Zachary-Caddell, a firm building in Beijing, China. Tyler recalled that it took almost a year to complete the necessary security and background checks required by the company. Once cleared, he flew to Texas where he passed the company’s extensive tests of his welding skills. After a four-day orientation program in San Antonio, Fisher flew to Beijing where he worked for a year building the new U.S. Embassy. He felt comfortable with the people, their culture, and the surroundings. He even learned to speak some Chinese.

Fisher found many advantages to working in Beijing. The company followed U.S. Occupational Safety and Health Administration (OSHA) standards and employed quality control inspectors on the job site. His work schedule at the embassy was demanding, and he had to work occasionally in tight quarters, but he was satisfied. The company paid him more than $80,000 per year in addition to providing his apartment and all of his food. What he did have to buy was inexpensive.

Fisher said that all around the embassy other buildings were under construction using Chinese workmen. They were doing the same type of structural welding that Fisher was doing, but they were paid an average of only $5 for a 12-h workday. Instead of welding helmets, the Chinese welders wore sunglasses with cardboard cutouts around them to shield their faces, and many of them wore short sleeves and flip-flops while working high up on the buildings.

One night, while working several stories up on the embassy, Fisher watched a magical scene of the welders in the other buildings. “It looked like fireworks all over the place from all the welders,” Fisher said. That sight is one of his most treasured memories.

While he spent most of his time working, he found time to travel extensively. He explored the Simatai section of the Great Wall of China, visited Xi’an and its famous Museum of Qin Terra Cotta Warriors and Horses (see figure), went trout fishing in New Zealand, rode a train through the Himalayas to Tibet, and visited Thailand and Australia.

Now 24 years old, Fisher’s skills are much in demand. He is, at this writing, embarking on another pipe welding assignment at an overseas nuclear power plant. He’s enthusiastic about his future job prospects, and can only speculate where his welding career will take him next.

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**Tyler Fisher is shown at the Museum of Terra Cotta Warriors in Xi’an, China.**
### Carbon Steel Flux Cored Electrodes’ Usability

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H = horizontal; F = flat; OH = overhead; VU = vertical with upward progression; VD = vertical with downward progression; DCEP = direct current electrode positive; DCEN = direct current electrode negative.

COMPARE
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School Profiles April 2008

Employers
Are you in need of good welders?

Students
Are you searching for a way to hone your skills?

Welders
Is it time to expand your talents and knowledge?

Below are welding schools across the country that have taken this advertising opportunity to promote their resources both to industry in need of welders and to those searching for a solid career path to employment. Contact them and take advantage of the services they can provide.

You will find specific information on welding courses offered, degrees and certifications available, school locations near you, fax, phone, website search data and the like. We appreciate any ideas you might have for making this welding school guide more useful to you. Please send comments or requests to be on our mailing list and e-mail list to receive advance information on future Welding School Profile edition of Welding Journal. Thank you.

University of Alaska Anchorage Welding and NDT Technology
Founded 1970

The Welding/NDT program at UAA offers a choice of certificates and an Associate of Applied Science degree that centers on welding skills, welding inspection and nondestructive testing. Program courses include skill development in major welding processes, pipe fitting and basic metallurgy, as well as hands-on NDT training in the RT, UT, MT and PT processes. Our program serves about 175 students each year.

Akron Testing Lab & Welding School Ltd.
Founded 1953

Akron Testing Lab and Welding School Ltd., has been training and qualifying welders for over 50 years. Founded in 1953 and located in Northeast Ohio, offers certificates classes or a Diploma program in “Welding Technology.” Classes offered include SMAW, Pipe welding, GMAW steel and aluminum, GTAW, FCAW, Oxyfuel, and blue print reading. Customized training is offered to employers. Ohio Registration 79-01-0631T.

Atlantic Technical Center
Founded 1973

Atlantic Technical Center provides a review for persons currently employed in welding occupations who wish to take an AWS test to become a Certified Welder, or first time students who are interested in learning advanced and basic welding skills techniques. Shop activities are an integral part of this course and provide instruction to develop skills in Industrial, Structural, Aircraft, Marine, Petroleum and Nuclear Welding. At the successful completion of laboratory activities, an AWS Welding Certification test is available. Accredited by the Commission of the Council on Occupational Education.

Butte-Glenn Community College
Founded 1967

The Welding Technology Program is a vocational core of courses designed to produce qualified personnel for certified welding jobs. Program performance standards for certifications are in accordance with those established by the American Welding Society and/or American Society of Mechanical Engineers. Courses are held in a completely modern and well-equipped welding lab. This program is designed to produce entry-level welding technicians in the 6-G pipe position (qualifies for all positions in plate and pipe). Heavy plate 3G and 4G are also obtainable. The student will be able to weld with SMAW, FCAW, GMAW, GTAW, OAW, OFC, PAC and AAC in all positions with a variety of metals and alloys. Students will be able to certify under at least one of the following codes: API, AWS, and ASME, according to individual skills.

Central Piedmont Community College
Jameis Turner Institute of Welding Technology
Founded 1963

CPCC offers welding training at its Charlotte, North Carolina campus. Earn a Certificate or Associate in Applied Science Degree in Welding Technology. We teach the skills needed for today’s work force: Oxyfuel, SMAW, GTAW, GMAW, FCAW and more. Key support courses such as Metallurgy, Blueprint Reading, Quality Control and Non-destructive Examination. We have been an AWS Accredited Testing Facility since 2000. In addition to our AWS student chapter we have an active blacksmithing group on campus.
Central Wyoming College

Central Wyoming College, located in the beautiful Wind River Valley, offers an employer-driven welding curriculum designed to provide graduates with entry-level backgrounds in the different aspects of welding. Central Wyoming College welding students receive rigorous hands-on training in various welding and cutting processes including Oxyfuel, SMAW, GMAW/FCAW, GTAW and pipe welding. Students have a choice of earning a credential, certificate or an Associate of Applied Sciences degree. Check out our program at www.cwc.edu.

2660 Peck Avenue
Riverton, WY 82501
(307) 855-2103
www.cwc.edu
Dudley Cole, (307)855-2138
Admissions (800) 865-0193

College of the Canyons

College of the Canyons, an LADBS and AWS testing facility, has trained welders for 32-plus years. Courses cover industrial welding, pipe, metallurgy, welding inspection, metallurgy and metal sculpturing, as well as technologies such as OFW, SMAW, FCAW, GMAW, FCAW, YAG and controlled atmospheric welding. Instructors are AWS CWI and CWE licensed. Certificates and degrees are offered. Courses are offered day and night, and most programs can often be completed in less than one year.

26455 Rockwell Canyon Road
Santa Clarita, CA 91355
(661) 259-7800
Email: tim.baber@canyons.edu
www.canyons.edu

Cosumnes River College

Cosumnes River College offers a “hands on” style welding program. The basic welding class starts with the introduction to welding (WELD 100). WELD 110 offers advanced SMAW and FCAW training. WELD 112 offers advanced GTAW and GMAW procedures on stainless and aluminum alloys. WELD 114 offers welder certification of AWS D1.1 to D1.8 codes. Jason Roberts is a Certified Welding Inspector, Certified Welding Educator, a Certified Welding Operator and a AWS Publicity Committee Chairperson for the Sacramento Valley. The program is heavily influenced with lectures on AWS welding code and OSHA 510 construction safety standards.

8401 Center Parkway
Sacramento, CA 95823-7146
www.crc.losrios.edu/

CWE

Dabney S. Lancaster Community College

Dabney S. Lancaster Community College offers welding training on its western Virginia campus. Earn a certificate or associate of applied science degree. Employer-driven curriculum teaches the skills needed in today's workforce: oxy fuel, SMAW, GTAW, GMAW and pipe welding. Key support courses such as metallurgy, blueprint reading and quality control. Benefit from free qualification testing. Enjoy small classes, free tutoring and personal attention. Customized courses available for employers. Offering quality, affordable education and training since 1967.

1000 Dabney Drive,
Interstate 64, exit 24
Clifton Forge, VA 24422-1000
(540)863-2895
Email: mbryan@dslcc.edu
www.dslcc.edu

Lynnes Welding Training, Inc.
Dave's Welding & Metal Fab. Inc.

Fast track your career in just a few weeks. Extensive hands on training w/blueprint reading. Small classes for more personal attention. Customized courses available for employers. Earn a certificate – GMAW, GTAW, SMAW, and Pipe (Tig or Stick). Assistance with job placement. Providing training since 2004 with over 375 students.

3201 Rockwell Ave
Scranton PA 18508
(570) 346-8471
Email: admctc@ctclc.edu
www.ctclc.edu

2801 1st Ave No
Fargo, ND 58102
(888) 356-0871
www.learntoweld.com
DeKalb Technical College
Founded 1961

DeKalb Technical College Welding program offers a four quarter diploma and six Technical Certificates of Credit in Oxyfuel, SMAW, GMAW, GTAW, pipe welding and ornamental iron worker. DeKalb Tech also offers customized courses to meet employer’s needs. The majority of the Welding program is hands-on in the lab. If you like working with your hands, building things and don’t mind getting dirty, DeKalb Technical College is the place to get your training!

The Divers Academy
International
Founded 1977

The Divers Academy offers the highest quality training in the shortest amount of time to jumpstart your career. It is known for its full-immersion training methodology and its modern training facilities. Underwater Cutting and Welding is just one part of a comprehensive 5-month curriculum. Founded in 1977, the Divers Academy International trains divers for commercial deep sea diving and wet welding, providing students with an employer’s most sought-after qualification: on-the-job experience. Financial aid is available for those who qualify.

Eastern Maine Community College
Founded 1966

Eastern Maine Community College offers a comprehensive welding program in Bangor, Maine. Students may earn a diploma or associate degree in welding or pipefitting technology preparing them to successfully enter the workplace. SMAW, GMAW, GTAW and cutting processes in both structural and piping applications are studied in a spacious training facility equipped with modern welding equipment. AWS testing facility offering weld testing, welder certification and customized training for both the public and industry.

Del Mar College
Founded 1935

Del Mar College is a comprehensive community college in Corpus Christi, Texas. The welding program offers AWS training and certification in SMAW, GMAW, GTAW, FCAW, and various other processes on plate and pipe welding to industry standards. Certificate and Associate Degree programs offered. Visit us on the Web or call 1-800-652-3357 for information.

Doña Ana Community College
Founded 1973

The Doña Ana Community College Welding Technology program has a national reputation for excellence, and is taught by top-notch AWS CWEs and CWIs. Our 75-90 full and part-time students take courses in SMAW, GMAW, GTAW, FCAW, SAW, steel, stainless, aluminum, pipe, metallurgy, NDT and DT, welding Codes, welding symbols and blueprint reading, pipe welding, fabrication, and welder qualification. Graduates leave as AWS/ASME certified welders. Courses are offered days or evenings. Certificate and Associate Degrees offered.

Eastern Wyoming College
Founded 1948

Eastern Wyoming College is a comprehensive community college. The EWC Welding Department benefits our students and area industry as an accredited AWS testing center. Students and workforce personnel learn in SMAW, GTAW, GMAW, FCAW, OAW and other processes. Students can attain a Certificate or Associate of Applied Science in Welding and Joining Technology, preparing them for structural, pipe, or maintenance welding. Students may also participate in competitions and leadership activities by joining our reputable SkillsUSA club. Student numbers are currently averaging 60 full time students per semester.
SCHOOL PROFILES APRIL 2008

El Camino College
Founded 1947

The El Camino College Welding Department strives to meet diverse student needs by providing quality instruction in morning, afternoon, and evening classes. Introductory through advanced courses are available in oxy-acetylene welding and cutting, GMAW, GTAW, FCAW, and SMAW. Special contact for women, call Women in Industry and Technology Program at 310.660.6780. Welding Certificate and/or Associate of Science Degree are available.

Welding Department
16007 Crenshaw Boulevard
Torrance, CA 90506
(310) 660-3600
www.elcamino.edu

Florence-Darlington Technical College
Founded 1963

Florence-Darlington Technical College (FDTC) offers welding training through its Advanced Welding and Cutting Center (AWCC). The AWCC offers a one-year certificate program and a one-year diploma program in welding. In addition, through FDTC’s Continuing Education Division, it offers a Pipe Welding Academy, customer specific welding classes, open enrollment welding classes, and robotic welding. The curriculum teaches skills in oxy fuel cutting and welding, plasma cutting, SMAW, GMAW, GTAW, FCAW, pipe welding, robotic welding, metal fabrication, blueprint reading, and more. AWS-accredited facility.

P.O. Box 100548
2715 West Lucas Street
Florence, South Carolina 29501-0548
(843) 661-8330
E-mail: Ross.Gandy@fdtc.edu
www.fdtc.edu

Great Basin College Welding
Founded 1967

Great Basin College offers an Associate of Applied Science Degree and a one-year Certificate in Welding Technology, established in 1990. Currently, 20 students are enrolled in a program that prepare them with skills to create new products; repair existing products; and work in the mining, manufacturing, construction, transportation and agricultural industries. Program highlights include instruction in welding theory, blueprint reading, fabrication, quality control, metallurgy, qualification testing, destructive and nondestructive testing principles, and safety.

Elko, Nevada
(775) 753-2207 or (775) 753-2170
Rich Barton e-mail: richardb@gwmail.gbcnv.edu
Jon Licht e-mail: jonl@gwmail.gbcnv.edu
www.gbcnv.edu

Harper College

Harper College’s 16 credit-hour certificate program provides students with entry-level skills in welding fabrication and repair. The program emphasizes advanced welding theory, extensive practice in major arc welding process, and out-of-position and multipass arc welding including GMAW, SMAW, and GTAW. Upon completion of the certificate program, students are prepared to pass guided bend tests to become certified welders in accordance with AWS (American Welding Society) D1.1 Structural Welding Code. Harper’s program also provides custom training in welding and fabrication for employees of area businesses. For more information, contact:

Kurt J. Billsten
Coordinator of Maintenance Technology
1200 West Algonquin Rd.
Palatine, IL 60067
(847) 925-6149
FAX: (847) 925-6049
kbillste@harpercollege.edu
www.harpercollege.edu

Hill College
Founded 1923

Hill College offers comprehensive welder training on both its Hillsboro and Cleburne, Texas campuses. Students can choose from several program options ranging from a marketable skills award to an Associate of Applied Science degree. Employer-driven curriculum covers SMAW, GMAW, FCAW, GTAW, pipe welding and blueprint reading. State-of-the-art technology combined with hands-on curriculum give Hill College students the experience to jump start their careers. Hill College also offers continuing education credits and customized courses for employers.

Welding Department
2112 Mayfield Parkway
Cleburne, Texas 76031
(817)556-2809 ext.201
Email: bbennett@hillcollege.edu
www.hillcollege.edu

Hobart Institute of Welding Technology
Founded 1930

Hobart Institute of Welding Technology’s Course Catalog explains in detail the wide range of welding classes and certifications offered by Hobart Institute of Welding Technology. More than 25 separate welding courses are described by course objective, content, and testing requirements. Also inside the catalog are course schedules, training rates, and enrollment forms. Training may be done at our facility or yours. Also offered are complete training programs including DVDs, Instructor Guides, and Student Workbooks.
HCC offers Certificates, Associate in Applied Science Degrees and industry training in Welding Technology. The AWS Certified Program includes all welding processes, as well as experience in fabrication and manufacturing methods. The welding and employability skills taught result in excellent graduate placement, as well as job opportunities while students pursue their education. Morning, afternoon and evening classes are available, with multiple entry opportunities. Our locations include Hutchinson and Newton, Kansas.

