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On the cover: This fully articulated, moving electron beam gun can
deposit metal feedstock, layer by layer. (Photo courtesy of Scioxy, Inc.,
Chicago, IL.)
University of New Orleans Awarded Shipbuilding Grant

The University of New Orleans (UNO) has been awarded a three-year, $4.8 million grant from the Office of Naval Research to advance the science and technology of titanium shipbuilding. The research will be focused on the manufacturability and structural performance of a titanium midship section.

Material requirements and welding processes, such as high-speed gas metal arc and friction stir welding, will be investigated for applications in titanium ship hull construction. Math-based design for fabrication techniques will also be developed to support build strategy and construction of a titanium midship section from piece part fabrication and interim production definition to final structural assembly.

Pingsha Dong, the Northrop Grumman endowed chair in shipbuilding and engineering in UNO's school of naval architecture and marine engineering, said the material's cost and lack of robust welding and joining techniques have prevented the shipbuilding industry from realizing the potential of titanium for ship hull applications, but with recent advances in welding and math-based design for fabrication techniques, this project represents perhaps the most comprehensive exploration of technologies to date by building a full-scale titanium midship section.

Selectrode Industries Opens Pittsburgh Facility

Selectrode Industries, Inc., recently opened a 73,000-sq-ft manufacturing facility on a ten-acre parcel outside of Pittsburgh, Pa., to manufacture welding electrodes. The production and electrode-drying rooms are temperature and humidity controlled for monitoring electrode drying rates. The plant houses a wire cutting operation along with flux mixing, packaging, warehousing, and distribution operations.

The facility was designed to conserve electricity, natural gas, and water. Natural light is utilized with windows and skylights; high-efficiency lighting is used throughout; a closed-loop chilling unit recycles the water used for cooling manufacturing equipment; and solar and geothermal technology supplement the (then facility won’t be hanging) green systems engineered into the facility.

For information on employment opportunities or product offerings, contact info@selectrode.com.

Thermadyne Holdings Acquisition Complete

Thermadyne Holdings Corp., St. Louis, Mo., a manufacturer and marketer of metal cutting and welding products and accessories, recently completed its acquisition by Irving Place Capital, a middle-market private equity firm.

Thermadyne shareholders will receive $15 in cash for each share of its common stock. The company’s common stock will also cease trading on NASDAQ and be delisted. Its executive team is continuing with and investing in the company.

In addition, Mike McLean has joined Thermadyne as executive chairman of the board of directors. Previously, McLean served as president, CEO, director, and chairman of Aearo Technologies, Inc., and president and CEO of DowBrands, Inc.

Dynamic Materials Ships Large Explosion-Welded Plates

Dynamic Materials Corp., Boulder, Colo., recently shipped an order incorporating the largest clad plates ever manufactured using explosion welding technology. The plates are 542 in. long, 120 in. wide, and 2.84 in. thick, each exceeding 53,000 lb and having a surface area of more than 450 sq ft. They will be used in equipment associated with a North American clean diesel fuel project.
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Recapturing the Spirit of ‘76

If the American Welding Society is to aspire to greatness in 2011, we can take inspiration from those who came before us. Much of what AWS has achieved around the world resulted from the pioneers who created our certification program. Thirty-five years ago, AWS had the boldness and vision to launch the Certified Welding Inspector (CWI) program. I would like to take this opportunity to revisit the spirit that made that happen — the spirit of 1976.

By 1976, nine editions of AWS D1.1, Structural Welding Code — Steel, had already been published, and each of these editions mandated the inspection of welds. But up to and including the 1975 edition, little was said about who should be entrusted to inspect those welds, other than “the person should be designated by the engineer.”

Interestingly, the AWS Welding Handbook edition from that era pointed out, “Improperly performed, inspection can be harmful by providing a false sense of security.” And, yet, there was still no standard by which a fabricator could be sure that the person designated to perform weld inspection was qualified.

During this time, the D1 Committee was becoming increasingly concerned that bad welds were being passed and good welds were being rejected. Consequently, the wheels of innovation began to turn and work commenced on addressing this issue.

More than 500 people attended a symposium at the 1976 Welding Show at which the new CWI program was introduced. By the first deadline of August 1976, more than 1300 CWI applications were filed. CWI exams that first year were held at 37 different sites.

What’s remarkable is that much of the core content of the CWI program is just as valid today as it was 35 years ago. For example, the 1976 QC1 document, the standard for certifying inspectors, included a code of ethics for inspectors. This concept was the first of its kind in the industry. Revolutionary! And it still stands to this day.

The CWI program has been a success because of the wisdom and commitment of AWS in that era of greatness. Industry has adopted the program because it captures the best practices in personnel qualification and in following codes and procedures. Today, more than 30,000 CWIs are working around the globe. About a third of these inspectors work outside the United States, and CWIs are located on every continent. Over the years, AWS has built upon this success with a Senior CWI program, as well as certifications for welders, radiographic interpreters, sales reps, supervisors, robotic technicians, bolting inspectors, educators, and fabricators.

The lasting effects of what transpired when the program began are evident when we consider that about 25 CWIs from that first class in 1976 are still practicing today.

On a personal level I, too, can speak regarding the CWI program’s impact. In 1973, I completed welder training at the San Antonio Trade School and began working for a public utility. I recently retired after having spent almost 36 years in the power industry. I can attest that the single most career-enhancing decision I ever made was to become a CWI.

My challenge to all of AWS in 2011 is to once again revive the spirit of 1976 and achieve even greater things. I challenge our members to raise issues that are important today. I challenge our Sections to harness the power of our membership. I challenge the leadership of our committees and our board of directors to be as bold as we have proven AWS can be. And I challenge the staff of AWS to help make our ambitions a reality.

May all of us boldly accept this challenge, and let us aspire to even greater accomplishments.

John L. Mendoza
AWS President
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Aerojet Completes Shipments of F-22 Raptor Parts

Aerojet, Sacramento, Calif., a GenCorp company, recently shipped the last F-22 Raptor forward boom to The Boeing Co. in Seattle, Wash. This completed the tenth lot of a procurement that spanned 17 years in support of the Boeing/Lockheed Martin/U.S. Air Force team.

The forward boom is a structural component providing wing, engine, and horizontal tail attach points to carry much of the F-22 aft fuselage load. Using electron beam welding (EBW), the company joins numerous titanium components together into a single monolithic structure meeting precise tolerances. The process allows the airframe design to merge complex features into a single component. This also reduces the need for fasteners, meaning fewer openings for possible fuel leaks; reduces weight; and simplifies assembly.

Aerojet’s program success is largely in F-22 boom manufacturing and its EBW technologies capable of producing large welded structures, including complete joint penetration welds of complex geometry with varying thickness and profile in a single pass. This capability can accommodate parts that fit in an envelope of 11 x 7 x 7 ft or larger. Additionally, its EBW machine has a chamber size of 138 x 150 x 185 in.

The company estimates since contract inception, it has produced more than seven miles of electron beam welds on the forward boom.

Alaska’s Oil Production Dwindles

In Newsweek’s October 18th issue, writer Daniel Stone discussed the Trans-Alaska Pipeline, the largest conduit of domestic oil, in “A Pipeline Problem in Alaska?” He brought up an important point — the Prudhoe wells are drying up, and the view of replacing them “appears ever more grim.”

The pipeline has the capacity to carry 2 million barrels a day, yet currently, its flow is less than 700,000 gal and falling at least 6% a year. A new study will see how low the supply can get before crude freezes in transit. “The most common estimate is about 500,000 barrels, a figure that ConocoPhillips recently predicted would be reached by 2015,” Stone stated in the article.

More oil would serve as an easy fix, but the search for new wells has slowed since 2007, and the industry has threatened more divestment. “That may mean trouble for Alaska’s economy and wallets nationwide,” Stone concluded.

AK Steel Achieves 100 Year Milestone

AK Steel recently marked 100 years at its research facility in Middletown, Ohio. The company’s predecessor, Armco, announced the creation of a research department on September 22, 1910. Since then, it has evolved to develop new products, provide customer technical services, and make steelmaking process improvements.

“AK Steel has a proud heritage of research and innovation,” said James L. Wainscott, its chairman, president, and CEO.

According to the company, it pioneered the world’s first continuous hot rolling sheet mill in the 1920s. Its research led to the development of various steels used in power transmission and distribution equipment. In the 1990s, the company helped the automotive exhaust market by introducing specific types of alu-

Research Center Created for Integrative Materials Joining Science

The National Science Foundation has established a new Industry/University Cooperative Research Center for Integrative Materials Joining Science (iCMJ). The center will focus on developing new joining technologies and materials to improve the performance and reliability of advanced aerospace and automotive systems.

Using electron beam welding, Aerojet joins many titanium components together into a single monolithic structure. Shown is an F-22 Raptor forward boom being machined on a 7-axis CNC vertical gantry mill.

Shown is the hot rolling lab at the AK Steel research facility in Middletown, Ohio. The company has had a research lab for 100 years.

minized stainless steels. Today, it is developing products for lighter, more fuel-efficient vehicles that maintain strength and safety performance.
Materials Joining Science for Energy Applications. It brings together The Ohio State University, Colorado School of Mines, Lehigh University, and the University of Wisconsin.

The center’s mission is to develop science-based methodologies for assessing material weldability that span the length scales from the nanometer to micron range. It will focus on projects to reduce the time and cost of deploying advanced materials for the new energy infrastructure, and extend the life of material joints within the aging energy infrastructure. Also, the center will provide a platform for training future engineering graduates with a materials joining background.

Membership allows organizations to identify project topics of interest to their industry and access to all the project topics supported through the center. Graduate students assigned to these projects work with engineers and scientists at the member organizations in a team-based environment. In addition, members meet annually to review project progress, participate in governing the center, and meet with faculty and students.

For more information, contact one of the following center directors: Dr. S. Suresh Babu, babu.13@osu.edu; Dr. John N. DuPont, jnd1@lehigh.edu; Dr. Sindo Kou, kou@engr.wisc.edu; or Dr. Stephen Liu, sliu@mines.edu.

New Labs at Vincennes University Feature Robots and Offer Teacher Training

ABB Robotics and Haas Automation, Inc., have opened training labs at the Indiana Center for Applied Technology at Vincennes University, Vincennes, Ind.

The ABB Robotics training lab features 29 robots and related work cells, software, and controllers. Students receive training in applications including robotic welding and plasma cutting; picking, packing, and palletizing; machine tending, material handling, and product assembly; and advanced vision-related programming.

Vincennes University’s Haas Technical Education Center (HTEC) CNC Teacher Training Center allows the college to become a training and certification center for teachers in more than 1400 HTEC schools.

Joining the opening ceremonies were Mark Everson, commissioner of the Indiana Department of Workforce Development, and Rollie Heimling, deputy commissioner of the Indiana Economic Development Corp. Industrial leaders who spoke included Dave Tucker, president of Haas Factory Outlet Midwest; Rob Schwamberger, regional sales manager for ABB Robotics; Mark
Summers, president of CNC Software, Mastercam; Bob Skodzinski, manager, North American HTEC Program; Brian Norris, vice president of marketing, Sandvik Coromant; and Penny DiCarlo, journalism manager for AMT.

Following the event, these labs opened for public tours and demonstrations. For more details about the college, visit www.vinu.edu.

**Hanford Waste Treatment Plant Setting Tracks for Large Crane**

Crews at the Hanford Waste Treatment Plant, Richland, Wash., are installing two crane rails in the Pretreatment Facility, totaling more than 900 ft long. Once complete, the rails will support a 30-ton-capacity overhead crane that will move the length of the facility’s 400-ft hot cell, as well as in and out of a maintenance area.

When the plant is operational, the hot cell will be a highly radioactive area to be accessed only by remote handling equipment. It will also be used to separate the high-level radioactive solid waste from the low-activity liquid waste.

“Setting the crane rails is part of our continued shift from civil construction activities — concrete and structural steel — to mechanical installations,” Ty Troutman, area project manager for the facility, said. “This shift is essential to completing facility construction in 2015 and reaching operations in 2019.”

To install the steel rails, crews are lifting 40-ft sections and mounting them to steel beams protruding from the wall of the hot cell, more than 30 ft off the ground. The sections, which each weigh approximately 2600 lb, are then thermite welded together at the ends to create two smooth, continuous rails that run in parallel, the length of the hot cell.

Hanford Waste Treatment Plant crews use thermite welding to install crane rails in the Pretreatment Facility’s 400-ft-long hot cell canyon. (Photo courtesy of Bechtel National, Inc.)
Hyundai Develops Digital Welding System

Hyundai Heavy Industries Co. Ltd., Korea, has developed digital welding technologies to upgrade conventional analog welding systems used for shipbuilding. The technology digitalizes data gathered from welding machines, transmitters and carriages. Also, it displays welding voltage and current on a liquid crystal screen.

According to the company, the process will improve productivity by 20%, reducing 1 million worker hours on welding each year, equivalent to welding five 300,000 deadweight very large crude carriers. Hyundai expects costs to be reduced by more than $100 million and anticipates it will increase the quality of finished products, bring changes in equipment management and welding data storage, and save 10% of welding cost by using less cable.

Maritime Training Center Opens in Alabama

Alabama Industrial Development Training (AIDT) celebrated the grand opening of its Maritime Training Center in Mobile, Ala. Described by Governor Bob Riley as “the newest weapon in Alabama’s economic development arsenal,” the $12 million 60,000-sq-ft facility will help prepare Alabama citizens for jobs in the expanding maritime industry.

The center is available to all the shipbuilding companies such as C&G Boatworks, Signal, BAE Systems, and Austal. Staff will offer instruction in industry standards, upgraded technologies, custom training, and intensive welding and ship fitting training.

“The completion of this facility is a giant step forward in our path to transform our job training platform in Alabama. The maritime industry requires specific training, and typically, companies are on their own to prepare their workers. Here we can partner with maritime companies and help meet their job training needs one worker at a time,” AIDT Executive Director Ed Castile said.

Classes at the center will tentatively start this month. Applications are accepted online. To apply for training or for more information, visit www.aidt.edu/jobs or www.maritime.aidt.edu.

Welding Program at Northland Pioneer College Receives Steel Donation

Summit Healthcare recently donated approximately 70,000 lb of surplus steel beams, representing a retail value between $45,000
At Northland Pioneer College, welding students will benefit from Summit Healthcare’s nearly 70,000-lb steel beam gift.

and $50,000, to the welding program at Northland Pioneer College (NPC) in Arizona. It will provide enough course work assignment material to last up to three years in the college’s welding classes at the Show Low, Holbrook, and St. Johns locations.

“In this economic climate, our student numbers approach 110 percent of capacity, with no additional state funding allowance to compensate for the overloaded classes,” said Curtis Casey, NPC welding department chairman.

Welding student Max Grover contacted Thomas Montoya, Summit’s plant operations supervisor and a graduate of the college’s welding program, about a pile of scrap steel beams left over from constructing the medical facility’s new tower. Montoya arranged a meeting, and Kent McQuillan, Summit’s chief information officer, recommended the donation to senior leadership, who approved the request.

Grover and fellow student Aaron Wiltbank joined Casey and welding instructors Randy Hoskins, Russ McCray, and Steve Elefante, plus assistant Bill Tomkinson, in loading the beams onto a borrowed wrecking truck from Show Low Auto Sales & Wrecking and a flatbed semitrailer from Steel Sensations. RSC Equipment donated the reach forklift, while La Cocina de Eva of Snowflake loaned the Bobcat loader to move the steel.

Educational Center Offers Automated Welding and Cutting Systems

Attendees at a recent automated plasma cutting seminar enjoyed visiting the Airgas Great Lakes new center in Grand Rapids, Mich.

Airgas Great Lakes marked the grand opening of its newest automation center with an educational event to help end users increase productivity and lower costs. Developed in partnership with — continued on page 107
TransSteel: An arc you would “steel” for

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Panasonic Establishes Welding System Company in India

Panasonic Corp., Osaka, Japan, recently set up a welding system company in Gurgaon, in the northern state of Haryana, India. The new company, Panasonic Welding Systems India, is expected to start production in August 2012.

India’s welding-related market has grown rapidly in recent years. Consumption of steel has grown year after year, and the country became the world’s third-largest consumer of steel in 2009, after China and the United States.

Panasonic Welding Systems India will produce energy-saving, high-quality arc welding equipment and supply Japan-made arc welding robots.

BAE Shipyard Apprentice Named UK’s Best Welder

David Crawford was named Britain’s best welder after winning ShipWeld 2010, a nationwide competition that aims to find the best trainee welder in the country. Crawford is a third-year apprentice at BAE Systems’ Govan shipyard on the Clyde in Glasgow, Scotland.

“This is my first time competing so I’m really pleased to have won,” Crawford said. “I’ve really enjoyed taking part as it’s given me the chance to put the skills I’ve learned through my apprenticeship into practice.”

The contest, which was sponsored by ESAB, took place at BAE’s Govan shipyard on the Clyde. The Clyde training department took the overall team award.

“The ShipWeld Competition is a great way of encouraging the development of welding skills and a fantastic opportunity for our apprentices to demonstrate their abilities in a friendly, competitive environment,” said Scott Graham, training coordinator at BAE Systems’ Surface Ships division.

Visteon Opens Auto Component Manufacturing Facility in Russia

Visteon Corp. recently opened a plant to manufacture components for automobile interiors in Kaluga, one of Russia’s main centers for automotive production, approximately 112 miles southwest of Moscow.

The plant features advanced injection molding lines and ultrasonic welding assembly cells, and is expected to be in full production during the first quarter of this year. It manufactures injection molded door panels and other interior components for the new Volkswagen Polo, which is to be sold in the domestic Russian market. The facility can be expanded as the company develops business in the area.

Hyundai Motor Co. Begins Construction of Third Plant in China

Hyundai Motor Co. recently began construction of a 400,000 unit per year plant in the Shunyi District of Beijing, China. The plant, a 50-50 joint venture between Hyundai Motor Co., South Korea’s largest automaker, and Beijing Automotive Industry Holding Co., is scheduled for completion by July 2012.

Hyundai already has two other plants in China with capabilities of up to 300,000 vehicles each. Construction of the third plant is in response to a growing demand for cars in China, the world’s largest automobile market.

“Today is a very important day for us, as we secure production capacity for one million units in China,” Mong-Koo Chung, chairman and CEO of Hyundai Motor said at the ground-breaking ceremony November 28, 2010.

The new plant is scheduled to produce small- or midsized models specifically designed for the Chinese market. Plans are to gradually expand its model lineup based on demand. The plant will be built on a 1.6 million-sq-m site, and will have floor space of 300,000 sq m. It will feature vehicle production facilities such as stamping, welding, painting, assembly, and module lines, as well as engine production facilities.

Foster Wheeler Expands Power Boiler Services in Germany and Finland

Foster Wheeler AG, Zug, Switzerland, recently announced its Global Power Group will be expanding its power boiler service business in Germany and Finland by establishing two new service centers that will supply spare parts, boiler pressure vessel components, and boiler modernizations to existing plants in those areas.

In Germany, the company has moved to a new service center in Krefeld-Linn, in northwestern Germany. The facility features 2300 sq m of office and workshop space. It is equipped with tube bender and welding machinery, cranes, and equipment for site work. It also offers storage facilities.

The new service center in Finland opened November 1, 2010, in Kurikka in western Finland. The 2000-sq-m facility also includes tube bending and welding equipment, cranes, and other service production and site equipment.

OneSteel Reinforcing Installs System to Contain Galvanized Steel Weld Fumes

OneSteel Reinforcing recently installed a fume-collection system at its Revesby, Australia, plant by Donaldson Australasia to ensure containment of welding fumes on its process line. The company produces galvanized wire mesh for commercial, residential, and civil construction as well as the mining and agriculture industries and manufacturing sector, and services the eastern seaboard of Australia.

The system is based on Donaldson’s Downflo DFO 3-18 technology. OneSteel’s management specified a collection capacity exceeding its current maximum fume output. The company recently installed a system for welding sheets of galvanized mesh and a purpose-specific gantry-operated handling machine to process the sheets. On average, three welding heads are working for around 22 hours per day; therefore, it was vital to OneSteel for Donaldson to design a system that could accommodate high rates of growth when needed.
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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, 2011. The Committee looks forward to receiving numerous Fellow nominations for 2012 consideration.

Sincerely,

Thomas M. Mustaleski
Chair, AWS Fellows Selection Committee
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The Lightweight, Economical Carrera
The Racing Inspired Python with outside Command Center

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Q: A review of AWS C1.1, Recommended Practices for Resistance Welding, does not appear to fully address the various aspects of weld quality with regard to forged projection weld nuts. Any insight you could provide would be appreciated.