Lincoln Land Community College
Founded 1967

Lincoln Land Community College offers a welding operator program at its eastern campus in Taylorville, Illinois and its western campus in Jacksonville, Illinois. Earn a certificate of achievement or certificate of completion. The program provides skills development in currently used welding processes including flat and out-of-position welding. Additional skills development offered in brazing, soldering, cutting, layout and fabrication techniques. Activities include oxyacetylene, shielded metal arc, gas metal arc (MIG) / gas tungsten arc (TIG) welding and cutting techniques. Upon successful completion of certificate of achievement, AWS certification is available. Enjoy small classes, personal attention and free tutoring.

Johnson County Community College
Metal Fab. & Welding Technology

JCCC welding technology/metal fabrication is safety-oriented. Students learn practical knowledge and skill competencies for welding and machining. Well-equipped JCCC laboratories enable students to receive excellent instruction using metallurgy and blueprint reading. JCCC is accredited as an AWS Participating Organization for Entry Level Welders. A series of welder related certificates are offered. Certificates and courses all lead toward the associate of applied science degree. Scholarships are available.

Locklin Tech

Locklin Tech offers secondary and post-secondary training for a broad range of careers in the welding industry. NCCER Contren® Learning Series curriculum helps students gain valuable global skills. Industry recognized credentials are maintained through NCCER’s National Registry. Instructor James Sullivan is active in SkillsUSA and has been the recipient of the AWS Howard E. Adkins Instructor Award at the section, district and national levels.

Kenai Peninsula College

Kenai Peninsula College is a branch of the University of Alaska located 150 miles South of Anchorage on the Kenai Peninsula. KPC offers certification on AWS D1.1, D, 375 steel plate 3G and 4G SMAW, ASME Section IX pipe certification on steel 6-inch schedule 80 6G SMAW. Our certificate program includes Math, Blueprint, and English (students must certify on pipe to complete certificate). KPC students are provided with 3M® powered air purifying respirator welding hoods.

Lincoln Electric Welding School
Founded 1917

Learn to weld at the Lincoln Electric Welding School. We have trained over 100,000 welders in many different trades (ironworkers, boilermakers, pipefitters, sheet metal, etc.). You will learn to weld with the latest technology in equipment, on different base metals (carbon steel, stainless, aluminum, cr/mo tubing, etc) and many different processes (SMAW, GMAW, GTAW, FCAW, SAW). Our instructors have real world experience doing trackside welding at motorsports events like Daytona (NASCAR-ROLEX), INDY (500, BRICKYARD 400), we also do job site training at your location.

12345 College Blvd. ATB 157 Box # 17
Overland Park, KS 66210-1299
(913) 469-8500
Richard Rowe, rrowe@jccc.edu Ext. 3358
John Barnes, jbarnes@jccc.edu Ext. 3651
Kenneth Gregory, kggregor@jccc.edu

22801 St. Clair Ave.
Cleveland, Ohio 44117
Bill West: (216) 383-2259
Jennifer Howell (216) 383-8325
www.lincolnelectric.com

5330 Berryhill Road
Milton, FL 32570
(850) 983-5700
www.locklintechn.com
Mesabi Range Community & Technical College

Mesabi Range offers a rigorous welding curriculum following national and international standards developed by the American Welding Society. The welding and fabrication programs are designed to provide a hands-on learning environment. We have 100% job placement in the last ten years. Welding certifications are available.

Moraine Park Technical College

Moraine Park Technical College offers a one-year welding diploma program focusing on GMAW, SMAW, and GTAW on steel, stainless and aluminum. The program includes Print Reading and Fabrication courses that focus on the manufacturing process of a product from conception to final production via basic layout tools and CNC equipment. Instruction includes AWS and ASME welding codes, including qualification tests and writing WPSs, with the opportunity to weld-certify upon completion of the program.

North Dakota State College of Science

The North Dakota State College of Science is a two-year, residential college that offers degrees, certificates and diplomas in over 80 academic options in traditional career and technical studies and in the liberal arts. NDSCS offers one-year certificates, two-year diplomas and A.A.S. degrees in Welding Technology. The college is an American Welding Society S.E.N.S.E. certified facility. Last year, 98 percent of NDSCS graduates entered the workforce or continued their college education. Unlike more two-year colleges, NDSCS offers a university atmosphere for students – residence halls, clubs and organizations, fine arts, athletics and numerous social activities.

Northcentral Technical College

At NTC, you will receive an education designed to give you the hands-on training and experience you need to succeed! Northcentral Technical College delivers state-of-the-art, industry-driven welding training in the SMAW, GMAW, FCAW, GTAW, and oxyfuel processes, as well as robotic welding and CNC plasma operation. Welding students also gain knowledge in supporting skills such as blueprint reading, metallurgy, technical math, and CAD. Whether you are pursuing an associate degree, technical diploma or short-term certificate, NTC offers a vast range of opportunities, making us the right fit at the right time for you. Customized training courses are also available to meet specific employer needs.

Northeast Wisconsin Technical College

Northeast Wisconsin Technical College offers training in welding, weld inspection and nondestructive testing in Green Bay and Marinette, Wisconsin, and by contract at worksites nationwide. NWTC welding graduates can build and repair metal components using major welding processes used by industry and knowledge of blueprints, metallurgy and layout; can weld to AWS and ASME codes; can work as maintenance welders, qualified welders, structural welders, welder/fabricators and pipe welders.
SCHOOL PROFILES APRIL 2008

Odessa College

The Welding Technology Department at Odessa College in Odessa, Texas, offers a full range of certificate and associate degree options. The lab areas are equipped with 45 modern welding stations for training in SMAW, GMAW, FCAW and GTAW processes as well as 15 OFW stations. Currently, classes are offered in the morning and evening to accommodate an average of 100 students each semester. Odessa College received a U.S. Department of Labor grant for $1.75 million in January 2007 for the Welding Training Center. This new 30 station training facility opened in January 2008 and offers an 8-week “Introduction to Welding Fundamentals” courses through the Continuing Education Division. The Welding Training Center “Grand Opening” was featured in the March 2008 issue of the Welding Journal.

201 W. University
Odessa, TX 79764
(432) 335-6474
James Mosman – Coordinator
Email: jmosman@odessa.edu

Owens Community College

Owens Community College Welding Technologies provides students with knowledge and skills for job placement in the welding industry. Students are educated in all aspects of welding including SMAW, MIG and TIG welding, torch and plasma cutting as well as brazing. Students who excel in their welding skills are encouraged to complete their plate and pipe welding certification. Students may also chose from coursework in welding fabrication, welding codes and procedures and Certified Welding Inspector.

Welding Technologies
P.O. Box 10,000
Oregon Road, Toledo, OH 43699
(567) 661-7729
Email: James_Gilmore@owens.edu

Orange Coast College

Founded 1947

The Orange Coast College welding curriculum has been a part of this college curriculum since the college was first conceived. Our program offerings include both a Welding Certificate of Achievement and an Associate in Science Degree. We are proud to offer a comprehensive welding program which includes Oxyacetylene welding and cutting, SMAW, GMAW, FCAW, GTAW, orbital welding and plasma arc cutting. On our academic side we teach metallurgy for welders, codes and specifications for welders, math and science for welders and testing and inspection for welders. Our instructors have AWS QC-I CWI and CWE credentials as well as California Community College teaching credentials. We qualify welders to ANSI standards and we are a licensed Los Angeles City testing laboratory. Our testing laboratory does both destructive and nondestructive examinations.

2701 Fairview Road
Costa Mesa, CA 92626
(714) 432-5820

Ozarks Technical Community College

Founded 1990

Ozarks Technical Community College offers multiple welding programs, providing opportunities for full- or part-time students, as well as customized training for employers. The Welding Technology program includes courses in several types of welding and welding inspection, leading to either a certificate or an A.A.S. The College also offers an accelerated 20-week Master Welder certificate program. The Center for Workforce Development offers short-term, non-credit welder training for local businesses. OTC is a fully equipped, fully accredited AWS Certified Test Facility.

1001 E. Chestnut Expwy
Springfield, MO 65802
(417) 447-7500
ask@otc.edu
www.otc.edu

Pennsylvania College of Technology

Founded 1989

Pennsylvania College of Technology, a Penn State affiliate since 1989, offers “degrees that work” in more than 100 careers including welding. In addition to an associate’s degree and certificate, Penn College offers a unique bachelor’s degree in Welding and Fabrication Engineering Technology that prepares graduates for technical careers and positions in mid-management, supervision, sales, service, and research. The College also is a regional partner for the National Center of Excellence in Welding Education and Training.

One College Avenue
Williamsport, PA 17701
(800) 367-9222
admissions@pct.edu
www.pct.edu/schools/iet/weld

Polaris Career Center

Polaris Career Center offers Welding training in Middleburg Heights, Ohio. Earn AWS certification in SMAW and GMAW and Certification through NCCER. These courses are designed to give the students valuable theory and practical application related to Oxyfuel welding and brazing, GTAW, GMAW, and FCAW. Course topics include Open V-groove welds, pipe welds, and vertical welding. The Adult Education/Job Training programs are conducted at night allowing students to work during the day while pursuing a career in welding.

7285 Old Oak Blvd.
Middleburg Hts., OH 44130
(440) 891-7750
Johnny Napier,
Welding Program Coordinator
jnapier@polaris.edu
www.polaris.edu

April 2008 School Profiles
Pulaski Technical College

The Welding Program at Pulaski Technical College in North Little Rock, Arkansas focuses on structural welding and offers AWS Level I and II certification. The two-semester Technical Certificate program includes instruction in welding processes, joint design and metallurgy. The Certificate of Proficiency will allow an individual to complete certification requirements in 3G (vertical) positioning.

Renton Technical College

Founded 1942

Renton Technical College, located just southeast of Seattle, Washington, offers preparatory welder training (AAS degree), supplemental training and up-grading classes. Placement in the industry is 98% for graduates. We offer welder certification in all of the popular processes. Curriculum is constantly updated to stay current with industry. Day, evening, and weekend classes are available in oxyfuel, SMAW, GMAW, GTAW, Fabrication, and Inspection. Our instructors are AWS-CWI/CWE with over 80 years collective experience.

Rock Valley College

RVC’s welding program currently includes 60 students trained in the facility which includes a lab with 28 welding booths. Welding processes being taught include: GMAW, FCAW, GTAW, SMAW, and Oxyacetylene. RVC is an AWS Certified Accredited Testing Facility. The welding lab has been at current location for six years staffed by one full time and five part-time faculty. RVC is a certified ICAR welding testing center. For information, contact Mike Merriman.

Santa Fe Community College

Serving Alachua and Bradford Counties

Founded 1966

The Applied Welding Technologies Program is a one and one-half year certificate program that consists of SMAW, GMAW, GTAW, FCAW, Oxy Fuel Welding/Cutting, blueprint reading and power tool and equipment operation performed on carbon steel, stainless steel and aluminum. The training helps prepare students to pass nationally recognized plate and pipe welding certification tests. The welding lab at SFCC is an AWS Accredited Testing Facility.

San Juan Basin Technical College

Earn a certificate as a Structural Welder, Combination/Fitter Welder and Pipe Welder (low/high pressure, and stainless steel.) Welding Technology helps to develop individual entry level or above skills through hands on experience under supervised instruction. Oxyfuel, SMAW, GTAW, GMAW, blueprint reading for welders and orbital arc pipe welding is available. We offer quality, affordable educational training in a new facility.

Solano Community College

Founded 1945

Solano Community College offers welding education and training at its Northern California campus in Fairfield, located between San Francisco/Oakland and Sacramento, California. Earn a Certificate or A.S. Degree with day, evening, Saturday and summer classes. Industrial driven curriculum teaches skills in SMAW, GTAW, GMAW, FCAW, Oxy-Acetylene and ornamental iron welding along with various cutting processes utilizing manual, semiautomatic and automatic processes. Customized courses are available for employers. Benefit from free qualification testing and tutoring, affordable tuition and personal attention. Elective courses and schedules are listed in the college website.
South Plains College
Founded: 1957

The SPC Welding Technology Program offers basic and advanced certificates along with an Associate of Applied Science degree. Entry level and advanced training certificates through AWS are also awarded to those who qualify. Specific areas of training include: OFC, PAC, SMAW plate and pipe, GMAW plate and pipe, FCAW plate and pipe, GTAW sheet and pipe, welding symbols, blueprint reading, welding metallurgy and structural and pipe layout and fabrication.

Pete Stracener
South Plains College
1401 S. College, Box 88
Levelland, TX 79336
(806) 894-9611, ext: 2284
pstracen@southplainscollege.edu
www.southplainscollege.edu/welding/index.htm

Southeastern Illinois College
Founded 1960

Southeastern Illinois College offers welding training leading to a one-year certificate or a two-year associate in applied science degree. Curriculum helps students develop skills needed in today's workforce. SIC offers training in shielded metal arc, gas tungsten arc, gas metal arc, and oxyfuel processes. Key support courses include metallurgy and blueprint reading. Enjoy small classes, free tutoring and personal attention. Job placement services available upon program completion. Offering quality training at one of the lowest tuition costs in Illinois.

Randy Key
3200 Ave. C
Big Spring, Texas 79720
(432) 264-3700 V/TTY
(432) 264-3707
rkey@howardcollege.edu
www.howardcollege.edu

Tri-County Technical College
Founded 1965

The welding department at Tri-County Technical College has trained welders for industry since 1965. We offer an associates degree, diploma, and two shorter certificate programs. With two CWI / CWEs on staff we can provide welder certification testing, as well as customized company training.

7900 Highway 76
Pendleton, SC 29670
(864) 646-1405
pphelps@tctc.edu

Trident Technical College
Founded in 1964

Trident Technical College’s welding technology program offers an associate degree in occupational technology with a welding career path and certificates in shielded metal arc, gas tungsten arc, gas metal arc and flux cored arc welding, as well as advanced certificates. The program is an AWS S.E.N.S.E. Level I and Level II program. With a student body of more than 12,000 students, TTC is committed to providing diverse and innovative educational programs and services in a highly technical and competitive global environment.

P.O. Box 118067
Charleston, SC 29423
(843) 574-6139
Fax: (843) 574-6173
ronald.vann@tridenttech.edu
www.tridenttech.edu

Tulsa Welding School
Founded 1949

Tulsa Welding School is the largest accredited* welding institution in America with training centers in Tulsa, Okla. and Jacksonville, Fla. Founded nearly 60 years ago, diplomas and Associate degrees are awarded. Welding competencies include structural, pipe, pipeline, and thin alloy welding. Associate degree also includes numerous NDT techniques plus QA/QC methods. Graduates are available every three weeks along with thousands of alumni who contact TWS. *ACCSCCT
SCHOOL PROFILES APRIL 2008

The Ketchikan Campus of the University of Alaska Southeast

The Ketchikan Campus of the University of Alaska Southeast is the primary post secondary welding department in the region. AWS Entry and Advanced Level classes are offered each semester. The sixteen stations are state of the art. Students are prepared for immediate employment in entry level welding jobs. Classes are geared for employment in production and construction industries. Welders will be needed on new projects in Alaska. Information available from Steve Brandow.