A: The feedback generated as a result of the recent projection weld schedule column (see the RWMA Q&A on page 16 of the September 2010 Welding Journal) reinforced the idea that it does not matter what aspect of projection welding (PW) one wants to discuss, the topic is generally at the top of most folks’ list of resistance welding concerns. This column describes various methods that can be used to help characterize the resistance welds of forged or coined projection weld fasteners. It is only through the proper characterization of these welds that it is possible to determine if they meet the engineering intent of the design authority. Remember, fastener in this context indicates all manner of solid, formed, or forged projection weld parts, including weld studs and weld nuts. As the scope of this subject is rather broad, it is broken into two parts: Nondestructive and destructive. The destructive portion will appear in the March issue of Welding Journal.

AWS A3.0:2010, Standard Welding Terms and Definitions, defines an acceptable weld as follows: “A weld that meets the applicable requirements.” The requirements of an acceptable weld are often established by the design authority and are frequently detailed in a specification that is unique to that particular job/customer/company. Care must be taken when reviewing the various standards and specifications as most do not differentiate between the welding of embossed/stamped or forged projections. There are significant differences between the two. With the aforementioned definition in mind, the following should help clarify the different types of inspection options available that permit for a quality determination of a welded fastener.

Nondestructive Quality Elements

Process Monitoring. The idea of process monitoring or control represents...
one of the most fundamental aspects of nondestructive evaluation — the prevention of a problem before it starts. Specifically, if the process is stable and capable of producing welds of acceptable quality, then those aspects of the process that can change or degrade over time should be monitored and actions taken as needed.

The list of items that can be monitored is potentially long and can include weld parameters (force, current, etc.), dimensional tooling items (pins, clamps, etc.), parts (hole location, projection size/consistency, etc.), and weld tooling items (braided shunts, electrodes, etc.). Regardless of what is monitored, the goal is to establish the acceptable limits of a particular parameter and then track it over time, noting any trends that present themselves and, if necessary, acting in a proactive manner before the process is out of control. A final thought on this important item: Experience has shown time and again that the facilities with the best maintenance programs typically have the best welding programs and that successful welding maintenance programs always include some form of process monitoring and proactive preventive maintenance system.

**Location/Normality.** The quality of the weld is almost irrelevant if the weld nut is not in the proper location or is welded at an incorrect angle. An issue with location or normality is most likely related to the tooling. However, do not make the mis-
take of doubting the ability of an improper set of welding parameters to manifest themselves in unique ways with regard to the final, as-welded position or angle of a fastener. The standards may have specific location or angularity requirements (e.g., angularity less than 5 deg, etc.), but I can assure you that those words will be tossed out the window if the end-user can’t attach the required hardware to the fastener, even if the parts are “in spec.” The lesson here is to make sure you know how an assembly is being used and ensure that this aspect is monitored, even if the required customer quality checks do not address it. While this can add a bit of cost to the inspection process, this insurance is far cheaper than a “quality spill” that results in some sort of containment or rework activity.

Flash/Expulsion/Melt-Through. These issues are typically associated with the actual welding process. The most common culprits are the welding parameters (force, current, time, etc.) but the use of less than optimal weld schedules may be more related to the design of the fastener and the manufacturer’s attempt to overcome a weakness in this area. The scheduling aspect of fastener welding was addressed in the previous column, but a few words on projection design as it potentially relates to flash/expulsion/melt-through are in order. By definition, it takes three points to define a plane. Any fastener utilizing a different number of projections will eventually experience the unequal force distribution possible with this less than optimal design (think of a stool with four legs that always rocks back and forth). Please note that a full-ring projection is considered, from a welding perspective, to be a less than optimal design. Of course, even if three projections are being used, they may be of such a poor geometric configuration, insufficient volume, or both so as to render the fastener almost unweldable without the presence of expulsion. Keep in mind this important consideration as you review a potential projection design for any welded fastener application: I have yet to receive a phone call from anyone who thought their fastener had projections that were too big, but I have received many calls where it was determined that the projections were too small.

Fastener Distortion/Thread Damage/Leakage. These elements differ from flash/expulsion/melt-through in that they relate directly to the functionality of the fastener. The root cause of any of these issues may be related to either welding or tooling. For example, an improperly designed electrode and pin package can expose the threads to small amounts of weld slag, thus causing customer assembly issues. A good way to avoid concerns in this area, apart from a proper welding process,
is to make sure you know how an assembly is being used and ensure that this aspect is part of its quality checks.

Upset Distance. The upset distance of a fastener (Fig. 1) after it is welded (also referred to as set down or gap) is, for purposes of this review, discussed separately from the topic of normality. The reason for this distinction is that, in this context, the term upset distance assumes that angularity/normality issues are not present. The term upset distance is sometimes associated with the quality of the weld whereby the more upset distance (or less gap) the better. Unfortunately, the upset distance of a fastener is a visual indicator that can be easily misinterpreted. A classic example of this is a fastener that has oversized projections. Once welded, it may well be fully set down but still exhibit poor mechanical characteristics as the welding process resulted in the projections being blown away instead of creating the required concentration of force and current needed to achieve a successful weld. If all other aspects of weld quality have been achieved except upset distance, the fastener will most likely be deemed acceptable, provided a larger gap does not present a clearance or assembly issue.

Process/Torque. If possible due to the weld fastener’s geometry, it may be desirable to verify, by means of an in-process torque evaluation, whether the welded fastener is capable of withstanding the assembly environment. A basic premise of performing a torque evaluation is that the fastener can support the application of a rotational force. The application of torque to round fasteners is not advised as it is much more problematic to apply in a nondestructive (or even destructive) manner. Also, the fastener threads should not be used to apply the desired torque (e.g., tightening a nut against a nut) as they may be damaged. The method used to establish the level of in-process torque the assembly can tolerate without resulting in damage is no easy task and should be approached in a methodical manner. A note of caution: The failure to properly establish the in-process torque limitations may have the unintended consequence of changing a nondestructive evaluation into a destructive one. Also, the personnel performing any torque checking procedure can have a significant impact on the results and should be trained and monitored so that their technique does not add more variability to the process. Additionally, the run-of-the-mill torque wrench may have limited accuracy, and calibration procedures must become a regular part of such a program.

Mechanical Inspection. Use of a hammer and/or pry bar as a nondestructive test to validate the integrity of a welded fastener should be minimal, if at all, due to the subjective nature of the process and the potential for part damage. These types of checks frequently fall to the production operators and are often employed when a problem has been discovered and the manufacturer is trying to close the back-door on an issue. In most cases, the potential damage that can result from these inaccurately applied inspections is not worth the effort and a redirection of resources to other aspects of the production and inspection process is advised. A final thought on this type of inspection may be in order: The migration toward more advanced materials and the ever higher quality standards required at all levels of manufacturing have, for all intents, transformed the hammer and/or pry bar inspection from a nondestructive to a destructive check.

As mentioned previously, the destructive elements that can be applied to a projection weld fastener will be discussed with the next column.

Acknowledgment

The author would like to thank Tom Morrissett, former AWS D8 chairman, for his invaluable perspective on projection weld quality.

References


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Electron Beam Welding in the United States

A glimpse is given of how electron beam welding has evolved in the United States over five decades

BY DONALD E. POWERS

Using an electron beam (EB) to perform material processing tasks first began in the early 1900s to melt refractory metals in vacuum. Since then, its utilization for processing other forms of material has steadily increased as the level of capability of its two main supporting technologies, vacuum engineering and electron optics, have continued to evolve and mature with time. Thus, as shown in Table 1, its present day use in the area of industrial material processing covers a broad range of applications — varying in nature from tasks that employ a very low power density beam (very shallow, surface types) to those that employ a very high power density beam (very deep, volumetric types).

EBW Process Fundamentals

A schematic representation on the type of EB gun and column assembly commonly employed to perform EB welding tasks is shown in Fig. 1. This figure illustrates a triode style (cathode, grid, and anode) gun being used to generate the beam, as well as the electron optical (focusing and deflection) system utilized for controlling the manner (final beam spot size produced and its positioning) in which this beam is then impinged on the workpiece. In operation, the cathode, an emitter that can be either directly or indirectly heated, provides a source of thermally emitted electrons that are simultaneously accelerated and shaped into a collimated beam by the electrostatic field geometry produced by the gun grid, anode configuration being employed, and then focused into a highly intense beam spot on the workpiece.

Use of a triode style gun allows, at any fixed operating voltage, the magnitude of electron flow exiting the gun (i.e., the beam operating current, and thus the resulting beam power being delivered to the workpiece) to readily be adjusted as desired. Thus, by simply varying the negative potential difference being applied between cathode and grid, the beam can easily be either instantaneously turned on/off or have its operating level ramped up/down in a highly controlled fashion. In addition to providing the ability to produce either a highly focused or slightly defocused beam spot on the workpiece, the electron optical system employed also provides the capacity for deflecting the beam spot in either a static (fixed positional change) or dynamic (oscillatory positional change) fashion.

In contrast to more conventional conductive means of welding, the main joining advantage EBW provides users is the ability to perform what is commonly referred to as “keyhole welding,” illustrated in Fig. 2. In keyhole welding, the highly intense beam impinged on the workpiece generates a vapor channel that penetrates into the workpiece. This allows the beam’s energy to be delivered directly to the weld joint faying surfaces deep inside the workpiece, rather than simply being deposited onto its top surface, as in the case of more conventional welding methods. As this vapor channel is advanced, molten metal being formed at its leading edge continuously flows around it, solidifying behind its trailing edge to form the final weld joint.

The 1960s through mid-1980s

Once introduced into the United States, interest in the EBW process quickly grew. Numerous EB symposiums, seminars, and conferences were held in the early 1960s, providing attendees with a continuous source of information about the process from both U.S. and foreign users and manufacturers. Concurrently, various suppliers of the equipment began exhibiting at the welding shows. The combination of these two events strongly contributed to the rapidly expanding interest the U.S. welding community had in both the EBW process and its growing use by industry.