Welder Training and Testing Institute
Founded in 1968

WTTI maintains a freestanding campus in Pennsylvania housing a weld lab equipped with sixty-five work stations. Training is provided in all major welding processes. Classrooms are fully equipped to support lessons in theory, blueprint-reading, and fitting. Specialized on-site training is available to industry with the option of a 10 station multi-process mobile welding lab. WTTI also offers CWI and NDT training and certification, as well as welder certification through our AWS Accredited Test Facility.

729 E. Highland Street
Allentown, PA 18109
(800)223-WTTI
Email: info@wtti.edu

Cuesta College Welding Technology
Founded 1965

Located on the central coast of California, the Cuesta College Welding Technology program has a strong history of preparing students for work in industry. Students certify to AWS D1.1 and ASME Section IX and have the opportunity to obtain Associate Science degrees in Welding Technology. Our curriculum is well rounded with courses ranging from basic welding through certification, as well as courses in metallurgy, blueprint reading and welding power. The shop facility includes twenty multi-process welding stations newly appointed with current power supply technology. We recently added a metallurgy lab to our program. There are a total of 8 part-time instructors and one full time instructor representing a collective total of 175 years industry experience and 90 years teaching experience in welding technology. Four of our instructors are CWIs.

P.O. Box 8106
San Luis Obispo, CA 93403-8106
(805)546-3100 ext 2737
Rob Thoresen, rthores@cuesta.edu

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**Experienced Welder Repair Technician**

Immediate openings for experienced Welder Repair Technician at our Salt Lake City facility. United States Welding, Inc, an independent distributor of Gases and Welding Equipment in the Rocky Mountain Region has been in business for over 70 years. We are seeking applicants with 3 or more years experience. An associate degree or better is a definite asset. We offer a full benefits package including: competitive salary, car allowance, medical and dental insurance, life and disability insurance, 401K, vacation and holiday pay, paid sick days. Some relocation expenses will be reimbursed. Interested applicants should submit resumes via fax to 1-801-972-8304. No phone calls please.

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Innovative results-oriented National Service Manager with an extensive background with CNC Cutting Machines, Plasma, Laser, and/or Welding Automation. Skilled at training and supervision of equipment installation and service. Management responsibility for United States and Canada. Duties include specification work at End User firms such as Steel Service Centers, Shipyards, Fabricators, etc. Set up, manage, train, evaluate and upgrading a large distribution network; directs installation and service to Distributor and Key accounts; process; application engineering; creating new opportunities. Must have direct transferrable and or competitive experience within the Industry. Direct responsibility for training, evaluation and performance of the distribution network, OEM's and select key accounts. Strong Product Training & Presentation Skills. Position is based in Cleveland. CNC controls (Hypertherm®, CMC, etc), CNC data management systems High Performance Plasma, Laser, Water Jet cutting processes Ability to read Drawings – CAD systems

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**Sr. QA Technician**

Requisition # 08-29-01 SR QA TC Open until filled. Duties: Inspection; auditing and reporting; QA data/record management; corrective and preventive action; statistical analysis. Requirements: BA in quality or technical vocation and/or 10 years minimum of QA work experience. Minimum 10 years experience in machining, manufacturing, or aluminum casting industry. Level II or higher certification such as NDE, CWI, or ASQ Quality Inspector or Technician. For full details and to apply go to www.wagstaff.com/employment. EEO/AA/Drug–Free Workplace

**Business Opportunities**

**Business Opportunity**

Seeking business partner who has expertise and capability of servicing stainless steel and aluminum in products used by restaurants and resorts. This business is focused in Florida. Outstanding niche, 100% + potential. All clients are major corporations, with 15 years of dedicated service. Candidates must be capable of expert stainless steel and aluminum work and product enhancement. If you have the ability to invest for success in a recession-proof environment.

E-mail compedgeservices@bell-south.net. Serious responses only.

**BAE SYSTEMS**

**Weld Manufacturing Engineer**

BAE Systems, the premier global defense and aerospace company, is seeking a professional, experienced Weld Manufacturing Engineer for its Minneapolis Minn. facility. The ideal candidate will possess a strong background in the fabrication of large, precision, complex weldments. This challenging position requires a minimum of five years experience as a manufacturing engineer across a wide variety of conventional weld practices and processes. A Bachelor’s degree in a related field is preferred as well as familiarity with AWS and/or military weld specifications. Responsibilities will include working within design teams, manufacturing process and fixture development, and providing fabrication shop floor support.

**BUSINESS OPPORTUNITIES**

**Sr. QA Technician**

Requisition # 08-29-01 SR QA TC Open until filled. Duties: Inspection; auditing and reporting; QA data/record management; corrective and preventive action; statistical analysis. Requirements: BA in quality or technical vocation and/or 10 years minimum of QA work experience. Minimum 10 years experience in machining, manufacturing, or aluminum casting industry. Level II or higher certification such as NDE, CWI, or ASQ Quality Inspector or Technician. For full details and to apply go to www.wagstaff.com/employment. EEO/AA/Drug–Free Workplace

**Business Opportunity**

Seeking business partner who has expertise and capability of servicing stainless steel and aluminum in products used by restaurants and resorts. This business is focused in Florida. Outstanding niche, 100% + potential. All clients are major corporations, with 15 years of dedicated service. Candidates must be capable of expert stainless steel and aluminum work and product enhancement. If you have the ability to invest for success in a recession-proof environment.

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Houma, LA July 26-Aug. 1

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(800) 489-2890
info@realeducational.com

The AWS Certification Committee
Is seeking the donation of sets of Shop and Erection drawings of highrise buildings greater than ten stories with Moment Connections including Ordinary Moment Resistant Frame (OMRF) and Special Moment Resistant Frame (SMRF) for use in AWS training and certification activities. Drawings should be in CAD format for reproduction purposes. Written permission for unrestricted reproduction, alteration, and reuse as training and testing material is requested from the owner and others holding intellectual rights. For further information, contact:
Joseph P. Kane
(631) 265-3422 (office)
(516) 658-7571 (cell)
joseph.kane11@verizon.net

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Measurement and Analysis of Three-Dimensional Specular Gas Tungsten Arc Weld Pool Surface

Two reconstruction schemes were verified as valid means of rebuilding a three-dimensional weld pool surface off-line

BY H. S. SONG AND Y. M. ZHANG

ABSTRACT. Measurement of weld pool surface is a difficult but urgent task in the welding community. It plays an important role not only in developing the next-generation intelligent welding machines but also for modeling complex welding processes. In recent years, different techniques have been applied in this area, but the specular characteristic of weld pool surface and the strong welding arc compromise their effectiveness. To better resolve this problem, a new vision-based sensing (measurement) system was proposed in our previous study, which utilizes the reflection property of the weld pool surface. In that system, a dot-matrix pattern of structured laser light was projected onto the specular weld pool surface and its reflection was imaged on a self-designed imaging plane. Then the distorted reflected image (pattern) was captured and processed. Based on the obtained information, two reconstruction schemes named interpolation reconstruction scheme (IRS) and extrapolation reconstruction scheme (ERS), are proposed in this paper in order to rebuild the three-dimensional weld pool surface off-line. The experimental results verify the effectiveness of the proposed methods and show that ERS can achieve better accuracy than IRS. Meanwhile, the variation of the weld pool surface in an experiment is also analyzed by using the proposed measurement system and extrapolation reconstruction scheme.

KEYWORDS
- Weld Pool Surface
- Specular Reflection
- Three-Dimensional Interpolation
- Extrapolation
- Surface Variation
- GTAW
- Control

Introduction

Welding is a labor-intensive operation. Although welding robots can provide consistent motion to help improve productivity, they lack the intelligence that human welders possess to ensure quality. Since skilled human welders can achieve good weld quality through observing the weld pool, the pool surface must contain sufficient information to judge weld quality, such as weld joint penetration. Meanwhile, the precise measurement of the weld pool surface can provide critical experimental data to validate numerical models of welding processes. Hence, the measurement of three-dimensional weld pool surface is a fundamental capability that the next-generation automated welding machines and welding researchers must possess, and a number of early efforts have been devoted to sensing weld pool related parameters including machine vision, X-ray radiation, ultrasonic, and acoustic emission (Refs. 1–4).

Among these methods, noncontact vision-based ones have been studied more extensively (Refs. 5–11). An important technique for a 2-D weld pool boundary measurement is the coaxial viewing of the weld pool, which was first proposed by Richardson et al. (Ref. 5). It has been widely investigated by some researchers. In the coaxial viewing method, the electrode is used to block the arc, but the image quality is decreased by the bright plasma. Agapakis and Bolstad presented an innovative vision sensing system that used intense stroboscopic illumination to overpower the arc light in the welding process and produce a clear image with synchronized camera (Ref. 6). This technique was further applied in the Welding Research Laboratory at the University of Kentucky by Kovacevic and Zhang.

The acquired image is shown in Fig. 1A and an image processing algorithm has been developed to analyze and extract the two-dimensional boundary of the weld pool so that control algorithms can use these parameters as feedback to adjust welding parameters (Ref. 7). To use this system in three-dimensional weld pool surface imaging, the structured illumination laser was projected through a frosted glass (Ref. 8), and an image with the three-dimensional shape information of weld pool surface was acquired as shown in Fig. 1B. Because of its cost and size, this specially designed system is not suitable for production.

In a separate effort, Mnich and his colleagues (Ref. 9) used stereovision to determine the three-dimensional shape of the weld pool in the GMAW process, but the complexity compromised its suitability for practical application. Another effort by Yoo and Lee (Ref. 10) used a similar principle but introduced the biprism technique to reduce the number of needed cameras from two to one. The accuracy of the system as mentioned by the authors is reasonable.
A structured light technique was used by Saeed et al. to determine the profile of the weld pool surface (Ref. 4). In the acquired image, the distortion of the projected laser line clearly showed the shape of the weld pool, while the unavoidable bright arc affected the observation. Another vision-based sensing system was developed for pulsed GTAW with wire filler metal by Zhao et al., which used an improved shape from shading (SFS) algorithm to recover the weld pool surface height (Ref. 11). While all these methods have achieved certain success, more accurate and direct methods are still desired. The authors recently proposed a different approach to observe the weld pool surface (Refs. 12, 13). It projects a low-power continuous structured laser pattern onto the weld pool surface and intercepts the reflection of the projected pattern from the specular weld pool surface. Because the arc radiation decays very fast with the travel distance while the reflection of the projected laser light remains intense, it is possible that the reflection of the projected laser can be clearly imaged on the interception plane. Since the small low-power laser diode is economical and compact, this approach is more cost-effective, convenient, and suitable for manufacturing applications. However, although the formation of the image is simply based on the reflection law, the reflected image itself does not provide an intuitive view about the dimensions of the weld pool surface. Thus, a reconstruction scheme is needed to derive the three-dimensional shape of the weld pool surface.

In this paper, two schemes named interpolation reconstruction scheme (IRS) and extrapolation reconstruction scheme (ERS) are proposed. Their difference lies in the methods of reconstructing the pool surface and determining the surface boundary. Experimental results verified the accuracy of both methods, and the extrapolation reconstruction scheme proved the better performer.

Sensing System Review

There are three major sequential steps for using the proposed method to reconstruct/measure the pool surface. The first one is to image the laser pattern reflected from the weld pool surface. Then, the acquired reflected image is processed to extract the information of the reflected laser pattern. The third step is to use the three-dimensional reconstruction scheme to rebuild the weld pool surface based on obtained data. The first two major steps are briefly reviewed in this section. Detailed procedures can be found in the literature (Refs. 12–14).

The proposed weld pool surface sensing system in a universal coordinate system is shown in Fig. 2 (Refs. 12, 13). The gas tungsten arc welding (GTAW) process without filler metal was used. The welding direction was along the positive Y axis. A 20-mW continuous illumination laser with a wavelength of 685 nm was used to project a $19 \times 19$ dot-matrix structured-light pattern onto the weld pool area under the electrode at a certain angle. The inter-beam angle of the laser pattern was 0.77 deg. During the welding process, the molten specular weld pool surface can reflect the majority of the incident laser light. Thus, on the other side of the torch, an imaging plane (a piece of glass attached with a grid paper) was placed about 50 mm away in order to intercept the reflected laser pattern. A high-speed camera was used to record the reflected images on the imaging plane. To minimize the influence of the strong arc, the camera was fitted with a 20-nm band-pass filter centered at a wavelength of 685 nm.

In one of the experiments, the laser was projected onto the workpiece at 31.14 deg with a distance of 31.48 mm to the origin of the coordinate system. Figure 3A and B shows the projected pattern and the acquired reflected image. As can be seen, only part of the projected dots located within the weld pool area was reflected, and the laser pattern was shaped by the weld pool surface as convex curves. Although the intensity of the reflected dots was low, the reflected image can still be processed by the proposed algorithms as shown in Fig. 3C.

After image acquisition, a point locat-
ing algorithm and a feature extraction algorithm are proposed to process the reflected images (Ref. 14). First, the reflected points in the image are extracted in the point locating algorithm by using some image processing techniques, such as block thresholding segmentation (Ref. 15), median filtering, and morphological operations (Ref. 16). It can be seen in Fig. 3B, although the reflected pattern is distorted, the basic row-column relationship in the pattern remained.

Then based on the reflected dot positions, some image features, such as row-column relationship and the “center reference point” can be successfully determined by the feature extraction algorithm. For instance, there are 7 rows (curves) and 16 columns found in Fig. 3B and C. As shown in Fig. 3A, the center point of the 19 × 19 dot matrix (at the 10th row and the 10th column) is intentionally absent, and it is introduced as the center reference point to ease the matching process although it does not actually exist. In Fig. 3C, the corresponding position of the center reference point can be easily found in the 6th row.

To investigate the possible corresponding relationships between projected and reflected dots, a corresponding simulation was conducted (Ref. 14). In the simulation, part of a sphere was used to present the weld pool surface. By testing some convex and concave surfaces with typical dimensional values, it can be concluded that to produce the convex reflected images like Fig. 3B, the corresponding relationship for a convex surface is sequential/sequential (S/S) and the one for a concave surface is inverse/inverse (I/I).

Here the relationship before the slash presents the column corresponding relationship, and the one after the slash presents the row corresponding relationship. In the proposed system, if the reflected column/row order is the same as that reflected from a flat surface, the relationship is defined as sequential; if the order is inverted, the relationship is inverse. Thus, combined with the corresponding position of reference point in the captured image, each reflected dot on the imaging plane can be successfully matched with a projected dot in the matrix by using the corresponding relationship. The matched point-ray pairs can be used to reconstruct the three-dimensional weld pool surface.

In Fig. 4, suppose \( R = \{ r_{k,t} \in I \} \) presents the set of reflected dots, on the reflected image \( I \), and \( P = \{ p_{i,j} \in S \} \) presents the set of corresponding reflection dots on the weld pool surface \( S \) (here...
the subscripts present the row and column positions of the dots, and the numbers of dots in sets P and R are the same). The row-column position of the reflected dots are shown in Fig. 4A, and the corresponding relationship is I/I, the matched points pair is \( r_{k,t} \rightarrow \text{reflection} \rightarrow p_{10+6-k,10+7-t} \). If the corresponding relationship is S/S, the matched points pair is \( r_{k,t} \rightarrow \text{reflection} \rightarrow p_{k+10-6,t+10-7} \), and the corresponding reflection points are shown in Fig. 4B. For example, the corresponding projected point of reflected point \( r_{1,5} \) is \( p_{5,8} \). As can be seen, only those points that are actually projected on the liquid weld pool surface are reflected onto the imaging plane and are imaged and processed to reconstruct the weld pool surface in the proposed method, and those projected on the solid surface will not be reflected to and imaged on the imaging plane.