During the early 1960s, it was established that the deep penetration results provided by the keyhole form of welding achieved with EB depended primarily on

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Table 1 — Overview on Various Uses of EBW for Industrial Processing

<table>
<thead>
<tr>
<th>Surface Type Processing</th>
<th>Power Density</th>
<th>Beam Power</th>
<th>Spot Size</th>
<th>Beam Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonthermal Processes</td>
<td>10^{-2}–10^{2} W/cm^2</td>
<td>1mW–100W</td>
<td>0.1µm–0.01mm</td>
<td>20kV–10MV</td>
</tr>
<tr>
<td>(lithography, doping, sterilization, and curing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat Treat Processes</td>
<td>10^2–10^3 W/cm^2</td>
<td>100W–1kW</td>
<td>0.5µm–30mm</td>
<td>20–150kV</td>
</tr>
<tr>
<td>(hardening, glazing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volumetric Type Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting and Evaporation Processes (vacuum refinement, material coating)</td>
<td>10^3–10^5 W/cm^2</td>
<td>1kW–2MW</td>
<td>3–50mm</td>
<td>10–50kV</td>
</tr>
<tr>
<td>Welding Processes (high vac, partial vac and nonvac)</td>
<td>10^5–10^7 W/cm^2</td>
<td>100W–100kW</td>
<td>0.3–3mm</td>
<td>30–300kV</td>
</tr>
<tr>
<td>Machining Processes (cutting, drilling)</td>
<td>10^7–10^9 W/cm^2</td>
<td>100W–10kW</td>
<td>0.03–1mm</td>
<td>10–200kV</td>
</tr>
</tbody>
</table>

the magnitude of beam power density being employed rather than the level of operating voltage utilized, and a variety of U.S.-based companies became involved with manufacturing EBW equipment having operating voltages spanning the full range from 25 to 150 kV. The list of these companies included Nuclide, National Research, Hamilton Standard, and Sciaky to name just a few. Before the end of the 1960s, however, many of these companies discontinued this manufacturing practice, leaving Hamilton Standard and Sciaky as the two leading U.S.-based producers of EBW equipment — a position both still hold today, although each has since changed ownership several times.

**The Golden Years**

The 1960s were unquestionably the golden years for EB welding in the United States. During this ten-year period alone, some 500 EBW machines, more than a third of the total number of units installed over the past 50-plus years, were installed in the United States. In addition, while the EBW units installed during the early 1960s mainly had relatively small high-vacuum chambers with very limited workpiece motion and beam power output capability, those being supplied by the mid-1960s consisted of units having fairly large high-vacuum chambers with the capacity to provide both multi-axis workpiece and/or gun motion and beam power outputs ranging up to 45 kW. At about the same time, units with the ability to apply the process under both partial vacuum and nonvacuum conditions, as well as high vacuum, were introduced concurrent with units that additionally employed both NC-operated workpiece motion and beam parameter control.

**EBW Shows Its Versatility**

During the 1960s, EBW became a multimode welding process viewed as having potential applications for virtually any type of joining task imaginable, including a metal dress produced from aluminum foil and mesh materials to highlight the joining versatility of the process. This resulted in the development of a number of fairly innovative means and methods for expanding the EBW process’s scope of application during that decade. A few examples follow:

1) **The Perforated Wall Hollow Cathode.** A cold cathode device for generating electron beams that could be configured into annular, cylindrical, and spherical shapes one form of which provided a fairly simple device for use in joining tubular components in a bell-jar style of environment.

2) **Hand-Held EB Gun.** A device developed for NASA astronauts to use for both fabrication and repair-type welding in space.

3) **Portable EBW Pipe Welding Machine.** A system produced for the AGA that employed a crane-supported, C-clamp style high-vacuum chamber containing a trolley-driven, right-angle EB gun for use in providing 360-deg peripheral welds on pipe segments in the field.

4) **Clam-Shell Style EBW System.** A unit delivered to Grumman Aerospace for welding the large wing-structure components used in the manufacture of the Grumman F-14 TOMCAT fighter aircraft.

Other products of the 1960s included the adaptation of nonvacuum EB to tube mills, which provided the capacity to perform high-speed out-of-vacuum tube welding that was continuously being...
formed directly from strip material. Another was the employment of individually pumped pre-high-vacuum and post-high-vacuum pressure stages, separated by apertures that allowed the constant passage of the dual strip material being joined in high vacuum. This provided the ability to weld the bimetal product being utilized by the saw blade industry in a continuous air-to-air fashion.

A Shift in the 1970s

Annual EBW machine installations in the United States, which had reached a peak of about 100 units per year before the end of the 1960s, began a noticeable decline by the start of the 1970s. This resulted from a saturation of EBW equipment in the primary markets of that era, the aerospace, medical, aeronautical, and AEC-DOE industries. However, during the 1960s, the U.S. automotive industry became quite interested in the various joining advantages EBW might offer if the production welding capacity of the process could be greatly increased. Batch loading methods were initially employed to help increase the number of parts capable of being processed each time the weld zone environment had to be evacuated to a high-vacuum level. Then, as the partial vacuum and nonvacuum modes of EBW application matured with use during the 1960s, much greater production rate capacities were made available since both these modes of EBW application either appreciably reduced or entirely eliminated any production time that would be lost loading parts into a high-vacuum environment.

Thus, with a growing number of EBW machine sales being made to the auto industry starting in the late 1960s and extending out through the 1970s, annual EBW machine installations in the United States again began approaching the 100 level. However, a series of events originating toward the close of the 1970s (problems in the auto industry, a general sagging economy, and the advent of laser beam welding [LBW] as a competitor) once again contributed to a decrease in this number by the start of the 1980s — Fig. 3.

The makeup of suppliers of EBW equipment to the U.S. market also began changing during the 1970s. Foreign manufacturers of the equipment (Steigerwald, TorrVac, and Wentgate) started entering the marketplace by licensing various U.S.-based companies originally involved with manufacturing EBW equipment, but that had discontinued that practice and started up EBW job shops to act as their sales representatives. Several new U.S.-based suppliers (Union Carbide and Westinghouse) also entered the market at about the same
time, thereby providing Sciaky and Hamilton Standard with a variety of new competitors for EBW machine sales.

With the auto industry being the primary U.S. procurer of EBW equipment in the 1970s, the majority of EBW units installed during that decade were either of the partial vacuum (PVEBW) or nonvacuum (NVEBW) variety. Two of the very earliest ones delivered to the auto industry, the drop-bottom style PVEBW flywheel welding machine (Fig. 4) supplied to Ford and the carousel-style NVEBW steering column jacket machine supplied to GM, were each installed and made fully operational by the very early 1970s. Before the mid-1970s, numerous drop-bottom styles, including sliding seal variety PVEBW and drop-bottom models, plus room variety NVEBW units, had been delivered to the auto industry, providing several auto plants with as many as 10 to 20 EBW units operating in production by the middle of that decade.

The 1970s also produced a number of changes in the nature of the EBW units being supplied. Although EBW manufacturers had previously been providing the aero space, nuclear, and other industries with systems that were quite satisfactory for their applications, once EBW equipment suppliers began providing units to the auto industry, they quickly learned that the systems had to be suitable for continuous operation (i.e., 24 hours a day, 7 days a week) during peak production and process performance improvements during the 1970s. At the same time, manufacturers also had to start replacing analog with digital-style controls in order to meet the auto industry’s growing requirement for a higher degree of operating flexibility and a greater ease of equipment serviceability. As a result, by the start of the 1980s, most of the EBW equipment being provided to the U.S. market employed some form of digital-style controls.

The mid-1980s to Present

Since EBW equipment being made available to the U.S. market by the mid-1980s had been appreciably enhanced over that which had been available during the 1960s and 1970s, and with most all suppliers of EBW units by then providing systems with PLC and/or CNC system controls, improved beam current, and deflection pattern control capabilities, as well as optionally offering joint tracking, data acquisition, and beam diagnostic packages, the cost of purchasing an EBW unit had increased significantly. Thus, with the state of the economy at that time and the tighter restrictions being placed on the purchase of capital equipment as a result of those poor economic conditions, the decrease in annual new machine sales that had begun near the start of the 1980s continued on throughout that entire decade.

However, with an installed base of better than 800 EBW units already in place in the United States by the beginning of the 1980s, the market was somewhat bolstered by an increase in the sales of customer support functions (field service, spare parts, and accessories), as well as by a new avenue for equipment sales that had begun opening up by then. This was the sale of “upgrade packages” (i.e., retrofit, refurbishment, and modernization kits) for existing equipment, an area that provided a good potential for sales since more than half the EBW units in the existing installed machine base were 1960s vintage units. Upgrade packages being offered consisted of such major items as PLC or CNC machine control changeovers and beam generation system changeovers, the major type of machine makeovers that could generally be funded through an existing maintenance budget, rather than requiring authorization for a capital equipment expenditure. This market for upgrades continues to provide an area of good sales opportunity even today, as present day estimates indicate that some 900 to 1000 of the roughly 1400 to 1500 EBW units installed in the United States during the past more than 50-year period (~75%) continue to remain in use today, either at the original purchaser’s facility or at the facility of the second or third (and even subsequent) owner of the unit. Several hundred of these units still in use today (~30%) are either 1960 or 1970 vintage systems.

The Growth of Job Shop EBW

Another area of business initiated by the increased cost involved with purchasing a new EBW system by the 1980s was that of performing contract, job shop EB
welding. This was due to the fact that this form of EBW business offered potential users of the process, those generally interested in applying it to their product but unable to achieve the level of machine time utilization necessary to justify the outright purchase of an EBW system, the opportunity to economically outsource welding tasks to an EB job shop. This job shop EB welding business has continued to expand with time, and, as indicated by Fig. 5, there are presently more than 50 EB job shops in operation across the United States. The majority of these shops are located on the East and West coasts, primarily in California and New England. These facilities range in size from small ones having as few as one or two EB units in operation up to large ones with as many as five to ten units in operation. Included in this are several EB job shop welding businesses being operated by both the leading U.S.-based EBW equipment providers, PTR (formerly Hamilton/Leybold) and Sciaky.

**New Offerings**

In the 1990s, EBW equipment suppliers began to offer more moderately priced, scaled-down systems (Fig. 6A) as an alternative to highly specialized, high-expense systems (Fig. 6B). These more compact and cost-effective units were generally of the low-voltage variety with a beam power output capacity of 15 kW, or under. Most, however, continued to provide their users with all the same equipment enhancements present on the larger and more expensive units. Purchasers of EBW equipment, since the early 1990s, were thereby provided with the choice of a full range of high- to low-voltage, high-vacuum, partial vacuum, and nonvacuum high to low power units that are high and moderately priced. The use of EBW equipment was also expanded during the 1980s and 1990s to include tasks other than welding such as surface treatment (hardening, glazing, and texturing, brazing, and free-form style fabrication (near-net-shape and additive manufacturing). Concurrently, the equipment was also shown to have the optional capacity of supplying users with computer-enhanced beam diagnostic images and the ability to perform “simulated” multibeam processing tasks.

**Summary**

During more than a 50-year period, EB welding in the United States has gradually evolved from being a unique laboratory tool initially considered of interest primarily to the nuclear and aerospace industries to a highly sophisticated production tool that is now utilized, to some degree, by most segments of U.S. industries. Thus, its present-day industrial usage spans a range of applications that provide highly expensive components (with fairly minimal production rate requirements) for aerospace and nuclear industries to relatively low expense components (with very high production rate requirements) for the auto and tool industries. Consequently, during these years, EBW has steadily grown to be a process that provides users with a highly reliable manufacturing procedure that has readily demonstrated its capacity to accomplish tasks of both the shallow surface variety and the deep penetration type. It is a process that, given the ongoing advancements being made in the areas of beam generation, control and deflection technology, will continue to grow in application capability well into the future.

**Reading List**

Want to Find Your Next Great Lead? Head to Monterrey!

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As an AWS Weldmex exhibitor you’ll meet with eager buyers in the following industries:
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The Georgia World Congress Center in Atlanta provided 371,000 sq ft of exhibition space for 1138 exhibitors at the 2010 FABTECH Show, Nov. 2-4. The 452 exhibitors on the welding side accounted for 150,675 sq ft. The 22,000 visitors were exposed to the latest technology in metal fabricating, forming, stamping, pipe and tube, coating, and welding. This represented a 12% growth in attendees from 2006 when FABTECH was last in Atlanta, and there were visitors from more than 50 countries. The exhibition not only provided an opportunity to get acquainted with the latest equipment and services in metal fabricating, but it also provided a forum to exchange knowledge and ideas through three days filled with
The world of welding, metal forming, and fabricating flocked to Atlanta to see the latest products, research breakthroughs, and industry developments

BY ANDREW CULLISON, KRISTIN CAMPBELL, AND CARLOS GUZMÁN

100 conferences, seminars, technical sessions, work shops, lectures, and keynote presentations.

AWS Annual Meeting

The 91st business session of the American Welding Society was called to order on Nov. 1 at the World Congress Center. Outgoing President John Bruskotter highlighted Society achievements throughout his presidential year: Membership in the Society is at an all-time high, financially AWS had one of its best years, the Gases and Welding Distributors Association (GAWDA) selected the AWS to manage its activities, a new headquarters building was purchased to provide much needed room for present and future activities, and the Resistance Welding Manufacturers Alliance (RWMA) and the Welding Equipment Manufacturers Committee (WEMCO) held a joint conference for the first time. “It was a great year to serve as your president,” he noted.

President-elect John Mendoza began his address to the audience with the concept “If the American Welding Society is to aspire to greatness in 2011, we can take inspiration from those who came before us.” He went on to give an example of a defining moment in the Society’s progress and the leadership that aspired to make it happen. The program he talked about was the Certified Welding Inspector certification. Its birth was in 1976, but before it saw the light of day, the program was debated long and hard. “Some thought we accept ‘If the American Welding Society is our proper role as an engineering society. And many thought the financial risk was too great,” he said. But he noted it was because of the boldness and vision of the Society’s leaders that it came into being. Prior to 1976, very little was said about the qualification of personnel for welding inspection in the codes, but as the CWI certification gained acceptance, industry began to demand qualified personnel for inspecting welds.

Today, this program is accepted around the world with about a third of the 33,000 CWIs applying their skills overseas on many continents. Mendoza also spoke of how the program has affected him personally, “The most career changing decision I ever made was when I became a CWI.” He noted it opened doors of opportunity for him, as it has done for many other CWIs. He also said that without the success of the CWI program, AWS would be a different organization from what it is today. His closing remarks presented a challenge. “AWS was bold in 1976 in launching an initiative that changed the world of welding. Thirty-five years later, there are new frontiers in welding. Let us work together to explore them.”

Adams Lecture

Horst Cerjak presented the 2010 Comfort A. Adams Lecture (Fig. 1) on the topic “Welding, Key Technology in the Power Generation Industry.” Cerjak has written 350 scientific papers and 14 books during his 40-year career on subjects such as nuclear materials, weldability, modeling, material development, and creep-resistant steels. From 1982 to 2008, he held the position of head of the Institute for Materials Science and Welding at Graz University of Technology, Austria.

In his opening remarks, Cerjak predicted the world’s electrical usage will double in the next 25 years. This places pressure on science and industry to investigate new materials and their weldability for meeting this increased demand. He sees the three main generating sources of electricity to be hydro, thermal, and nuclear. He gave an example of hydropower where penstocks are delivering water from mountain lakes. The penstock material of the 1900s may have had a yield strength of 600 MPa, but today’s quenched and tempered steels have a strength of 800–900 MPa. The Q & T steel has good weldability, but the heat-affected zone is susceptible to hydrogen-induced cracking. He gave an example of a penstock that had only been in service for six months but had catastrophically failed in a section of the line. The culprit was hydrogen cracking, which is difficult to detect. To avoid replacing the whole line, the solution in this case was to weld a sleeve of lesser strength steel around the joint.

In thermal generation of power from coal-fired plants, it has been established that an increase in temperature can decrease CO₂ emissions. This puts a demand on developing steels that can withstand higher temperatures and exhibit better creep resistance. Increasing the thickness of the material will provide those desirable characteristics, but adds cost to construction and decreases the net efficiency of the steel. A new material NF616 (P92) shows promise in improving creep resistance at high temperatures, thereby reducing the thickness of the steel and increasing its efficiency.

There are plans for building nuclear power plants around the globe. Extensive welding will be conducted in their construction with some heavy sections as thick as 600 mm. Strip cladding with 20Mn-MoNi55 and 22NiMoCr37 has presented problems with underbead cracking. There was a loss of ductility and a coarse grain area developed in the surfacing weld, but upon reheating, there was improvement. The reheating was accomplished by ap-

Fig. 1 — Horst Cerjak presented the 2010 Comfort A. Adams Lecture on the critical need for welding technology in the future of power generation.

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thing that can be just stopped nor should it be feared. The United States must do what it does best — innovate.”

In addition, he provided an update on the changing face of U.S. manufacturing and mentioned it remains a significant part of the U.S. economy, generating $1.64 trillion worth of goods in 2008. Manufacturing is no longer the dominant sector of the U.S. economy, although it remains a critically important component.

Most people select careers other than engineering, and most engineers are not welding engineers. Welding engineering is a multidisciplinary endeavor that can lead to marketable jobs, Madigan said. What’s more, welding manufacturing is becoming more complex. With higher levels of automation and advanced processes and materials, it takes smarter people to complete more technically challenging operations.

However, he said, high school students are poorly prepared for engineering. Most of them do not know what they want to do for a career and, having a limited forward vision, they avoid “hard” classes. Undergrad engineering student retention is another problem.

Montana Tech’s approach to prepping high school students consists of increased coverage during recruiting trips to educate counselors on engineering course requirements, plus an introductory course on study skills and engineering careers.

Madigan’s solutions to welding education problems include the following:

- Recognize that all young people need the opportunity to receive some level of postsecondary education;
- Students have different capacities for learning and acquiring knowledge;
- Impress on students thoughts for being a contributing member of world citizenship;
- A need to encourage more women into the trades, engineering, and sciences;
- Be models for students;
- Have an attitude of positive thoughts and avoid self-abusing words;
- Employ successful virtues;
- Meet U.S. welding manufacturing challenges by working both ends simultaneously; and
- Address the lack of undergraduate welding engineering texts.

He also stated that out of the learning stages, the initial eagerness/thirst to gain new knowledge is short-lived but is the most powerful, moving, and important activity of human endeavor.

He concluded by pointing out today’s college students are winners. “Young people today want to contribute immediately and know the value of their work,” Madigan said. They communicate via e-mail, multimedia, online content and tests, forums, and social networking. To keep up with these trends, Madigan developed online presentations and homework/quizss because students appreciate completing assignments on their own time.

**Thomas Lecture**

Lincoln Electric's David Fink, Thomas Medal Award Recipient, in his talk titled “Are We There Yet?” discussed the current status of international standardization of welding consumables — Fig. 3. Fink addressed several key issues, such as the need for more ISO filler metals standards to be adopted by U.S. industry (and the reluctance of U.S. industry to work with SI metric units), and the lack of a new generation of committee members to lobby for further international standardization in the welding consumables field.

Fink, who has worked in the welding industry for nearly 40 years and has remained active with AWS technical committees for almost 35 years, was awarded the Thomas Medal for his work with the IIW and the International Organization for Standardization (ISO). Fink is currently the chair of the U.S. Technical Advisory Group for ISO/TC 44/SC 3 — Welding Consumables.

**Keynote Presentation**

On Nov. 3, the Keynote Presentation “Make Green by Going Green: How Manufacturers Can Gain a Competitive Advantage” addressed ways three companies have done just that — Fig. 4. Jon DeWys, president of DeWys Manufacturing, Marne, Mich., a metal fabrication shop, reviewed green initiatives in the company’s paintline area. These included using a well water and drain field system; replumbing a five-stage wash to recycle heated water from cleaner to more contaminated stages; creating a radiator circulation system between the wash station and adjacent stand-alone parts cleaning station; and improving preventative maintenance on cure oven temperature settings. “The key of what we do is integrate lean and green,” DeWys said. Other initiatives consist of sheet size consolidation and reducing energy consumption.

**Fig. 2 — During his Plummer Lecture, R. Bruce Madigan spoke about Montana Tech, offered updates on global and U.S. manufacturing, and reviewed society trends and welding engineering education.**

**Fig. 3 — David Fink presented the Thomas Lecture, “Are We There Yet?” about the current status of international standardization of welding consumables.**

**Fig. 4 — Jon DeWys, president of DeWys Manufacturing, Marne, Mich., spoke during the Keynote Presentation, “Make Green by Going Green: How Manufacturers Can Gain a Competitive Advantage.”**
Fig. 4 — Jim Warren (at the lectern) moderated the keynote presentation “Make Green by Going Green: How Manufacturers Can Gain a Competitive Advantage.” Its three panelists (from left) were Jon DeWys, Mary Ellen Mika, and John Spangler.

Mary Ellen Mika, manager, sustainability and energy supply chain management for Steelcase, Inc., Grand Rapids, Mich., a provider of office furniture, stated being green is a core value for the company. A majority of customers have quotation requests including sustainable inquiries, so it’s important to find leaner, cost-effective, and green solutions. The company also pursues voluntary initiatives for general sustainability, educational, and marketing purposes. “By our 100th anniversary (2012), we are committed to reducing water and energy use — among many other environmental metrics — by at least 25%,” Mika said.

John Spangler, technical steward at Caterpillar, Peoria, Ill., said the company has utilized many lean and green finishing initiatives and technologies. These include minimizing and recycling paint and chemicals; modular and redeployable finishing technologies including controls, conveyance, and process equipment; and a new technology, the environmental liquid spray booth, as a low-cost volatile organic compound capture system. “Producing a quality product in a lean manufacturing way,” Spangler said, “is essential.”