### Reconstruction Schemes

From previous steps, two discrete sets of points \( (R = (r_{k,t}, (k,t) \in I), P = (p_{i,j}, (i,j) \in S)) \) and their possible corresponding relationships were obtained. Now the task is to derive the three-dimensional weld pool surface from these matched discrete point sets based on the governing reflection law. It is apparent that the issue is not to apply the reflection law to calculate the reflection of incident rays. Instead, the issue here is to see what three-dimensional surface may generate a set of reflected points that are close enough to the given \( R = (r_{k,t}, (k,t) \in I) \). The issue is thus an inverse problem of the reflection law, and it appears an analytical solution does not exist.

To resolve this issue, an iterative engineering method is needed and the authors thus propose two schemes, interpolation and extrapolation reconstruction schemes (IRS and ERS), to find an optimally estimated three-dimensional surface. The ERS differs from the IRS in the way to construct the pool surface and determine the surface boundary. The details of the schemes proposed are presented below.

**Step 0:** A flat plane \((Z = 0)\) is used as the initial estimate of the weld pool surface.

Since generally the depth of the weld pool is much smaller than its width and length for the GTAW process, it is reasonable to use a flat plane, i.e., \( Z = 0 \), as the initial estimate of the weld pool surface.

**Step 1:** Use the assumed surface to compute the slope field. Based on the results of corresponding simulation (Ref. 14), the tested corresponding relationships are chosen for the different shapes of reflected image. For example, for the “convex” image (Fig. 3B), two corresponding relationships (I/I and S/S) are tested sequentially, which can be seen in Fig. 5. Once the relationship is decided, the pairs of projected and reflected dots can be determined.

In the first step, the estimate of the weld pool surface was used to calculate the positions of the estimated reflection dots \( p'_{i,j} \) in set \( P = (p'_{i,j}, (i,j) \in S) \) where \( S \) is the assumed surface and \( i/j \) is the row/column number. Thus all the reflection lines are determined. By using the reflection law, the normal of every reflection point \( p'_{i,j} \) on the surface can be further computed. Then the tangent plane of the surface at the reflection dot \( p'_{i,j} \) can be obtained, which is referred to as its 3-D slope. This tangent plane intersects with the row plane and the column plane of dot \( p'_{i,j} \) to find two tangent lines and the 3-D slope is thus decomposed into two 2-D slopes: row and column slopes. For example, in Fig. 6A the row slopes of reflection
dots at the 5th row are shown. Here the row/column plane of a dot refers to a plane passing through the laser diode and all the dots on the same row/column. These slopes of the estimated reflection dots form a slope field, which is used to produce the reflected image.

**Step 2: Compute the new slope-oriented reflection points based on the slope field.** It is obvious that the used surface in the first step cannot meet the slope requirements to produce the captured reflected image. Thus, in the second step the new slope-oriented reflection point set \( P'' = \{ p''_{r,j} \} \) is calculated to better approximate the actual weld pool surface based on these estimates of slopes.

**Assumption of base point.** In IRS and ERS, the positions of new slope-oriented reflection points are all calculated in relation to a base point, whose position is assumed. In IRS, the reflection point corresponding to the left-down reflected dot (\( r_{1,5} \) in Fig. 4) is chosen as the base point. In Fig. 4, dot \( p_{5,8}, p'_{5,8}, p''_{5,8} \) is the base point for S/S corresponding relationship. In IRS, the height of the base point is sequentially selected in a range, such as \((-0.5, 0.5)\). While in ERS, the base point is chosen according to different corresponding relationships so as to make it on the left head part of the weld pool surface. For instance, in Fig. 4B \( p_{11,6}, p'_{11,6}, p''_{11,6} \) is the base point for S/S corresponding relationship in ERS. The height of the base point can be reasonably assumed to be zero instead of searching in a range since the base point is on the boundary of the head of the weld pool surface.

**Computation of new slope-oriented reflection points.** Based on the selected base point, all the other reflection points on the pool surface can be calculated. There are three computation procedures for ERS and IRS as shown in Fig. 7. First, the new slope-oriented reflection dots on the same row as the base point are computed using their row slopes. In Fig. 6, the new reflection points at the 5th row are computed by using their row slopes in IRS. Since the position of base point \( p^{s}_{5,8} \) is decided, the adjacent dot \( p'_{5,9} \) can be located as the intersection point of projected ray LM and line \( p^{s}_{5,8}A \), and the slope of line \( p^{s}_{5,8}A \) can be decided as Equation 1

\[
S_{p^{s}_{5,8}A} = \text{sign} \left( S_{p_{5,8}A} \right)
\]

\[
S_{p_{5,8}A} + S_{p'_{5,9}} \right)/2
\]

(1)

where the function sign () means the positive or negative sign of the slope and \( S_{p^{s}_{5,8}} \) and \( S_{p'_{5,9}} \) refer to the row slopes of the reflection point of \( p^{s}_{5,8} \) and \( p'_{5,9} \), respectively. Following the same procedures, all the other reflection points in the 5th row can be calculated as shown in Fig. 6B. Then based on the middle point of the row with base point \( p''_{5,12} \) and \( p''_{11,11} \) for IRS and ERS, the middle points at the same column (12th column), but different rows can be calculated by using column slopes just as done in the previous step. At last, row slopes are used to compute the positions of all the other new reflection points based on the positions of the middle points at their rows. Thus, the positions of all updated reflection dots are calculated by using the computed slope field.

**Step 3: Reconstruction of weld pool surface using new reflection points.** In the third step, a weld pool surface should be deduced depending on the reflection points \( P'' \) computed in the second step. Here the interpolation method (Ref. 17) is used in IRS and the method (Ref. 18) that can realize both interpolation and extrapolation is applied in ERS. They both can produce a smooth surface from nonuniformly sampled data in the form of Equation 2

\[
z = f(x,y)
\]

(2)

In IRS the area of reconstructed surface is limited by the reflection points while in ERS the area of the reconstructed surface is not, which makes their ways to determine boundary different.

**Step 4: Compute the error of the reconstructed surface.** In the fourth step, based on the knowledge of the projected dot matrix and the surface reconstructed in the third step, the reflected points set \( R' \) (\( R' = \{ r'_{k,t} \; (k,t) \in I \} \)) on the imaging plane can be recomputed and compared with the positions of the captured reflected point set \( R \). The distances between the actual and computed reflected points can thus be calculated and be further mapped to the weld pool surface as “reflection error,” which is discussed later. After error calculation, the estimated surface in Step 3 is used as the new assumed surface to continue the first step within pre-set loops for each corresponding relationship. At last, after all possible corresponding relationships are tried, the computed surface with the minimum reflection error is chosen as the optimally estimated weld pool surface.

**Step 5: Calculate 2-D surface model and use it to find the weld pool boundary.** In this step, a two-dimensional piece-wise boundary model \( r(\theta) \) in a polar coordinate system is developed to determine the three-dimensional boundary of the weld pool surface. First, the two end points in each reflection row are selected as bound-
ary points in Fig. 4B, and they are classified into three sets: left (L), right (R), and head (H) sets as shown in Fig. 8A. Here, S/S corresponding relationship is assumed, and the origin of the system is chosen as the middle point of the longest row (8th row in Fig. 8). Then the polar coordinate models in Equation 3 are used to describe the three parts (left, right, and head part) of the weld pool boundary. The points in three sets can be used to fit the models respectively and the coefficients \( \omega_i \) can thus be decided by using the mean square method.

\[
\begin{align*}
\theta_R &= \theta_H + \sum_{i=1}^{3} \omega_{H Li} \theta_i \\
\theta_L &= \theta_L + \sum_{i=1}^{3} \omega_{L Li} \theta_i \\
\theta_R &= \theta_R + \sum_{i=1}^{3} \omega_{R Li} \theta_i
\end{align*}
\]

At last, the whole two-dimensional piecewise boundary model of the weld pool surface can be expressed by Equation 4. As shown in Fig. 8B, it is composed of five segments (including two transition segments).

\[
\begin{align*}
\theta_R &= \theta_H + \sum_{i=1}^{3} \omega_{H Hi} \theta_i \\
\theta_L &= \theta_L + \sum_{i=1}^{3} \omega_{L Li} \theta_i \\
\theta_R &= \theta_R + \sum_{i=1}^{3} \omega_{R Ri} \theta_i
\end{align*}
\]

Fig. 9 — Optimal estimated weld pool surface. A — The interpolation result of IRS; B — the extrapolation result of ERS.

Fig. 10 — Computed and actual reflected points compare using different schemes. A — Result of IRS; B — result of ERS.

Reconstruction Results

In this section, a reflected image shown in Fig. 3B is used to test IRS and ERS. The results of the two schemes are compared and discussed. As can be seen, an iteration process is used in IRS and ERS to find the optimally estimated surface according to the computed error. To define a meaning-
Fig. 11 — Fitted two-dimensional weld pool boundary model (on Z = 0 plane).

Fig. 12 — Results of different reconstruction schemes. A — Weld pool surface using interpolation reconstruction scheme (different views); B — weld pool surface using extrapolation reconstruction scheme (different views).

Fig. 13 — Captured reflected images.
A ful error that can describe the difference between the calculated and actual reflection points on weld pool surface, the authors propose an error measurement parameter: average reflection error (ARE). Its definition is shown in Equation 6.

\[
\text{ARE} = \frac{1}{n} \sum_{k,l} E_{k,l} \quad \text{for all } (k,l) \in I
\]

(6)

where \( I \) refers to the reflected image and \( n \) represents the total number of the reflected points on the imaging plane. \( E_{k,l} \) represents the reflection error for the corresponding reflection point of \( r_{k,l} \), and it is defined as Equation 7.

\[
E_{k,l} = \left( e_{x_{k,l}}^2 + \frac{W_p}{W_r} e_{z_{k,l}}^2 \right) + \left( e_{x_{k,l}}^2 + \frac{L_p}{L_r} e_{z_{k,l}}^2 \right)
\]

(7)

where \( e_{x_{k,l}} \) and \( e_{z_{k,l}} \) are the distances between estimated reflected point \( r'_{k,l} \) and actual reflected point \( r_{k,l} \) along horizontal direction (X axis) and vertical direction (Z axis) on the imaging plane. \( W_r \) and \( L_r \) represent the horizontal and vertical ranges of the reflected dots, and \( W_p \) and \( L_p \) represent the horizontal (X axis) and vertical (Y axis) ranges of the corresponding projected dots on the workpiece (Z = 0). It can be seen the error parameter ARE effectively maps the difference between calculated and actual reflected points to the error of the reflection points on the weld pool surface.

The optimal surfaces by using IRS and ERS are shown in Fig. 9, and their corresponding relationships are all S/S. By using extrapolation reconstruction scheme (ERS), the computed minimal average reflection error (ARE) is 0.1234 mm, which is a little smaller than the result of IRS 0.1691 mm. In IRS, the smallest ARE is achieved when the height of the base point is 0. It can be seen that the area of optimally interpolated surface reconstructed by IRS is limited by the reflection points, but it is not the case for ERS.

In Fig. 10, the positions of actual reflection points and computed reflected points using optimally estimated surface are shown for the two schemes. These two results are similar, but for the matching extent of edge points, the performance of ERS is better since the extrapolation method works better than interpolation to deduce the boundary. One thing should be noted here. The absent dot \( r_{6,7} \), which corresponds to the center reference point in Fig. 4, is still considered as a reflected point in the schemes, and its position is assumed in the middle of its adjacent two dots in the 6th row in Fig. 10.

Based on the results of interpolation or extrapolation reconstruction methods and the Sequential/Sequential (S/S) corresponding relationship, the fitted two-dimensional (2-D) boundary (at \( Z = 0 \) plane) shown in Fig. 11 is used to find the boundary points. The point in the center is the origin of the used polar coordinate system for the model, and it is defined as the center point of the weld pool. The shape of the modeled 2-D boundary is similar as the ones shown in Fig. 1. Because the welding speed is slow (3 mm per second), the difference between width (6.7313 mm) and length (7.1182 mm) is small and the 2-D shape is like a circle, which can be verified by the measurement result after the experiment. Since the welding electrode is on the Z axis, it can be found in Fig. 11 that the distance between the coordinate origin and the weld pool head is smaller than the distance to its tail.

In Fig. 12, the whole 3-D weld pool surfaces are reconstructed by using both the boundary model and the optimally estimated surfaces in IRS and ERS. The two reconstructed surfaces are both convex. (This is probably related to the properties of the mild steel workpiece.) The heights of the surfaces are 0.3045 mm and 0.2533 mm.
mm, respectively, in Fig. 12A and B. The difference is small, while the difference between their boundaries is obvious due to different ways to compute the boundary. The result of the extrapolation reconstruction scheme is more reasonable since the boundary is not exactly on \( Z = 0 \) plane.

**Analysis of Variations in Weld Pool Surface**

A series of reflected images are recorded during an experiment using the same nominal constant welding parameters in order to examine if the weld pool surface would remain unchanged. Figure 13 shows reflected images at a rate of 60 frames per second. During this experiment, a sheet of 2-mm-thick mild steel was used as the workpiece and the welding current was 75 A with a constant welding speed of 3 mm/s. The distance between the torch and imaging plane was 50 mm, and the projection angle of laser diode was about 31 deg. From the reflected images, the shape changes of the weld pool surface can be seen clearly. The first variation is the number of rows of reflected dots, which varies from 6 to 8. This means the length of the weld pool surface is changing. The second change is the corresponding position of the center reference point in the reflected images, which shows the position change of the weld pool surface. Even when the number of rows is the same in some images, the number of dots in a row still changes. It reflects the variation of width in the weld pool surface. These deductions are drawn based on the facts that projected laser dot matrix covers the whole weld pool surface immovably and only the dots on the pool surface can be reflected onto the imaging plane.

In order to further investigate the variation of weld pool quantitatively, the extrapolation reconstruction scheme (ERS) was applied to reconstruct the weld pool surface for each reflected image in Fig. 13. One thing should be noted here. In our study, some unclear dots located in upper fragmental rows are neglected since some dots in the row are blocked by the torch and they are not suitable for the proposed reconstruction schemes, such as the ones in Fig. 13H, K, and M. By using the ERS, the optimal estimates of three-dimensional weld pool surfaces are reconstructed for each reflected image in Fig. 13, and the differences between computed reflected images by using optimally estimated surfaces and the actual captured ones are shown in Fig. 14.

After the computation of the two-dimensional boundary model, the whole weld pool surface can be reconstructed by using ERS. The results are shown in Fig. 15. The shapes variation of these reconstructed surfaces can be clearly seen. In Fig. 16, the computed average reflection errors (ARE) for different reflected images vary insignificantly in a range of \( (0.13632 \text{ mm}, 0.25247 \text{ mm}) \).