The Latest Products

Attendees could not only find nearly every welding-related product at the show, but often could try them out themselves. Following is a sampling of products shown this year.

Hypertherm introduced its Hylntensity Fiber Laser HFL015 — Fig. 5. This is the first time the company has put together a full package for laser cutting, which includes the power source, interface consoles, cutting head, software, gas supply, and motion controls. This 1.5-kW unit has cutting capacity up to ½ in. (12.4 mm) for mild steel, and ⅜ in. (9.5 mm) for stainless steel. The fiber laser system has a smaller footprint than CO2 lasers, a company spokesperson noted, so the fiber laser can be integrated into a shop’s existing cutting table, since the table size requirements of CO2 lasers are eliminated. The system has taken three years to be perfected for this introduction, and cutting demonstrations were performed throughout the Show. Hypertherm, Inc., (800) 643-0030, www.hypertherm.com.

Over the years, as the cost has come down and the quality has gone up, right-angle grinders have become more desirable for a diverse number of applications, including grinding, cut off, and blending. Norton has a complete line of discs for right-angle grinders (Fig. 6) that meets the needs of many applications. Products introduced at the show included SG Blaze Plus flap discs with ceramic alumina abrasive for efficient grinding. This disc is designed to perform well on stainless steel, titanium, and superalloys. The NorZon BlueFire F826 fiber disc blends ceramic alumina and zirconia alumina abrasive that self sharpens for strong cutting. Norton, Saint-Gobain Abrasives, Inc., (508) 795-4435, www.nortonabrasives.com.

Sunstone Engineering was exhibiting at its first FABTECH show. The company specializes in microwelding and the Orion Pulse 250i (Fig. 7) system was introduced. The unit utilizes both resistance welding and pulsed arc welding. In the pulsed-arc mode, it is capable of three different energy outputs: Ultra, Micro, and Nano at 250, 30, and 0.5–5 J, respectively. The welding machine can store 18 prepro-
The American Welding Society (AWS) and the Welding Equipment Manufacturers Committee (WEMCO) honored the 2010 Image of Welding Award recipients Nov. 2 at a ceremony during FABTECH — Fig. A. Issued in six categories, these awards recognize individuals and organizations that have shown exemplary dedication to promoting the image of welding in their communities. The winners were also instrumental in raising the image of welding and strengthening the industry.

The Individual Category went to AWS District 14 Director Robert L. Richwine, Chesterfield, Ind. A welder for almost 40 years, he has been an active AWS member for more than 20 years and serves on many advisory boards for area vocational schools. Welding students at Ivy Tech State College, where Richwine currently teaches, have dubbed him “The Welding God.”

James Lee Brantley, Miami, Fla., won the Educator Category. He has taught welding technology in Miami-Dade Public Schools for more than 30 years. Recently, Brantley and his students teamed up with AWS and actress Patricia Arquette to turn shipping containers into homes for families displaced by the devastating earthquake in Haiti last January.

In the Educational Facility category, Gadsden State Community College, Gadsden, Ala., took top honors. The college created the first centralized industry-supported, innovative welding training center providing highly advanced automated orbital training on a college campus with its Alabama Regional Center for Welding Automation. The new center serves as a magnet for qualified welders seeking training and certification in the highly specialized automated orbital welding skills set.

Colmac Coil Manufacturing, Inc., Collville, Wash., earned the Small Business award. A privately held, third-generation family-owned company, it has grown to be a leading manufacturer of new and replacement coils. Colmac focuses on not only the future of the company but that of the community and welding industry. The company donated the use of a gas tungsten arc welding machine to a local high school welding class and also donated materials such as piping, tubing, and sheet metal for use in the school’s welding program.

The Large Business division award went to PSEG Fossil, Newark, N.J. In 2007, the company began revitalizing its technical training program and designed and developed a mobile training welding unit. PSEG Fossil now has a 53-ft-long trailer customized with an expandable classroom, instruction station, six weld booths, heating and air, and compressed air and storage space for gas bottles. The mobile unit is a way for the company to train and certify welders across four states.

The North Central Florida Section captured the AWS Section prize. As an active AWS Section, it’s committed to promoting the image of welding. It has adopted an approach to cater to the industry’s future by focusing on students. The success paid off at the District 5 conference earlier last year when four of the five District scholarships were awarded to students from this Section.

To make its M200 orbital welding power source (Fig. 8) more versatile, Swagelok added an inside-diameter (ID) purge control system. Reacting to feedback from customers of the problems encountered with ID purging, the system is designed with pressure sensors that send signals to the power source to keep pressure constant at the weld head. Purge gas flow automatically adjusts to variations in the root opening, and when that is combined with the shielding gas flow on the outside diameter, the weld is completely protected. The purge system is available with new orders. Existing M200 power sources can be retrofitted.

A new touch screen control for gantry cutting systems was introduced by ESAB. The Vision T5 control has an 18.5-in.-wide screen (Fig. 9) for visibility and improved access to the display layout. It is designed for durability in manufacturing conditions. The controls are simplified to enhance training and the operator is guided with step-by-step cutting instructions. There are also steps for machine positioning and torch setup. The graphics on the...
screen provide the operator with visual prompts to control both plasma and oxy-fuel cutting, beveling, and marking. A shape library and autonesting programs are part of the internal database. One unit controls up to 12 stations with multiple axes. ESAB Welding and Cutting Products, (843) 669-4411, www.esabna.com.

Thermo Scientific offers a line of hand-held XRF (X-ray fluorescence) analyzers suitable for a wide variety of applications, such as metal and alloy testing, consumer goods, mining, and environmental analysis. The Niton® brand consists of the XL2 Series (Fig. 10) and the XL3t Series. All models include an easy-to-read display. The most affordable XL2 has a standard analysis range of more than 25 elements, and the XL2 GOLDD (geometrically optimized large area drift detector) adds the ability to measure light elements (Mg-S) without vacuum assistance or helium. The XL3t adds a tilting, color, touch-screen display, and an optional camera. The top-of-the-line XL3t GOLDD+ adds light-element analysis, faster measurement times, and a helium purge option. Thermo Scientific, (978) 670-7460, www.thermoscientific.com.

The Clean Air Smart Collector™ from Clean Air America is designed for weld smoke, grinding particulate, laser and plasma cutting dust, and various other dry filtration applications — Fig. 11. They are available in various sizes from 1 to 48 cartridges, and air-processing volume of 500-30,000 ft³/min and more. These collectors require a ducted system, making them fit for applications such as welding, grinding, plasma and laser cutting, buffing, polishing, sanding, mixing, and blasting. One of the company’s newest products is the ScandMist, which removes oil mist and smoke from the machining floor environment and efficiently separates oil from the air. These collectors are ideal for welding and cutting, and can process air volumes from 500-30,000 ft³/min.

ESAB/OCC Chopper Debuts at the Show

Recently, ESAB Welding & Cutting Products entered into a partnership with Orange County Choppers (OCC) as its exclusive welding equipment and filler metal provider. As part of the arrangement, OCC built a custom-designed chopper for ESAB using its equipment. The bike features the company’s logo, signature yellow and black colors, a welding helmet used as a headlight, and a gas metal arc gun on the rear wheel.

Paul Teutul Sr., OCC’s founder, along with Mark Elender, ESAB’s senior vice president of sales and marketing, unveiled the motorcycle to the public for the first time at the 2010 FABTECH Show on Nov. 2 — Fig. A. During the event, fans had the opportunity to meet Teutul, take a picture with him, and see the chopper up close.

The motorcycle’s production, which features Teutul’s OCC shop was highlighted in an episode of the TLC network’s American Chopper.

The chopper will make its home at ESAB’s North American headquarters in Florence, S.C., and be available for special events.
fumes, oil mist, oily dust, and emulsion mist, returning clean air to the workspace. 


The new ABIMIG® GRIP A GMAW air-cooled guns feature a two-component handle system that offers great ergonomics and a secure grip for optimal handling — Fig. 12. This new design reduces fatigue and can help prevent carpal tunnel syndrome. The guns use low-weight Bikox™ cables, which contribute to a weight reduction of about 50%. Other features are screw-on gas nozzles with thermoprotective insulation, laminar gas feed, and changeable gas nozzles seats. Abicor Binzel, (301) 846-4196, www.binzel-abicor.com.

3M has introduced a new line of welding helmets with graphics and features designed specifically for female welders — Fig. 13. The 3M™ Speedglas™ 100 Series Women’s Collection includes four different designs: Steel Rose, Wild-N-Pink, Steel Eyes, and Skull Jewels. Besides the graphics, these helmets also feature an ergonomic headband that accommodates smaller head sizes, and optional accessories such as additional neck and head protection and magnifying lenses. Each helmet is available with an autodarkening filter, and they offer the same protection and performance as other models in the Speedglas line. 3M, (800) 328-1667, www.3M.com/SpeedglasWomen.

Three Welding Students Move on to SkillsUSA Championships

Three of the six top finalists who competed at the 2010 Weld-Off Competition sponsored by the American Welding Society at the FABTECH Show in Atlanta have advanced to the SkillsUSA Championships to be held this coming summer. Moving on to the next phase of the competition and vying to represent the United States at the World Trials Competition are Zackery Brown from Leakesville, Miss., and Bradley Clink and Alex Pazkowski, both from Saline, Mich.

The three students will face off against each other at the SkillsUSA Championships in Kansas City, Mo., June 19–25. From there, one student will go on to represent the United States at the 41st World Skills Competition, October 5–8 in London. Also present was the Australian champion, Guy Brooks, who will compete at the WorldSkills contest. Brooks participated as a guest and had the opportunity to practice his skills along with the Weld-Off Competition competitors.

ABB Robotics displayed 12 welding, metal fabrication, and painting robots that feature equipment and power sources from the major welding and metal fabrication suppliers including Miller Electric, Lincoln Electric, ESAB, Fronius, POM Group, LaserMech, Presitec, Preston & Easton, Easom, RoboVent, and Pilz. The array of equipment and systems represented the scope of the integrated metal fabrication processes supported by the company. Some of the systems presented included the IRB 4600 robot, dressed for heavy welding and featuring a Lincoln 455 PowerWave™, remote push wire feeder, and ESAB Marathon Payoff Pack. ABB claims that the IRB 4600 is the fastest, most accurate, low-weight, medium-size robot ever developed for general industrial applications. Also on display was the heavy-duty IRB 6600 robot.


Fig. 12 — The new ABIMIG® GRIP welding guns combine lightweight necks and cables for easy handling.

Fig. 13 — The Wild-N-Pink graphic is one of the four patterns available in the new 3M™ Speedglas™ 100 Series Women’s Collection.

Fig. 12 — The new ABIMIG® GRIP welding guns combine lightweight necks and cables for easy handling.
The IRB 6600 robot, presented here with servo spot welding equipment, has upper-arm extenders and different wrist modules that allow customization to each process. ABB Robotics, (248) 391-8400, www.abb.com/robotics.

To maximize productivity when welding thick plate and/or operating for prolonged duty cycles, Tregaskiss introduced a new version of the TOUGH GUN™ robotic water-cooled GMAW gun — Fig. 15. It includes a wire brake feature that works in conjunction with wire touch sensing to help determine the location of weld joints and is available for wire sizes from 0.035 to ½ in. diameter. Also, the gun includes a high-flow gooseneck with four cooling channels and a water-cooled power cable. It has a stainless steel docking body capable of withstanding the environments common to high-amperage welding applications, along with a conduit that swivels independently. The gun has an accessible front housing, quick-change fittings, and replaceable components. It uses the company’s Common Consumable Platform based on its TOUGH LOCK™ contact tips and QUICK LOAD™ liners. Additionally, it provides 600 A welding capacity at 100% duty cycle with CO₂ shielding gas or 60% duty cycle when welding with mixed gases. As of December 31, the gun replaced the company’s existing TOUGH GUN quick-change water-cooled and keyed water-cooled robotic GMAW guns. Tregaskiss, (877) 737-3111, www.tregaskiss.com.

The Axcess® E with Insight™ GMAW system from Miller Electric includes an integrated data monitoring capability within the power source — Fig. 16. The system’s Part Tracking™ feature monitors the fabrication of each part on a weld-by-weld basis. Extra benefits include a reduction in mistakes with monitoring each weld in accordance to preset parameter limits, facilitating the detection of missed welds, underwelding, and overwelding; potential defect identification by being configured to notify the operator or management if a weld has not met the expectations for current, voltage, wire feed speed, gas flow, or duration; and providing data on cost, productivity, and quality with the company’s Insight Reporter™. It uses Ethernet technology and the factory network system to not only interface with each welding system but transfer critical data. Interfacing is done using a Web-based application accessible with any compliant browser, so any machine in the fleet can be accessed from virtually anywhere in the world. The Insight Centerpoint™ graphical user interface gives access to all welding data and monitoring settings. Miller Electric Mfg. Co., (800) 426-4553, www.millerwelds.com.

Three new units in the Thermal Arc® portable DC welding machine series build upon the 95S model — Fig. 17. The 161S is for basic DC SMAW and lift GTAW operations, and provides a greater output range for the advanced hobbyist or light industrial projects. It’s capable of delivering 110 A on standard 115-V circuits for SMAW and GTAW. When used on 230-V circuits, maximum output is 160 A for either welding process. The machine features optimized hot start and arc-force circuits built into the power supply, delivering good arc starting and control for SMAW. The 161STL provides increased control and good arc performance for more demanding DC SMAW and lift GTAW jobs. It’s capable of delivering 110 A on standard 115-V circuits for SMAW and 160 A for GTAW. When used on 230-V circuits, maximum output is 160 A for either welding process. For improved control on DC lift GTAW, it includes a trigger hold function (2T/4T), downslope timers, a gas solenoid for flow-through gas, and the ability to use torch switches or a foot control. Available this spring, the 201TS is designed for tradesmen or welders with more experience. The unit provides increased control with good arc performance for demanding DC SMAW and GTAW jobs. It can provide a maximum output of 200 A for either welding process when used on 230 circuits. Thermal Arc®, (800) 426-1888, www.thermalarconthemove.com.
Lincoln Electric’s personal protection clothing is featured in the Red Line™ — Fig. 18. Its five glove styles include premium leather and traditional GMAW/SMAW, leather GTAW, heat-resistant, and full leather Steel Worker™. Four jacket options offer flame-retardant cloth and heavy-duty leather panels. Plus, four pairs of indoor safety glasses and four for outdoor use enable a choice of clear, shaded, and mirrored lenses. This apparel works in tandem with the company’s VIKING™ autodarkening welding helmets that have also been updated. The 1840 series features a 1.8-in. viewing area height; has an externally controlled, continuously variable 9–13 shade control; weighs 19.5 oz; and comes in standard black or four graphic styles, including the Amp Angel™ designed for female welders. The 2450 series offers a 2.4-in. viewing area height; contains a protected internal continuously variable 9–13 shade control; weighs 21 oz; and is offered in standard black and four graphic styles, including the Street Rod™ sporting red flames. The Lincoln Electric Co., (888) 355-3213, www.lincolnelectric.com.

The CMT Advanced offers an expanded range of applications for arc welding with extending the ability to weld or braze thin and very thin sheets with low levels of spatter — Fig. 19. The focus is on applications demanding a low and adjustable heat input, but the extensions primarily concern the joint’s potential and quality. It permits higher wire feed speeds and deposition rates with the same levels of energy input. Users benefit from larger and more precise adjustment windows along with improved guidance and weld pool control. Other highlights include good root opening bridging properties and producing a uniformly even weld seam. The technology integrates the welding current’s polarity, combined with a reversing motion of the wire, into the process control. The polarity change is carried out during the short-circuit phase, and there is no arc during the short circuit. This process allows the user to adjust the number of consecutive positive or negative current pulses or phases at will, while the CMT Pulse Advanced process is a combination of a negative CMT phase and a positive pulse phase. Fronius USA, LLC, (877) 376-6487, www.fronius-usa.com.

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Electron Beam Near-Net-Shape Processing Using Wire Feed

Electron beam direct manufacturing processes can be used to build an entire structure or add detailed features to a casting or forging

BY KENN LACHENBERG

High-energy-beam processes have been widely accepted in autogenous welding operations that require repeatable, high-quality welds that cannot be duplicated using conventional welding techniques. When the wire feed system and the motion components are designed to handle long cycle times, heavy vapor loads, and intelligent process control, the system can be employed to provide near-net-shape processed components. This article covers the additive process to produce near-net-shape components using an electron beam (EB) welding system.

There are two main classes of EB deposition processes in use today for near-net-shape fabrication of three-dimensional parts, based upon the type of feedstock used and how it is delivered to the molten pool. One class uses a wire-feed-based feedstock method, while the other utilizes a powder-bed feedstock approach. Myriad other electron beam deposition processes also exist for depositing thin films and coatings, or for performing surface modification and etching. These processes are typically used in the electronics and semiconductor industries, and are generally focused on coverage of precise layers on a micro scale (such as EB sputtering, physical vapor deposition, lithography, electron beam induced deposition, etc.).

Electron beam direct manufacturing (EBDM) is an emerging technology used to generate near-net-shape processed components that can utilize both classes of feedstock, but is more commonly used with wire — Fig. 1. In either case, three-dimensional (3D) EB deposition processing takes place by introducing metal feedstock into a molten pool that is created and sustained using a focus-controlled EB in a high vacuum environment (1 x 10^-4 torr or lower).

Modeling/Tool-Path and CAD/CAM Tools

Regardless of the specific machine being used, all components fabricated using EB deposition processes start with a 3D model produced in a computer-aided design (CAD) environment. In this operation, the deposition path and process parameters are generated from postprocessing the virtual 3D model, which is typically executed by a real-time computer control. Any CAD package may be used to develop the solid model, as long as the data can be exported into a format that can be interpreted by the postprocessors used to develop the machine codes to build the components. Postprocessors can slice the solid model into layers, then generate a tool path to control the beam and motion system (depending upon the EB deposition arrangement). Some systems can also take the computer-aided manufacturing (CAM) outputs from standard CAD packages to develop the tool paths and output the results into standard G-code.

Thermal residual stresses are generated within parts built using EB deposition because of the thermal gradients induced between the base plate at ambient temperature and the molten region below the electron beam. Thermal modeling has been used to calculate the distribution of residual stresses, predict the distortion expected as a result of the EB deposition processes, and guide the processing parameters and tool paths to mitigate or minimize the generation of thermal residual stresses. Process modeling has also been performed to help guide the closed-loop control development and to understand the effects of processing parameters on the resulting geometry, microstructure, chemistry, and mechanical properties of the deposited material.

Wire-Feed Systems and Process Variables

With wire-feed systems (Fig. 2), four of the most significant process variables, which are easily controlled, are the translation speed, wire-feed rate, beam power, and beam focus. The diameter of the wire feedstock is the controlling factor. It determines the smallest detail attainable using this process. Fine-diameter wires may be used for adding fine details, while larger-diameter wires can be used to increase deposition rate for bulk deposition. Due to spreading of the molten pool, a good rule of thumb for the smallest width feature possible is on the order of one and a half to two times the diameter of the wire. This rule of thumb does not apply to the widest width possible, as that is determined by the volume of wire being fed into the molten pool and sufficient power being delivered to melt large amounts of wire.

Multiple wire feeders have also been demonstrated to operate simultaneously, enabling either an increase in the volume of wire delivered to the molten pool or functionally graded alloying, where the alloy chemistry is changed over time. In this case, the width and depth of the layer being deposited is limited more by the ability to fully capture and melt wire being fed at a high wire feed rate. For higher translation speed, the lower heat input and lower volume of wire being fed into the molten pool results in a smaller diameter, shallower molten pool. This combined effect produces a decreasing taper in both the width and height of the deposit.
Fig. 1 — A simplified view of the electron beam direct manufacturing (EBDM) process elements.

Fig. 2 — An EB wire-feed assembly from Sciaky, Inc.

Fig. 3 — Aerospace components that underwent EBDM process qualification.

Fig. 4 — Example of cylinders built using EBDM, with and without closed-loop control.

Fig. 5 — Sciaky’s closed-loop gun design.

as the translation speed increases. The higher translation speed produces more rapid cooling and results in a homogeneous microstructure.

Deposition rate in wire-feed systems is directly controlled by the wire feed rate, but beam power and translation speed are also important factors in defining the final dimensions of the deposited layer. Increasing the beam power and decreasing the translation speed increases the heat input into the part, resulting in a deeper and wider molten pool. The increased wire feed rate adds more material to the molten pool, resulting in the greater deposition rate.

Material Quality

Since the EBDM process is typically operated within a high-vacuum environment, this provides for an oxygen-free atmosphere. Thus, secondary inert gases are not required to ensure the chemical integrity of the material. Furthermore, the quality of substrate and feedstock materials may be traced for critical applications and the degree of traceability would be specific to an end user’s industry. Currently, a majority of the EBDM development work has been performed on aluminum and titanium alloys. However, a variety of weldable alloys can be processed using the EBDM processes. New research on nonequilibrium processing is also being pursued for typically nonweldable alloys, functionally graded alloys, and selectively reinforced materials.