Figure 17 shows the variations of two-dimensional parameters of the reconstructed weld pool: the width and the length, which are decided by the boundary model. The width of the weld pool surface varies in the range of 6.4643 to 6.9183 mm, or \( \pm 3.5\% \). The average width and its variance are calculated as Equation 8.

\[
\bar{w} = \frac{\sum_{i=1}^{15} w_i}{15} = 6.6645 \text{ mm},
\]

\[
V_w = \frac{\sum_{i=1}^{15} (w_i - \bar{w})^2}{15} = 0.15 \text{ mm}^2
\]

where \( w_i \) represents the width of the \( i \)-th reconstructed weld pool surface. The length of the pool surface varies in the range of 7.1303 to 8.1092 mm or \( \pm 6.4\% \). The average length and its variance are shown in Equation 9.

\[
\bar{l} = \frac{\sum_{i=1}^{15} l_i}{15} = 7.4549 \text{ mm},
\]

\[
V_l = \frac{\sum_{i=1}^{15} (l_i - \bar{l})^2}{15} = 0.46 \text{ mm}^2
\]

where \( l_i \) presents the length of the \( i \)-th reconstructed weld pool surface. It can be seen that the variation of weld pool surface length is greater than that of the width.

Figure 18 shows the height variation of the weld pool surface. Since the reconstructed surfaces are all convex, and the \( Z \) coordinate of the highest point in the surface is considered as the height of the weld pool surface. From the figure, it can be seen that the heights of the surfaces vary from 0.2514 to 0.3236 mm or in the range of \( \pm 12.6\% \). The average height and variance are shown in Equation 10.

\[
\bar{h} = \frac{\sum_{i=1}^{15} h_i}{15} = 0.2943 \text{ mm},
\]

\[
V_h = \frac{\sum_{i=1}^{15} (h_i - \bar{h})^2}{15} = 0.0199 \text{ mm}^2
\]

where \( h_i \) represents the height of the \( i \)-th reconstructed surface. The relative variation of the height is thus much greater than those of the width and length.

In Fig. 19, the variation of the weld pool positions is shown. It also can be seen that the positions of the center point and the highest point of the weld pool surface are also changing for the studied images. The position of the center point of the weld pool is shown in Fig. 11. The variations of these three-dimensional parameters discussed above prove that the weld
pool surface has fluctuations even in the same nominal welding conditions. The possible reasons include the possible small fluctuations in the welding current and speed, possible shielding gas turbulence, and other possible interference factors.

Discussion

Although the reconstruction results of the three-dimensional weld pool surface proved the effectiveness of the proposed system, the accuracy of the reconstructed surface still needs to be discussed. In section 4, the reconstructed pool surfaces are shown in Fig. 12. There is no obvious concave region inside the weld pool surface under the torch, which is practical because of the arc pressure. The possible explanation is that the concave region in the weld pool surface is very small due to the low welding current (75 A) and/or there is no laser dots projected onto it.

In previous discussion, it was seen that some slightly concave regions exist among upper rows in some of the reflected images in Fig. 13, and the irregular concave regions are embedded in some of the reconstructed weld pool surfaces in Fig. 15. Figure 20 shows some of those cases corresponding to Fig. 13B, E, and N. For example, in Fig. 20A the reflected dots at 4th, 5th, and 6th row form nonsmooth convex curves with slightly concave regions, which gives the reconstructed surface an obvious concave region inside it. The possible reason is the variation of the weld pool surface makes more rays project onto the small concave region of the surface. Although the errors of optimal results are small, obvious differences between the reflected images still can be seen in Figs. 10 and 14. Since it is a sensing system for a small object, there are many factors in the scheme that may cause errors, such as the parameter measurement, image processing, the surface interpolation/extrapolation, and boundary modeling process. Thus, an error analysis of the proposed system is needed, and future work should be done to improve the accuracy of the reconstructed three-dimensional weld pool surface.

Conclusions

A sensing system has been proposed to image the reflection of projected laser pattern from the specular weld pool surface. To derive the three-dimensional weld pool surface based on the image processing results, two reconstruction schemes (IRS and ERS) are proposed for off-line computation. Based on the studies and analyses in this paper, the following conclusions can be drawn:

• The proposed reconstruction schemes can be used to resolve the inverse problem of the reflection law to derive the three-dimensional weld pool surface from the image processing results.
• The proposed error measurement...
parameter provides an effective way to estimate and quantify the accuracy of the resultant weld pool surface and the convergence of the solution.

In ERS, the base point is chosen on the head of weld pool surface, and its height is reasonably assumed zero. The iterative search process used in IRS can thus be avoided and the reconstruction speed is improved accordingly.

In comparison with interpolation reconstruction scheme (IRS), the extrapolation reconstruction scheme (ERS) can achieve better accuracy especially for the rear of the weld pool surface.

Through applying ERS to a series of reflected images acquired from an experiment with nominal constant welding parameters, the variations of the three-dimensional weld pool surface are studied. It is found that the variation of the length is greater than that of the weld pool width, and the relative variation of the height (depth) of the weld pool surface is much greater in comparison with those of the length and width.

Acknowledgments

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References


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ABSTRACT. Finite element modeling and fracture mechanics calculations were used to predict the resistance spot weld failure mode and loads in shear-tension tests of advanced high-strength steels (AHSS). The results were compared to those obtained for an interstitial-free (IF) steel. The results of the work confirmed the existence of a competition between two different types of failure modes, namely full button pullout and interfacial fracture. The force required to cause a complete weld button pullout-type failure was found to be proportional to the tensile strength and the thickness of the base material as well as the diameter of the weld. The force to cause an interfacial weld fracture was related to the fracture toughness of the weld, sheet thickness, and weld diameter. For high-strength steels, it was determined that there is a critical sheet thickness above which the expected failure mode could transition from pullout to interfacial fracture. In this analysis it was shown that, as the strength of the steel increases, the fracture toughness of the weld required to avoid interfacial failure must also increase. Therefore, despite higher load-carrying capacity, due to their high hardness, the welds in high-strength steels may be prone to interfacial fractures. Tensile testing showed that the load-carrying capacity of the samples that failed via interfacial fracture was found to be more than 90% of the load associated with a full button pullout. This indicates that the load-bearing capacity of the welds is not affected by the fracture mode. Therefore, the mode of failure should not be the only criteria used to judge the quality of spot welds. The load-bearing capacity of the weld should be the primary focus in the evaluation of the shear-tension test results in AHSS.

Introduction

The use of advanced high-strength steels (AHSS), such as dual-phase and transformation-induced plasticity (TRIP) steels, has been steadily increasing over the past few years in automotive applications (Refs. 1, 2). This is due to the advantages that AHSS grades offer, in terms of higher strength that enables the automakers to decrease the vehicle weight for improved fuel economy and improved crash energy absorption for better occupant protection. The two grades of AHSS that have seen increased use in automobiles are the dual-phase and TRIP steels. The steel grades that are used commercially in automotive bodies at present are those with minimum strength levels of 500, 590, and 780 MPa. Resistance welding is the predominant mode of fabrication in automotive production with a typical vehicle in North America containing about 4000 to 5000 welds. Therefore, good resistance welding is one of the key characteristics of any steel grade to be considered for use in automobile body production.

Several tests are generally used to characterize the resistance spot welding behavior of steels. These include the welding current range determination, metallographic characterization of the weld and heat-affected zone microstructures, microhardness, and weld tensile tests (Ref. 3). One type of weld tensile test typically done is called the shear-tension test (sometimes referred to as lap-shear test). In this test, two sheet samples, 140 mm long by 60 mm wide are overlapped by 45 mm and joined with a single spot weld located at the center of the overlapped region — Fig. 1. The sample is then pulled in tension. Due to the offset of the sheets, the application of tension creates a bending moment that causes rotation of the weld nugget. This type of deformation is demonstrated with a finite element simulation — Fig. 2. For clarity, only one half of the model is shown. The combination of bending and shear loading that results from this deformation causes a complicated stress pattern to develop in and around the nugget.

There are two different failure modes that are generally observed in shear-tension tests, namely, “interfacial fractures” and “full button pullout” — Fig. 3. In the interfacial fracture, the weld fails at the interface of the two sheets, leaving half of the weld nugget in one sheet and half in the other. In the full button pullout, fracture occurs in the base metal or in the weld heat-affected zone at the perimeter of the weld. In this failure mode, the weld nugget is completely torn from one of the sheets with the weld remaining intact. It is also possible to get a combination of the two failure modes in which a portion of the nugget is pulled out of one of the sheets and the rest of the nugget shears at the interface.

A review of the literature showed that considerable work has been done to understand the behavior of spot welds under tensile and shear loading. Work done by Davidson and Imhof (Refs. 4–6) showed that spot weld strength in the shear-tension test is related to the stiffness of the joint. They found that, for stiffer test specimens the degree of rotation that the spot welds undergo is less than that for a full button pullout-type failure. This suggests that the absence of an interfacial fracture may not necessarily indicate weld failure. Therefore, it is important to characterize the resistance spot welding behavior of steels.
weld undergoes becomes smaller, which in turn, leads to increased joint strength. Davidson and Imhof correlated the joint strength with weld nugget rotation but did not offer a relationship for the stress intensity at the weld. Pook (Ref. 7) developed a relationship for the stress intensity at the weld nugget based on analytical solutions. Pook showed that the weld diameter and sheet thickness have an effect on the stress intensity at the nugget perimeter. Chao (Ref. 8) studied the expected failure modes and failure loads for spot welds based on assumed stress distributions around the perimeter of the weld resulting from a combination of shear and tensile loading. Radaj and Zhang (Ref. 9) and Zhang (Ref. 10) performed detailed finite element modeling of spot welds under shear tension load to predict the stress intensity around the weld. This analysis suggested that correlations and trends predicted in earlier work did not correlate well with the detailed computer models. Radaj and Zhang developed some simplified equations to predict the stress intensity of spot welds in various tests, including the shear-tension test. The correlations were consistent with the computer simulations. However, the simulations are computationally intensive and time consuming.

In the evaluation of the shear-tension test results in spot welds, it is generally believed in the automotive industry that an interfacial shear failure is indicative of poor weld integrity. This has generally been true for low-strength steels (tensile strength equal to or less than 300 MPa), in which interfacial failure is normally associated with insufficient fusion or some sort of a weld imperfection, such as gross porosity. However, it is not clear if interfacial fractures in shear-tension tests indicate poor weld integrity in AHSS grades. With the increased use of these steels in automotive bodies, it is important to study their fracture behavior in shear-tension tests so that welds, otherwise sound, do not get rejected solely based on fracture appearance. Furthermore, an understanding of the fracture behavior may allow the automotive companies to use these steels and enable them to take advantage of the benefits that these steel grades offer. Additionally, the tensile fracture behavior of the recently introduced advanced high-strength steels, such as dual-phase and TRIP steels, has not been reported previously. Therefore, a study was undertaken to examine and predict the fracture modes possible in shear tension tests in dual-phase steels with a minimum tensile strength of 590 and 780 MPa and TRIP steel with a minimum tensile strength of 780 MPa. An attempt based on finite element modeling (FEM) and fracture mechanics calculations on data collected from actual shear-tension tests was made to predict the resistance spot weld failure modes in shear-tension tests.

Materials and Experimental Procedure

Dual-phase steel coils with a minimum ultimate tensile strength of 590 and 780 MPa, transformation-induced plasticity

Table 1 — Welding Conditions

<table>
<thead>
<tr>
<th>Welding Machine Manufacturer</th>
<th>Taylor Winfield Corp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding Machine Type</td>
<td>Pedestal-type</td>
</tr>
<tr>
<td>Welding Machine Transformer</td>
<td>100 kVA</td>
</tr>
<tr>
<td>Welding Controller</td>
<td>TrueAmp IV</td>
</tr>
<tr>
<td>Electrode Face Diameter</td>
<td>6 mm</td>
</tr>
<tr>
<td>Electrode Force</td>
<td></td>
</tr>
<tr>
<td>For IF Steel:</td>
<td></td>
</tr>
<tr>
<td>3.1 kN (697 lbf)</td>
<td></td>
</tr>
<tr>
<td>For AHSS Grades:</td>
<td></td>
</tr>
<tr>
<td>4.2 kN (945 lbf) for 1 mm</td>
<td></td>
</tr>
<tr>
<td>5.4 kN (1200 lbf) for 1.2</td>
<td></td>
</tr>
<tr>
<td>and 1.6 mm</td>
<td></td>
</tr>
<tr>
<td>Squeeze Time</td>
<td>75 cycles</td>
</tr>
<tr>
<td>Weld Time</td>
<td>13 cycles (for 1-mm sheets)</td>
</tr>
<tr>
<td></td>
<td>14 cycles (for 1.2-mm sheets)</td>
</tr>
<tr>
<td></td>
<td>18 cycles (for 1.6-mm sheets)</td>
</tr>
<tr>
<td>Hold Time</td>
<td>10 cycles</td>
</tr>
<tr>
<td>Preheating</td>
<td>None</td>
</tr>
<tr>
<td>Postheating</td>
<td>None</td>
</tr>
<tr>
<td>Electrode Coolant Water Temperature</td>
<td>21°C</td>
</tr>
<tr>
<td>Tip Cooling</td>
<td>3.7 L/min (1 gal/min)</td>
</tr>
</tbody>
</table>

Table 2 — Material Properties Used

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Yield Strength, MPa</th>
<th>Tensile Strength, MPa</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>137</td>
<td>302</td>
<td>45</td>
</tr>
<tr>
<td>590 Dual Phase</td>
<td>370</td>
<td>650</td>
<td>25</td>
</tr>
<tr>
<td>780 Dual Phase</td>
<td>470</td>
<td>805</td>
<td>19</td>
</tr>
<tr>
<td>780 TRIP</td>
<td>440</td>
<td>844</td>
<td>24</td>
</tr>
</tbody>
</table>

Note: Elastic Modulus of 207 GPa and Poisson’s Ratio of 0.29 used for each case.
tension tests were conducted per Ref. 3. Prior to shipping the coils, weld shear-welds on both ends of each sample were made to attach shims for tensile testing. The spot welds in the as-received condition without any cleaning of the mill oil used to coat the coils were tested and the average values reported. In each case, five tensile samples were tested and the average values reported.

In order to better understand the sample behavior and failure modes that occur in the shear-tension test, finite element computer simulations of this test were performed. The modeling was done using ABAQUS Version 6.5 general-purpose finite element modeling (FEM) software. The simulations were run on a Silicon Graphics Octane 2 workstation. Three-dimensional models of the test sample were developed using eight-node brick elements. Model strain predictions were found to converge for a local element size near the weld that is less than 25% of the sheet thickness for each of the three thicknesses evaluated. An example of a finite element model of the shear-tension test sample for a 1-mm sheet with a 6-mm button is shown in Fig. 4. The lower picture in Fig. 4 shows a close-up view of the mesh in the vicinity of the spot weld. In order to reduce computation time, symmetry conditions were applied so that only one half of the sample had to be represented. In the study, several models were developed to represent different sheet thicknesses and weld diameters.

The stress-strain behaviors of the three types of steel grades used in the simulations are shown in Fig. 5. The computer modeling software allows for the definition of elastic as well as plastic behavior of materials and the appropriate data points were defined to describe the load-displacement behavior. This was done using the highest current possible without causing expulsion in the samples. The welding parameters used for making the test samples are shown in Table 1. Load to failure and the weld fracture morphology were noted in each case. In each case, five tensile samples were tested and the average values reported.

The current required to produce a weld button size equal to or 90% of the face diameter of the electrode tip used was determined. This was done using the highest current possible without causing expulsion in the samples. The welding parameters used for making the test samples are shown in Table 1. Load to failure and the weld fracture morphology were noted in each case. In each case, five tensile samples were tested and the average values reported.

### Table 3 — Results of Simulations for Interstitial-Free Steel Samples (Ultimate Tensile Strength = 300 MPa)

<table>
<thead>
<tr>
<th>Weld Diameter (mm)</th>
<th>Nominal Sheet Thickness (mm)</th>
<th>FEM Failure Mode(a)</th>
<th>FEM Failure Load (N)</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>1.0</td>
<td>IF</td>
<td>1200</td>
<td>0.62</td>
</tr>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>PO</td>
<td>3640</td>
<td>2.32</td>
</tr>
<tr>
<td>7.5</td>
<td>1.0</td>
<td>PO</td>
<td>5400</td>
<td>2.30</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>PO</td>
<td>7070</td>
<td>2.26</td>
</tr>
<tr>
<td>2.5</td>
<td>1.5</td>
<td>IF</td>
<td>1200</td>
<td>0.61</td>
</tr>
<tr>
<td>5.0</td>
<td>1.5</td>
<td>IF</td>
<td>4720</td>
<td>0.60</td>
</tr>
<tr>
<td>7.5</td>
<td>1.5</td>
<td>PO</td>
<td>8140</td>
<td>2.31</td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>PO</td>
<td>10700</td>
<td>2.28</td>
</tr>
<tr>
<td>2.5</td>
<td>2.0</td>
<td>IF</td>
<td>1200</td>
<td>0.61</td>
</tr>
<tr>
<td>5.0</td>
<td>2.0</td>
<td>IF</td>
<td>4540</td>
<td>0.56</td>
</tr>
<tr>
<td>7.5</td>
<td>2.0</td>
<td>IF</td>
<td>10280</td>
<td>0.58</td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
<td>PO</td>
<td>13920</td>
<td>2.22</td>
</tr>
<tr>
<td>13</td>
<td>2.0</td>
<td>PO</td>
<td>16700</td>
<td>2.17</td>
</tr>
</tbody>
</table>

(a) IF – interfacial fracture; PO – full button pullout fracture.
placement behavior shown in Fig. 5. The material properties defined in the analysis are shown in Table 2.

As a starting point in the study, the properties of the entire test specimen were considered to be homogeneous. It was assumed that the properties of the weld and the heat-affected zone were the same as those of the base metal. The homogeneous model was used only to estimate loads required for pullout failure. This assumption was made to examine the effect of button size and sheet thickness on the behavior of the weld in this test.

To predict the failure loads associated with interfacial fracture, additional considerations were made. It was observed that the interfacial failures initiated at the notch created at the sheet interface at the periphery of the weld. This suggested that the fracture toughness of the weld and heat-affected zone controlled the failure mode and load. Previous work (Ref. 10) provided a means to estimate the stress intensity at the root of the notch at the sheet interface and is described in later sections.

In the analysis, sheet thicknesses of 1.0, 1.5, and 2.0 mm were simulated. For each sheet thickness, four or five different weld sizes were modeled ranging in diameter from 2.5 to 13 mm. For all models, the sample length and width were held constant. A total of 39 simulations were run, 13 for each of the three steel types, namely IF, dual-phase, and TRIP steels.

In all models, one end of the sample was held fixed and an applied axial displacement was applied to the opposite end. The reaction force was monitored as a function of the applied displacement. When the failure strain was reached in either the weld or the base metal outside the weld, failure was assumed to have occurred. The magnitude of the reaction force at the point when failure strain was reached was considered to be the load-carrying capacity of the sample.

**Results and Discussion**

The results of the analyses of the homogeneous shear-tension test samples are shown in Tables 3–5 and in Figs. 6–11. Figure 6 shows the model-predicted deformation of a sample at the onset of a pullout failure. In this failure mode, the strength of the material outside the weld...
nugget is exceeded and necking begins to occur at the location shown. After failure of the material at this location, the weld button is peeled out of the base metal around the weld perimeter. A more detailed model of this mechanism is shown in Fig. 7, which is a contour plot of the plastic strain in the homogeneous sample. As the figure shows, the maximum plastic strain is concentrated outside the weld nugget, which leads to necking and failure at this location. The predicted deformation that occurs during the interfacial failure is shown in Fig. 8. Nearly all of the strain is concentrated in the weld at the interface of the two sheets. Figure 9 shows the plastic strain distribution associated with the interfacial failure. There is some strain outside the weld nugget, but shear failure of the weld occurs before the pullout failure can initiate. These results are shown in graphical form in Fig. 10. The maximum plastic strain in the weld at the interface of the sheets and the maximum strain in the base metal outside the weld nugget are plotted as a function of the applied end displacement. For the case of full button pullout, the strain in the base metal outside the weld nugget is greater than that developed at the weld interface and the opposite is true for the case of the weld interfacial failure. Based on these results, it is apparent that there is a competition between the pullout and the interfacial failure modes.

For the pullout failure, the results of the finite element simulations showed that there was a strong correlation between failure load and the material strength, sheet thickness, and weld diameter. The load to cause interfacial failure was found to be more strongly dependent on the weld diameter and less on the sheet thickness. The predicted failure loads were found to adhere to the following correlations:

\[
F_{PO} = k_{PO} \cdot \sigma_{UT} \cdot d \cdot t \\
F_{IF} = k_{IF} \cdot \sigma_{UT} \cdot d^2
\]

Where \( F_{PO} \) is the failure load for pullout failure, \( F_{IF} \) is the failure load for interfacial fracture, \( \sigma_{UT} \) is the tensile strength of the material, \( d \) is the weld diameter, and \( t \) is the sheet thickness. Equations 1 and 2 were derived based on the fact that the force required to cause failure is equal to the product of the strength of the material and the failed area of cross section. In this analysis, the material was assumed to be homogeneous. Therefore, the strength of the weld and the base metal are both equal to \( \sigma_{UT} \). In Equations 1 and 2, \( k_{PO} \) and \( k_{IF} \) were constants determined from the modeling.

The results of the analysis of the homogeneous sample analysis are shown in Tables 3–5. Each table corresponds to a different steel type (IF, DP, and TRIP) and shows the combinations of sheet thickness and weld diameter that were simulated. As predicted in Equations 1 and 2, the failure loads to cause pullout were found to be proportional to the weld diameter and the sheet thickness while those for interfacial failure were proportional to the square of the weld diameters. The predicted failure mode and failure load as well as the constant \( k_{PO} \) or \( k_{IF} \) are shown in the tables. The values for \( k_{PO} \) and \( k_{IF} \) were backcalculated from Equations 1 and 2 by using the model-predicted failure loads, weld diameters, sheet thicknesses, and base metal strengths. The fact that the values of these two constants were fairly consistent for each case (\( k_{PO} \sim 2.2 \) and \( k_{IF} \sim 0.6 \)) indicates that Equations 1 and 2 are good estimates of the model-predicted failure mode (for the homogeneous samples that were simulated).

Examination of Figs. 6–9 showed that, due to offset of the sheets, the shear-tension test specimens undergo rotation along an axis perpendicular to the loading direction. The degree of rotation was found to be greater for the cases of full button pullout failures (Figs. 6, 7) compared to those that failed interfacially (Figs. 8, 9). Davidson and Imhof (Ref. 6)

### Table 4 — Results of Simulations for DP 590 Steel (Minimum Ultimate Tensile Strength = 590 MPa)

<table>
<thead>
<tr>
<th>Weld Diameter (mm)</th>
<th>Nominal Sheet Thickness (mm)</th>
<th>FEM Failure Mode(s)</th>
<th>FEM Failure Load (N)</th>
<th>K-Factor</th>
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<tbody>
<tr>
<td>2.5</td>
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<td>IF</td>
<td>2290</td>
<td>0.55</td>
</tr>
<tr>
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<td>PO</td>
<td>7600</td>
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</tr>
<tr>
<td>7.5</td>
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<td>PO</td>
<td>11600</td>
<td>2.31</td>
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<td>10</td>
<td>1.0</td>
<td>PO</td>
<td>15060</td>
<td>2.25</td>
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<tr>
<td>2.5</td>
<td>1.5</td>
<td>IF</td>
<td>2260</td>
<td>0.54</td>
</tr>
<tr>
<td>5.0</td>
<td>1.5</td>
<td>IF</td>
<td>9660</td>
<td>0.58</td>
</tr>
<tr>
<td>7.5</td>
<td>1.5</td>
<td>PO</td>
<td>16860</td>
<td>2.24</td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>PO</td>
<td>22700</td>
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</tr>
<tr>
<td>2.5</td>
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<td>IF</td>
<td>2300</td>
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<tr>
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<td>2.0</td>
<td>IF</td>
<td>9300</td>
<td>0.56</td>
</tr>
<tr>
<td>7.5</td>
<td>2.0</td>
<td>IF</td>
<td>22150</td>
<td>0.59</td>
</tr>
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<td>10</td>
<td>2.0</td>
<td>PO</td>
<td>28700</td>
<td>2.14</td>
</tr>
<tr>
<td>13</td>
<td>2.0</td>
<td>PO</td>
<td>35500</td>
<td>2.12</td>
</tr>
</tbody>
</table>

(a) IF – interfacial fracture; PO – full button pullout fracture.
that failed via pullout is shown in Fig. 12.

### Table 5 — Results of Simulations for Dual-Phase and TRIP 780 Steels (Minimum Ultimate Strength = 780 MPa)

<table>
<thead>
<tr>
<th>Weld Diameter (mm)</th>
<th>Nominal Sheet Thickness (mm)</th>
<th>FEM Failure Mode</th>
<th>FEM Failure Load (N)</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>1.0</td>
<td>IF</td>
<td>3000</td>
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</tr>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>PO</td>
<td>8950</td>
<td>2.17</td>
</tr>
<tr>
<td>7.5</td>
<td>1.0</td>
<td>PO</td>
<td>13600</td>
<td>2.20</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>IF</td>
<td>17780</td>
<td>2.15</td>
</tr>
<tr>
<td>2.5</td>
<td>1.5</td>
<td>IF</td>
<td>3030</td>
<td>0.59</td>
</tr>
<tr>
<td>5.0</td>
<td>1.5</td>
<td>IF</td>
<td>11900</td>
<td>0.58</td>
</tr>
<tr>
<td>7.5</td>
<td>1.5</td>
<td>PO</td>
<td>20500</td>
<td>2.21</td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>PO</td>
<td>26400</td>
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</tr>
<tr>
<td>2.5</td>
<td>2.0</td>
<td>IF</td>
<td>2920</td>
<td>0.57</td>
</tr>
<tr>
<td>5.0</td>
<td>2.0</td>
<td>PO</td>
<td>11530</td>
<td>0.56</td>
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<tr>
<td>7.5</td>
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<td>IF</td>
<td>26760</td>
<td>0.58</td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
<td>PO</td>
<td>34760</td>
<td>2.11</td>
</tr>
<tr>
<td>13</td>
<td>2.0</td>
<td>PO</td>
<td>43700</td>
<td>2.12</td>
</tr>
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</table>

#### Notes
- (a) IF – interfacial fracture; PO – full button pullout fracture.

### Table 6 — Actual Test Results and Predicted Stress Intensity at Failure

<table>
<thead>
<tr>
<th>Material</th>
<th>Nominal Sheet Thickness (mm)</th>
<th>Weld Diameter (mm)</th>
<th>FEM Failure Mode</th>
<th>FEM Failure Load (N)</th>
<th>Stress Intensity (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>780 DP</td>
<td>1.2</td>
<td>7.0</td>
<td>IF</td>
<td>14230</td>
<td>1294</td>
</tr>
<tr>
<td>590 DP</td>
<td>1.0</td>
<td>6.0</td>
<td>IF</td>
<td>9790</td>
<td>1126</td>
</tr>
<tr>
<td>780 TRIP</td>
<td>1.6</td>
<td>8.5</td>
<td>IF</td>
<td>21800</td>
<td>1385</td>
</tr>
<tr>
<td>780 DP</td>
<td>1.2</td>
<td>7.0</td>
<td>PO</td>
<td>15520</td>
<td>1411</td>
</tr>
<tr>
<td>780 DP</td>
<td>1.6</td>
<td>8.0</td>
<td>PO</td>
<td>22900</td>
<td>1581</td>
</tr>
</tbody>
</table>

#### Notes
- (a) IF – interfacial fracture; PO – full button pullout fracture.

---

the significance of specimen rotation during fatigue testing of spot welded samples. In fatigue testing, shear-tension test coupons are subjected to repeated tensile loads in the same manner as in static shear-tension testing. Davidson and Imhof showed that the stiffness of test samples affected the degree of rotation and that the weld failure mode was affected by the degree of rotation. They observed that stiffer samples (less rotation) failed interfacially, whereas, below a certain critical stiffness, the samples failed in the base metal and the weld remained intact.

Equations 1 and 2 are plotted graphically in Fig. 11 for dual-phase 590 steel and show the predicted interfacial and pullout failure load as a function of weld diameter. In this plot, the sheet thickness was assumed to be 1.5 mm and the sheet tensile strength equal to 590 MPa. A sheet thickness of 1.5 mm was chosen because it represented the mid-thickness of the normal range of steels (1 to 2 mm) used in automotive bodies. The minimum allowable tensile strength of the steel (590 MPa) was used for this case. According to the analysis, the lower of the two predicted failure loads will determine the mode of failure. Thus, the point where the two curves intersect indicates where the failure mode changes. The figure shows that, for this sheet thickness and strength, interfacial failures were predicted to occur for weld diameters below 6 mm and pullout failures for diameters greater than 6 mm. Figure 11B shows a similar plot with the exception that the weld diameter was assumed to be constant at 7 mm and the failure loads are plotted as a function of sheet thickness. These results indicate that pullout failures are more likely to occur on thinner sheet samples, and the mode can change to interfacial when the sheet thickness reaches a critical value (for this example ~ 1.7 mm). By setting Equations 1 and 2 equal to each other, the ratio of the weld diameter to the sheet thickness is determined to be roughly equal to 4. This suggests, for a homogeneous test sample, pullout failures will occur if the weld diameter is greater than four times the sheet thickness. Likewise, for a given weld diameter, the sheet thickness has to be less than 25% of the weld diameter for pullout to occur.

The homogeneous model predictions agreed well with the test data for cases where pullout failures occurred. This is because the pullout failures most often initiated in the base metal outside of the notch at the perimeter of the weld. A comparison of the actual failure loads and model-predicted failure loads for samples that failed via pullout is shown in Fig. 12. However, when comparing the homogeneous model results to actual test data, the predicted failure loads for the interfacial fractures were not consistent — Fig. 12. It was theorized that there were two main reasons for the differences. First, the model assumed that the sample was homogeneous. In reality, the mechanical properties of the weld, base metal, and different parts of the heat-affected zone are significantly different. For example, it was shown that the hardness of weld fusion zones and the heat-affected zones are much higher than those of the base material in dual-phase steels (Ref. 13). Further, the computer models did not account for the stress intensity at the perimeter of the weld. The model considered that the weld would fail when the strength of the weld metal is exceeded at the interface of the two sheets. This would more closely represent a shear overload of the weld metal rather than a fracture of the weld nugget initiating at the notch around the perimeter of the nugget.

A fracture mechanics study by Zhang (Ref. 9) provided an estimate of the stress intensity at the perimeter of the spot weld specifically for the shear-tension test. Fracture mechanics theory provides a means to evaluate the load-bearing ability of materials that have cracks or flaws. In fracture theory, the fitness for service of a structural member that contains a crack is determined by comparing the predicted stress intensity at the crack tip to the fracture toughness of the material. Like material properties such as tensile strength and elongation, fracture toughness is a material property that is determined from testing. Fracture analysis of a cracked member (in which stress intensity is compared to fracture toughness) is analogous to the analysis of notch-free structural members in which predicted stresses are compared to the strength of the material. Zhang’s analysis yielded the following relationship for the stress intensity at the perimeter of the weld in the shear-tension test.

\[
K_{eq} = 0.694 \cdot \frac{F}{d \sqrt{t}}
\]

\[
F_{eq} = 1.44 \cdot K_C \cdot d \cdot \sqrt{t}
\]

In Equation 3, \(K_{eq}\) is the equivalent stress intensity factor at the spot weld, \(F\) is the applied load, \(d\) is the weld diameter, and \(t\) is the sheet thickness. Some actual test results are shown in Table 6. The table lists the steel grades, weld dimensions, failure mode, failure load, and the calculated
stress intensity at failure. The stress intensities were calculated using Equation 3. The first three samples listed in the table failed via interfacial fracture. This suggests that the listed stress intensity at the time of failure is comparable to the fracture toughness of the weld. The stress intensities for the samples that failed via button pullout are also shown. For these two cases, the fracture toughness of the weld was apparently high enough to avoid interfacial fracture (i.e., the fracture toughness was greater than the values listed for the stress intensity when the pullout failure occurred).

Table 7 shows additional data comparing the model predictions to measured data. The table lists the steel grades, weld diameter, sheet thickness, actual failure load, and mode as well as the predicted failure load had pullout failures occurred.

Table 7 — Comparison of Actual Shear Tension Test Results and Model Predictions

<table>
<thead>
<tr>
<th>Material</th>
<th>Sheet Thickness (mm)</th>
<th>Weld Diameter (mm)</th>
<th>Failure Mode(a)</th>
<th>Actual Test Data Failure Load (N)</th>
<th>FEM Failure Mode</th>
<th>Model Predictions FEM Failure Load (N)</th>
<th>Percent of Max PO Load(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>780 DP</td>
<td>1.2</td>
<td>7.5</td>
<td>PO</td>
<td>15500</td>
<td>PO</td>
<td>15820</td>
<td>—</td>
</tr>
<tr>
<td>780 DP</td>
<td>1.6</td>
<td>8.3</td>
<td>PO</td>
<td>22900</td>
<td>PO</td>
<td>22250</td>
<td>—</td>
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<td>7.0</td>
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<td>9900</td>
<td>PO</td>
<td>10340</td>
<td>96</td>
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<td>IF</td>
<td>14680</td>
<td>PO</td>
<td>15820</td>
<td>93</td>
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<tr>
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<td>8.5</td>
<td>IF</td>
<td>22060</td>
<td>PO</td>
<td>24330</td>
<td>91</td>
</tr>
</tbody>
</table>

(a) IF — interfacial fracture; PO — full button pullout.
(b) Ratio of the actual failure load to the model-predicted pullout failure load if the failure were to occur by the pullout mode (multiplied by 100).
in each case. The first two samples listed failed via button pullout and the model-predicted failure loads were in good agreement with the actual loads. The following three samples in the table failed via interfacial fracture. For these cases, the model-predicted loads for pullout failure are listed. The interesting results shown here are that, although interfacial fracture occurred in the samples, the load-carrying capacity of the weld was greater than 90% of the predicted failure load if pullout had occurred. This indicates that the load-bearing capacity of these welds was not significantly affected by the fracture mode. Therefore, the mode of failure should not be the only criteria used to judge the quality of spot welds. The load-bearing capacity of the weld should be the primary focus in the evaluation of the shear-tension test results in AHSS.

In order to get an estimate of the load required for interfacial fracture in the shear-tension test, the stress intensity in Equation 3 was set equal to the fracture toughness of the material and the load was solved for. This is shown in Equation 4 where \( F_{IP} \) is the load to cause interfacial fracture of the weld, and \( K_C \) is the fracture toughness of the material. The fracture toughness describes the ability of a material to carry load in the presence of a flaw and is determined from testing. Generally, ductile materials tend to have high fracture toughness while the opposite is true for brittle materials. Based on the work done by Zhang (Ref. 9), Equation 4 (rather than Equation 2) was thought to better represent the parameters governing the interfacial fracture mode. The previously determined load to cause pullout failure (Equation 1) was, however, considered to be appropriate. The predicted relationship for pullout load likely agreed well with the measured data because this failure initiates in the form of necking in the base metal near the weld heat-affected zone as opposed to at the notch radius around the perimeter of the weld nugget.

Equations 1 and 4 are plotted graphically in Fig. 13. In this plot, the weld diameter was assumed to be constant at 8 mm and the tensile strength assumed was the minimum allowable for this grade (780 MPa).
MPa), and the failure load is plotted as a function of sheet thickness. The interfacial fracture load is plotted assuming a fracture toughness of 1560 N/mm$^{3/2}$, and the pullout failure load is plotted for a low-strength steel (300 MPa) and a higher-strength steel (780 MPa). For the curve representing the low-strength steel, the predicted pullout failure load is less than the interfacial fracture load over this entire range of sheet thickness. This indicates that pullout failure will occur in every case. For the higher-strength sample, the curve for pullout failure and interfacial fracture intersect at a sheet thickness of 1.6 mm. This indicates that for the high-strength sheet sample, interfacial fracture will be the expected failure mode for sheet thicknesses greater than 1.6 mm.

The critical parameters that control the transition between failure modes can be determined by setting Equation 4 equal to Equation 1. Some of these results are shown in the last four figures. Figure 14 shows that critical sheet thickness above which interfacial fracture will occur becomes less as the strength of the sheet increases. Thus, for higher-strength sheet, interfacial fracture can become the expected failure mode in thicker samples. Figure 15 shows the fracture toughness of the weld required to maintain pullout failures increases with the strength of the sheet indicating that interfacial fractures are more likely to occur with high-strength steels. Figure 16 shows that the weld toughness required to avoid interfacial fracture also increases with sheet thickness. Figure 17 shows the predicted failure load as a function of sheet thickness for a low-strength steel having a weld with poor load-carrying capacity. For a low-strength sheet, a pullout failure is predicted even when the load-carrying capacity of the weld is poor.
shown in the plot. This indicates that for low-strength steels, a full button pullout failure could be expected even for the case where the weld has poor load-carrying capacity. For high-strength steels, however, this was not found to be the case. Interfacial fracture was predicted to occur for cases where the weld has superior fracture toughness and high load-carrying capacity. These predictions shown in Figs. 15–17 agree well with known characteristics of spot welds.

Conclusions

An analysis was performed in which a combination of finite element modeling and fracture mechanics calculations was used to predict the weld failure modes in the shear-tension tests of resistance spot welds in AHSS grades. In the finite element model, the base material and heat-affected zone and weld properties were assumed to be homogeneous. The homogeneous model predictions agreed well with the test data for cases where pullout failures occurred. This is because the pullout failures most often initiated in the base metal outside of the notch at the perimeter of the weld. However, when comparing the homogeneous model results to actual test data, the predicted failure loads for the interfacial fractures were not consistent. For the case of the interfacial failure mode, a relationship was found in the literature to estimate the stress intensity at the weld notch tip. This relationship was used along with the equation developed for the pullout failure to define variables that affect the failure mode and load for the shear-tension test.

The results of the analyses showed the following:
1. The mathematical equation derived based on the finite element modeling showed that the force required to cause a button pullout fracture was found to be proportional to the tensile strength of the sheet as well as the diameter of the weld and the thickness of the sheet.
2. The present analyses showed that, for low-strength steels (tensile strength less than or equal to 300 MPa), a full button pullout could occur even when welds have a poor load-carrying capacity. For high-strength steels, however, this was not found to be the case. Interfacial fracture was predicted to occur in the shear tension test for cases where the weld has superior fracture toughness and high load-carrying capacity.
3. It was determined that there is a critical sheet thickness above which the expected failure mode could move from pullout to interfacial fracture. It was shown that, as the strength of the sheet increases, the fracture toughness of the weld required to avoid interfacial fractures must also increase. In the higher-strength, less-ductile steels, this is not likely to occur and interfacial fracture could become the expected failure mode.
4. The load-carrying capacity of the samples that failed via interfacial fracture was found to be more than 90% of the maximum load associated with the full button pullout. This indicates that the load-bearing capacity of these welds is not significantly affected by the fracture mode. Thus, the mode of failure should not be the only criteria used to judge the results of the shear-tension test. The load-carrying capacity of the weld should be considered the most important parameter when evaluating the shear-tension test results in AHSS.

References


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Nominees Solicited for Prof. Koichi Masubuchi Award

November 3, 2008, is the deadline for submitting nominations for the 2009 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology. It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development. The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an AWS member. The nominations should be prepared by someone familiar with the research background of the candidate. Include a résumé listing background, experience, publications, honors, awards, plus at least three letters of recommendation from researchers.

This award was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures.

Submit your nominations to Prof. John DuPont at jnd@lehigh.edu.
WELDING RESEARCH

Characterization of Welding Fume from SMAW Electrodes — Part I

Size and mass distributions, fume generation rates, and chemistry are compared for three SMAW electrodes

BY J. W. SOWARDS, J. C. LIPPOLD, D. W. DICKINSON, AND A. J. RAMIREZ

ABSTRACT. An electrical low pressure impactor (ELPI) was used to collect welding fume from E6010 and E308-16 electrodes at two heat input levels, and E7018 electrodes at a nominal heat input level. This paper describes the collection procedures and presents data on the fume generation rates (FGR), particle number and mass distributions as a function of size, and identifies compounds present in the bulk fume. Part II of this paper describes the detailed characterization of this fume conducted using transmission and scanning electron microscopy, and a surface-sensitive analysis technique known as X-ray photoelectron spectroscopy.

Using the ELPI, the fume is separated by particle size in 13 size ranges from 0.03 to 10 micrometers. Size and mass distributions were determined over these size ranges for the three consumables using this technique. Fume was also collected using a modified AWS F1.2:1999 bulk collection technique to determine fume generation rates and provide samples for bulk X-ray diffraction (XRD) studies. X-ray diffraction revealed that the predominant phase in fume generated by all electrodes was a Fe₃O₄ compound (magnetite) with the magnetite structure. Fume generation rates were highest for E6010 followed by E7018 and E308-16, respectively. Varying heat input changed fume generation rates but did not affect the chemical nature of the fume, nor alter the size and mass distributions to any great extent. Particle size distributions of all three electrodes reached peak concentrations in the fine (0.1–2.5 μm) particle size regions.

Introduction

Fume generated by the shielded metal arc welding (SMAW) process may be a cause for concern due to possible health problems experienced by individuals in the welding industry after long-term exposure. Welding fume particles may cause metal fume fever, and perhaps more importantly, manganese- or chromium-related poisoning after inhalation and ingestion into the human body. For example, it has been proposed that long term, low concentration doses of Mn are linked to nervous system disorders (Ref. 1). Studies have also shown that welders working with stainless steels who have had cases of lung cancer may be due to possible hexavalent chromium exposure, although there has been no direct evidence linking the cancer to welding fume exposure (Ref. 2). Occupational exposure limits (OEL), which are revised quite regularly (Ref. 3), determine the amount of these compounds and elements that may be ingested without becoming harmful to human tissues. Though epidemiological reactions to the different compounds present in welding fume are important, they are beyond the scope of this study, which was designed to characterize the fume particles produced by metal joining processes.

An aerosol consisting of fume and spatter is produced during welding with SMAW electrodes. Previous studies have shown that SMAW fume consists of an assortment of metals, oxides, and other compounds, which form from evaporation of elements in the arc and fluxes covering the electrode (Refs. 4–6). The fume particles generally vary over a wide range of sizes, thus it becomes important to consider fume particles in each size range as opposed to bulk composition alone. Relationships between particle size and composition have also been found (Refs. 5, 7).

Number and mass distributions of welding fumes have been measured with a variety of techniques including cascade impactors, scanning mobility particle sizes, and optical particle counters (Refs. 5, 7–9). These distributions have typically shown that fume particles are present in a broad range of sizes but are generally present in higher concentrations of small particle sizes and higher masses of the larger particle sizes.

Fume formation is of great interest in order to understand the varying morphologies and compositions of bulk fume. The effect of aerosol physics on welding fume formation has been described in detail by Zimmer et al. (Refs. 9, 10). Jenkins has provided a thorough summary of formation mechanisms and corresponding size ranges that govern welding fume particle formation (Ref. 7). The three mechanisms and approximate formation ranges are nucleation (< 100 nm), accumulation (100 nm–1 μm), and the coarse range (> 1 μm). The degree of particle growth in the nucleation range is primarily controlled by the amount of supercooling following particle nucleation. Accumulation describes particle growth by collision with other particles from diffusion and impaction. As particles continue to collide with one another they may also form agglomerates, which may adhere due to a number of mechanisms. These include 1) contact of multiple particles still in the liquid state, 2) sintering, and 3) electrostatic and Van der Waals forces (Ref. 11).

Agglomerate sizes may be large compared to individual particles, yet their aerodynamic diameters can still be quite small. An aerodynamic diameter is the diameter of a unit density sphere with the same particle mass and particle mobility as the particle in question (Refs. 11, 12). Aerodynamic diameter can be quite low for open structured agglomerates, compared to spherical particles (Ref. 13). Coarse fume particles are formed by mechanical means such as ejection of spatter.

KEYWORDS

Electrical Low Pressure Impactor (ELPI)
Shielded Metal Arc Welding (SMAW)
Fume Generation Rates (FGR)
X-Ray Diffraction (XRD)
E6010, E308-16, and E7018
from the arc or molten weld pool. These formation factors must be considered when analyzing composition and particle size distributions.

Fume generation rates (FGR) of SMAW electrodes are second only to flux cored arc welding (FCAW) processes among the various welding processes that are used commercially (Ref. 14). Fume generation is a function of different formation steps and competing mechanisms (Refs. 7, 10). The dynamics of aerosol nucleation and fume formation are thoroughly described elsewhere (Refs. 15, 16).

The various elements and compounds within the welding consumable and base material are vaporized as a result of the intense heat produced by the welding arc. A general sequence of welding fume formation is as follows after vaporization: 1) the aerosol particles will homogenously nucleate from the supersaturated vapor; 2) then they will grow by condensation and/or coagulation; 3) possibly develop a core-shell structure by condensation due to varying vapor pressure of different species, or due to liquid phase separation; 4) form an oxide shell around the metallic core due to the exposure of the aerosol particle to oxygen-rich atmosphere; 5) fully react with oxygen to form metal-oxides; and 6) coagulate to form aerosol particle agglomerates. If flux is used, as is the case with SMAW and FCAW electrodes, then the fume particle will be exposed to vapor formed from the vaporized flux elements resulting in condensation of additional elements on preexisting particles.

Condensation temperature variations between compounds such as Fe₃O₄ and SiO₂ in aerosols have been shown to contribute to regions of compositional variation in the individual particles, leading to a “core-shell” morphology (Ref. 17). These different formation mechanisms will result in a large size-range of particles during shielded metal arc welding, ranging

<table>
<thead>
<tr>
<th>Table 1 — Welding Conditions and Calculated Heat Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current, Amps</td>
</tr>
<tr>
<td>Voltage, Volts</td>
</tr>
<tr>
<td>Travel Speed, in./min (mm/s)</td>
</tr>
<tr>
<td>Heat Input, kJ/in. (kJ/mm)</td>
</tr>
<tr>
<td>Electrode Diameter, in. (mm)</td>
</tr>
<tr>
<td>Coating Type</td>
</tr>
</tbody>
</table>
from ultrafine (<0.1 μm) to fine (0.1–2.5 μm) to coarse (>2.5 μm) sizes (Ref. 18). The fine and ultrafine size ranges have been suggested to be the main concern with respect to possible health problems, since they are more likely to be deposited in the lungs. Techniques, such as those described here, to characterize the nature of welding fume as a function of size distributions are required to fully understand the health-related impact of welding fume.

A fume collection system and procedure has been developed and was used to test the three electrodes in this study as well as a number of other consumable/process combinations. This testing includes collection of fume and measurement of FGR using an AWS-type collection system, coupled with smaller filter pore sizes than those recommended by the F1.2:1999 standard (Ref. 19). A critical component of these studies is the fume collection with an electrical low pressure impactor (ELPI). The ELPI is capable of separating particles by aerodynamic diameter and monitoring size distributions in real time. This is accomplished through various principles including particle charging, inertial classification, and electrical detection of the particles using electrometers (Ref. 20). Fume is drawn into the ELPI by means of a vacuum pump, and is passed through a particle charger before being separated in the impactor. The impactor has multiple stages, which size particles according to their aerodynamic diameter in the range of 0.03–10 μm. A given stage will trap particles if they are unable to make the sharp turn required, due to their inertia, to reach the next stage. This principle of particle impaction along with the particle size trapped by each stage is shown in Fig. 1. Each stage has the capability to detect the charge on the incoming particles via electrometers thus allowing for real-time monitoring by a PC data acquisition system. Weight analyses are commonly used in fume studies but the large particles, even if they are low in concentration, may dominate a percent weight analysis (Ref. 21). Therefore, a considerable advantage to using an ELPI system is its ability to retrieve a particle number distribution for a fume collection in addition to measuring mass collected on each stage of the system.

**Table 2 — Fume Generation Rates**

<table>
<thead>
<tr>
<th>Electrode</th>
<th>E6010 Low HI</th>
<th>E6010 High HI</th>
<th>E308-16 Low HI</th>
<th>E308-16 High HI</th>
<th>E7018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat input (kJ/in.)</td>
<td>15.8</td>
<td>19.1</td>
<td>11.1</td>
<td>17.3</td>
<td>16.8</td>
</tr>
<tr>
<td>Average FGR (g/min)</td>
<td>0.387</td>
<td>0.598</td>
<td>0.091</td>
<td>0.198</td>
<td>0.365</td>
</tr>
</tbody>
</table>

**Table 3 — Statistical Analyses Results for Number and Mass Distributions Presented in Figs. 6 and 7. Diameter Values are Reported in Nanometers.**

<table>
<thead>
<tr>
<th>Electrode</th>
<th>E6010 Low HI</th>
<th>E6010 High HI</th>
<th>E308-16 Low HI</th>
<th>E308-16 High HI</th>
<th>E7018</th>
</tr>
</thead>
<tbody>
<tr>
<td>number distributions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dₜₜ</td>
<td>102.4</td>
<td>128.7</td>
<td>206.2</td>
<td>252.9</td>
<td>105.1</td>
</tr>
<tr>
<td>σₜₜ</td>
<td>1.18</td>
<td>1.18</td>
<td>1.18</td>
<td>1.15</td>
<td>1.25</td>
</tr>
<tr>
<td>67%</td>
<td>120.4</td>
<td>152.1</td>
<td>243.0</td>
<td>290.3</td>
<td>131.2</td>
</tr>
<tr>
<td>95%</td>
<td>43.6</td>
<td>54.5</td>
<td>87.5</td>
<td>110.2</td>
<td>42.1</td>
</tr>
<tr>
<td>mass distributions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dₜₜ</td>
<td>592.0</td>
<td>661.5</td>
<td>624.8</td>
<td>556.7</td>
<td>746.5</td>
</tr>
<tr>
<td>σₜₜ</td>
<td>1.13</td>
<td>1.17</td>
<td>1.11</td>
<td>1.11</td>
<td>1.32</td>
</tr>
<tr>
<td>67%</td>
<td>524.9</td>
<td>563.6</td>
<td>561.4</td>
<td>501.1</td>
<td>566.1</td>
</tr>
<tr>
<td>95%</td>
<td>262.4</td>
<td>281.8</td>
<td>280.7</td>
<td>250.5</td>
<td>283.0</td>
</tr>
</tbody>
</table>

**Procedure**

A detailed procedure developed by Sowards et al. was followed for the analysis of welding fume from SMAW electrodes (Ref. 22). A36 steel was used as a base material for E6010 and E7018 electrodes, and Type 304L stainless steel was used as a base material for the E308-16 electrode. All welding procedures used were in accordance with the consumable manufacturer recommendations, i.e., operating current, voltage, work angle, and low-hydrogen electrode control (E7018,
E308-16. All welds were performed in the flat position, and the base material was moved relative to the electrode using a linear positioner for ELPI collections and rotary positioner for fume hood collections. An arc voltage controller (AVC) was used in conjunction with a linear positioner to feed the covered electrodes while maintaining a constant arc voltage, thus maintaining repeatability of heat input. All welding parameters were monitored and recorded during testing. Averages of the parameters were used to calculate heat input as shown in Table 1. Heat input is a commonly used parameter for specifying a welding procedure, therefore two levels were used. It was not a goal of this study to examine the effect of voltage and current on fume formation.

Fume was collected in a sequence of several trials. The first consisted of using the fume hood to measure fume generation rates and collect bulk samples for X-ray diffraction (XRD) analysis. High flow-rate glass fiber filters with a pore size of 0.3 μm and an efficiency of 99.98% were used for these collections. The filters were non-hygrosopic so moisture in the atmosphere had negligible effect on filter weights. A digital manometer with PC control was used to record pressure drop across the filter during all fume hood collection. The pressure drop provides insight into filter performance and indicates when the filters become saturated with fume. Due to limited physical space in the fume hood chamber, a rotary positioner with DC stepper control was used to provide base metal travel instead of the linear positioner used in ELPI collections.

After FGR were measured, the ELPI was used to collect fume for particle number and mass distributions. Particle number distributions were recorded in real time by the ELPI. Mass distributions were obtained by weighing aluminum collection substrates placed on each stage of the ELPI. Following a collection run, the substrate on each stage was reweighed to find the fume mass deposited during testing. Substrate weight was measured to an accuracy of 10^{-5} grams with an analytical balance.

Results and Discussion

Fume Generation Rate

The fume generation results for E6010, E7018, and E308-16 electrodes using the modified fume collection hood are presented in Table 2. These FGR values represent an average of three collections for
The total fume generated for the E7018 was slightly less than the E6010 electrode at low heat input suggesting E6010 has the highest relative FGR. E308-16 generated less than 25% of the fume of both mild steel electrode fumes at the lower heat input level. Qualitative visual examination revealed that the E308-16 welds had a much thicker slag coating, which likely equates to a larger percentage of the flux coating ending up as slag instead of fume as compared to the other electrodes. Also, melting and vaporization rates of mild and stainless steels are considerably different because of differences in thermal conductivity as compared to mild steels. Effects of voltage and current on FGR are shown in Figs. 2 and 3, respectively. Each point represents the average current and voltage recorded for a given electrode over the duration of the weld. Three welds were made at each heat input level. For both E6010 and E308-16, an increase in fume generation was noted with increasing current and voltage (i.e., between the two levels of heat input).

X-Ray Diffraction Results

X-ray diffraction was performed on bulk fume filters from each of the electrodes to identify metallic species or compounds present in the fume. The samples contained the full particle size range as described in the procedure section. Fume was removed from the bulk filter and pressed onto zero background holders before the diffraction experiments took place, providing a better peak to background ratio than the fume filter itself. Figure 4 shows the results for the E6010 electrode after a 60-s collection with the fume hood. The peaks show a strong correlation to a magnetite (Fe₃O₄) type structure. However, slight peak shifts were present, suggesting the other elements (Mn and Si) are substituting for Fe and shifting the 2θ values. X-ray diffraction results for E308-16 transferred fume are shown in Fig. 5. These peaks show the presence of magnetite (Fe₃O₄) and a potassium-rich oxide (K₂M₀₄). The M in the formula represents Fe, Mn, Ni, or Cr. Based on the spectrum, it is not possible to separate the in-

Fig. 8 — Particle mass distributions as a function of particle diameter for the following: A — E6010 low heat input; B — E6010 high heat input; C — E308-16 low heat input; D — E308-16 high heat input; E — E7018 nominal heat input. Vertical lines correspond to geometric mean diameter (GMD) of distributions.
dividual compounds for these peaks. Therefore, $M$ should be considered as a mixture of the four metals, although TEM analysis showed that the predominant element is Fe. A weak match for NaF was also observed in the E308-16 spectrum. The XRD spectrum for the E7018 fume (Fig. 6) has strong peaks for $\text{Fe}_3\text{O}_4$, $\text{CaF}_2$, and NaF. Once again, slight shifts were observed for the magnetite peaks, which were most likely caused by a Mn and Si substitution for Fe.

Number and Mass Distributions

The ELPI was used to measure both size and mass distributions using the techniques described previously. The number distribution, measured by the ELPI as a function of the aerodynamic diameter, was determined for two heat input conditions of E6010 and E308-16 and a single heat input of E7018. Resulting distributions are presented in Fig. 7 where the normalized number of particles ($dN/d\log(Dp)$) is plotted vs. log of particle diameter, $Dp$. The mass distributions of the same collections are presented in Fig. 8 where normalized particle mass ($dM/d\log(Dp)$) is plotted vs. log of particle diameter. It is convenient to plot aerosol distributions vs. the log of particle diameter to compress the region containing coarse particles and enlarge the fine and ultrafine regions since these are of greatest interest. Percentage of particle size and mass for each ELPI stage are also included in Figs. 7 and 8. Error bars indicate one standard deviation (for percentage scale) of the average of three collections performed for each condition. Geometric mean diameters are represented by the vertical dashed line shown on each distribution. Statistical analyses may be performed on log-normal distributions of aerosols to obtain a geometric mean diameter and variance of particle size. Results of these statistical analyses are displayed in Table 3.

E6010 — Distributions

Comparing the particle number distributions between the two different heat inputs of E6010 fume (Fig. 7A and B) shows good consistency. Approximately 95% of particles are less than 0.3 $\mu$m in diameter, making the bulk of the size distributions for both heat inputs lie in the particle nucleation and accumulation size ranges as described elsewhere (Ref. 7). More than 70% of the fume mass lies in the accumulation range (particles below 1 $\mu$m in diameter). The mass of particles below 0.1 $\mu$m is very small, representing less than 2% of the total fume mass. Geometric mean diameters of the number distributions were both at the transition between the nucleation and accumulation ranges, suggesting these are the dominant fume formation mechanisms, though there is some speculation in distinction between the two regions (Ref. 9). E6010 distributions change only slightly with heat input as shown by the similar results in statistical methods. The number distribution for the high heat input welds is slightly skewed to larger average particle sizes relative to the low heat input collections. Both heat input levels had the highest percentage based on total weight at approximately 0.6 $\mu$m average aerodynamic diameter.

E308-16 — Distributions

The average number percentage for the E308-16 electrode as a function of the aerodynamic diameter as measured from the ELPI stages for both heat inputs are presented in Fig. 7C and D and mass distributions for both heat input conditions are shown in Fig. 8C and D. Similar to what was observed for the E6010 electrodes, there was little change in size distribution between the low and high heat input welds. The number distribution shifts to larger particle sizes, and mass distribution decreases slightly in diameter for the higher heat input. Particles in the size range of approximately 0.2–0.3 $\mu$m were predominant, accounting more than 60% of the total number of particles. Comparing the E6010 to the E308-16, the particle size distribution is biased toward the large size particles in the E308-16 fume. This may be related to the degree of supercooling between the two materials or because of different nucleation rates. The E308-16 fume contains Ni and Cr, which have lower thermal conductivities than the strictly Fe-based particles found in E6010 fume. Since these particles may have slower cooling than the E6010 particles, they could possibly have more time to grow by diffusion after colliding with more particles. The mass distribution between the two heat inputs is also consistent. Mass distribution was spread over a wider particle size range than the E6010. Once again, the mass of particles below 0.1 $\mu$m is very small, accounting for about 1.5% of the total fume mass.

E7018 — Distributions

Average number and mass distributions for E7018 at a nominal heat input are presented in Figs. 7E and 8E, respectively. The number distribution of E7018 is shifted toward the small aerodynamic diameters of the ELPI size range as compared with number distributions of E6010 and E308-16, which both exhibited distributions with the majority of the particles falling in the 0.1–0.2 $\mu$m size range. The mass distribution of E7018 peaks at approximately 0.6 $\mu$m average diameter with a geometric mean diameter of 0.75 $\mu$m. The mean diameter is increased since higher masses were measured on the larger stages of the ELPI. The size and mass distributions appeared multimodal. The size distribution had a mode in the nucleation and accumulation range. The mass distribution had an additional mode in the coarse range, which may be associated with spatter formation (Ref. 10).

Summary of Number and Mass Distribution Results

Clearly the number distributions for the three electrodes are biased toward smaller diameter particles as compared with mass distributions. However, the mass of these small particles is insignificant in comparison with mass of the particle sizes where mass distribution peaks (0.6–0.75 $\mu$m). Some speculation exists as to which size range of fume particles, whether it is the fine or ultrafine regions, are most damaging when inhaled by welding personnel (Ref. 18). It is generally accepted that respirable particles are those that are less than 10 $\mu$m in size. Agglomerates of various sizes were present on all stages of the ELPI collections for each of the electrodes tested as observed by characterization techniques discussed in Part II of this paper. Equivalent aerodynamic diameters of agglomerates must be considered when analyzing data from the ELPI since it only provides an average behavior of each stage cut-off size. Agglomerated particles may have a large physical size compared to their aerodynamic diameter. Thus, larger-sized agglomerates may be collected on the lower stages of the impactor. For all three electrodes, a high percentage of the fume particles on the lower stages were agglomerates, while the upper stages contained a higher fraction of spherical particles. The higher fraction of isolated spherical particles on upper stages may be explained by the fact that spatter is the dominant fume formation mode at the larger size scales as opposed to particle accumulation (Refs. 7, 10).

As this occurs, seemingly large agglomerates are counted on the lower stages because their aerodynamic diameter is actually small. Models of the human oral-pharyngeal cavities suggest that these agglomerates that are held together by Van der Waals forces may disperse back into individual particles if the flow rate is substantially large as in human lung models (30–200 L/min) (Ref. 23). The ELPI used for this study was only operated at a flow rate of 10 L/min, which is not adequate to break these loosely attractive forces. However, many of these agglomerates are held together by forces other than Van der Waals bonding suggesting agglomerate disassociation will likely not
WELDING RESEARCH

Welding Fume Analysis LLC, representing a consortium of past and current consumable manufacturers.

References


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