The EBDM process offers the potential for improved performance through control of microstructures and compositions at a much finer scale than parts machined from thick products. Typical thick sections have high degrees of microstructural inhomogeneity, leading to inconsistent mechanical properties. This is a direct result of differences in cooling rates and an inability to impart work evenly through a thick section. Working with smaller billets, in conjunction with layer-additive processes, can result in more optimal microstructural features, potentially improving the mechanical properties of the resultant part as compared to a similar part machined from a thick section billet. Finally, compositional gradients offer improved performance and reduced cost by allowing grading from an inexpensive material for the bulk of the product to an expensive material at the surface for enhanced wear resistance, corrosion resistance, etc.

Process Qualification

Process qualification may be required
to adopt EBDM methods for select applications. This qualification requirement would be more evident for critical applications, such as those implemented in the aerospace industry — Fig. 3. Presently, several efforts are underway to collect a database of material properties and to identify an appropriate process specification. Because the EB deposition processes tend to operate continuously in transient rather than steady-state thermodynamic conditions, maintaining consistent output parameters (such as molten pool width and depth and base temperatures) requires real-time monitoring and adjustments to one or more of the input parameters (beam power, scan speed, translation speed, wire feed rate, etc.). This presents challenges in defining an applicable process specification because the starting input parameters are actively modified throughout the deposition process.

Sciaky, Inc., recently introduced the benefit of closed-loop control to the market, which provides the process consistency to enable reproducibility from part to part, machine to machine, as well as day to day — Figs. 4, 5. Once the process control has been translated into a process specification that can truly be representative of the conditions required to achieve a given end product, and the material database has proven that these conditions are reproducible, process qualification can be realized.

Certification efforts are currently underway to enable application of EB deposition parts to enter into service trials for the aerospace industry for structural aircraft components, and in the medical industry as custom-designed medical implants. Within a short period of time, after certification has been achieved, applications and uses may accelerate for components fabricated using the EB deposition processes.

General Applications

Large-scale EB deposition processes like EBDM are capable of producing large components directly on plate (Fig. 6), rather than hogging out large volumes of chips from a forging. Direct cost savings can also be realized through repair and salvage of parts, reduced machining time, and reduced waste. Electron beam direct manufacturing can be used to repair broken or out-of-tolerance parts at a fraction of the cost of remanufacturing. This can be particularly significant when there is a large investment, either in capital expenditures, high-value materials, or large amounts of time already invested in a part.

Electron beam direct manufacturing processes can be used to build an entire structure, or to add detailed features to a simplified casting or forging — Fig. 7. However, the replacement technology must be cost-competitive. Thus, issues such as high deposition rates, process efficiencies, process quality, and material compatibility are paramount to insertion of a new technology into a competitive metals-forming market. Implementing these processes can thereby reduce the material wasted during machining operations, reduce lead time and raw material costs by reducing billet sizes, and enable production of a generic, simplified part by conventional methods with addition of specific details at a later time. Beside the raw material cost savings, there is an ease in handling smaller billets of raw feedstock and the by-products or scrap produced from a less-extensively machined part.
Furthering the Art and Science of Electron Beam Technology

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The Case for U.S. Manufacturing

Suggestions are offered on why it is necessary to keep manufacturing in the United States, and how to make that happen

By Emily Stover DeRocco

For a generation now, manufacturers have been fighting a negative perception in the United States about industry. So it comes as a shock to most people when you point out the facts:

- The United States is still the largest manufacturer in the world, producing more than 20% of the world's goods, a figure that has barely changed in 25 years;
- Foreign manufacturers are moving their operations to the United States, increasing their direct investments by more than 500% in the last 20 years;
- Manufacturing now accounts for nearly 60% of all U.S. exports, providing a valuable source of external wealth; and
- There are still more than 280,000 manufacturing firms in this country employing nearly 12 million Americans.

Even with these facts in hand though, there is almost an air of inevitability and resignation around our loss of manufacturing jobs and the disappearance of our industrial base. It truly astounds me, because for all the attention, money, and political power that other industries have accumulated, I believe manufacturing is still the single most important industry in this country.

The first and most basic of reasons for this is national security. The people of any country must produce the tools needed to defend themselves; otherwise, they are at the mercy of whichever country provides them those tools. This was never an issue in the past. In fact, American manufacturing used to be known as the “arsenal of democracy.” We produced the ships, tanks, and planes that effectively ended imperialism, fascism, and communism and shaped the world as we know it.

The enemy is different today and so are the tools, but we still must make the drones, satellites, and laptops that enable our soldiers to dominate the battlefield. If these high-tech weapons are not American made, then we increase the risks for our servicemen and women while putting our future ability to produce and control the tools of battle in jeopardy.

Just as our national security depends upon manufacturing, so too does our economic security. At its foundation, all economic activity is based on the process of adding value. Successful economies are those that can take raw materials and transform them into something more valuable.

Raw materials are usually thought of as basic elements like iron or silicon or copper, but they can also be ideas. In either case, the first step in transforming those raw materials is manufacturing. It is what makes everything else possible. The value of bankers, or consultants, or lawyers is entirely dependent on what someone else makes. In today’s terms, we call this a multiplier effect. For manufacturing, the value it creates is 140% of its investment — Fig. 1. No other economic sector even comes close.

What Other Countries Are Doing

Unfortunately, the economic importance of manufacturing is not a secret that only we possess. Nearly every other country in the world is zealously pursuing the manufacturing industry. For example:

- Germany, who has long been viewed as the world leader in craftsmanship, has structured much of its society to support manufacturing. From its extensive vocational schools, where children are essentially channeled into industry, to its export-dominated view of economic growth, Germany is a country built for manufacturing;
- China is still in the process of building its economy, but it is clear that manufacturing is the top priority. Its system has included a steady supply of labor moving from the inland to the coastal manufacturing centers, a currency peg to keep its exports to the West stable and growing, and a massive government effort to attract western firms to build plants in China;
- Even India, which has mostly been associated with the growth of offshore IT and back-office operations, is now pursuing manufacturing. Nearly all of the major car companies in the world are building what the Wall Street Journal called a “New Detroit” in southern India.

Then there are the other first-world Asian economies like Japan, South Korea, and Taiwan, which in addition to strong overall manufacturing sectors, are creating world-class clusters in high-end markets like semiconductors and electronics.

And, finally, there is the growth of other low-cost labor centers in Asia like Vietnam and Indonesia. Each of these countries is now going to great lengths to develop its manufacturing sector.

One of the consequences of this worldwide focus on manufacturing is that the demand for all things related to the industry has soared. This has driven up the costs of everything from the raw materials re-

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This article is based on a presentation made at the Edison Welding Institute/American Welding Society Conference on Trends in Materials Joining held August 3, 2010, in Newark, Ohio.
quired to produce goods, to the energy needed to run plants, to the shipping rates on trucks and freighters. Even in the midst of a recession, when consumer demand is well below traditional levels, the cost to produce products is increasing.

**Changing the Educational System**

The challenge that U.S. manufacturers face is to continue producing high-performance products while maintaining reasonable costs. This is becoming increasingly difficult using traditional business processes.

For the last 25 years, the concept of “lean” manufacturing has provided a way for firms to meet the cost challenge. Indeed, most of the manufacturing business processes have been studied and dissected by consultants, authors, and MBA students, and efficiency models are available for most of those processes. But one area has received very little scrutiny — human resources.

Human resource departments are one of the last places where our fathers and even our grandfathers would recognize the operations. We post positions on job boards, wait for applications to come in, select the best — though how we select them is more art than science — and then send these new hires to a training program while they simultaneously learn on the job.

It is a slow process that costs companies significant resources in terms of HR staffing, employee productivity, and workforce consistency and certainty. And given the demographic challenges that we will all soon face, the time is right for manufacturers to rethink how we approach human resources and get ahead of what is going to be an economy-wide competition for talent. Young people today want to contribute immediately, know the value of their work, and see clear paths to promotion and greater earnings. More than any other industry, manufacturing can provide that opportunity.

Manufacturers now have a unique chance to create and shape a reliable supply chain for their workforce just as they would for the rest of their business needs. To help meet this challenge, The Manufacturing Institute has created a system designed to build the pipeline of qualified workers and remove some of the uncertainty and costs associated with hiring new workers.

To develop our solution, called the National Association of Manufacturers (NAM)-Endorsed Manufacturing Skills Certification System, we joined with several other leading industry groups last year to create a system of nationally portable, industry-recognized credentials. These credentials — and the training required to obtain them — certify that an individual possesses the basic skills required to work in any sector of the manufacturing industry. This certification system is designed to be integrated into high school and community college degree programs of study.

This system can be envisioned as a pyramid of skills certifications. The initial focus is on the following skills, which are required for all entry-level jobs in manufacturing today:

- Personal effectiveness skills.
- Foundational academic competencies. For manufacturers, those are applied math, reading, and locating and using information.
- General workplace competencies that cover the fundamentals of business.
- The industry-wide technical skills related to basic manufacturing processes including production, logistics, quality assurance, safety and health, and technology.

The foundational competencies in the first tiers are grounded in ACT's National...
Career Readiness Certificate. Manufacturers believe every student should graduate from high school ready for work and ready to pursue additional education and training.

For the welding and broader materials joining industries, the set of technical skills credentials includes the American Welding Society’s Certified Welder series. These are skills that span across many types of manufacturing.

In addition to the Certified Welder credentials, the Manufacturing Skill Standards Council’s Certified Production Technician, and the National Institute for Metalworking Skills’ Machining and Metalforming certifications. Finally, the Society of Manufacturing Engineers’ Engineering Technologist certification caps our entry-level skills system, recognizing the infusion of technology into all manufacturing processes.

These stackable credentials have been organized, aligned, and translated into corresponding educational levels — Fig. 2. We are now developing version 2.0 of the Skills Certification System that will define and credential the higher-level skills required for positions in each of the 14 distinct sectors of Advanced Manufacturing.

Today, 25 states are in the process of implementing or strategically planning implementation of this system. The Bill & Melinda Gates Foundation and the Lumina Foundation have provided The Manufacturing Institute with significant resources to conduct a deep dive into five states where their community colleges are aggressively aligning their educational and industry certification pathways.

Ohio is one of those states and Lorain County Community College outside of Cleveland is where we are initially implementing this solution. Figure 3 illustrates Lorain’s educational pathway in welding.

While, on its face, the idea of a skills certification system may not seem transformational, it is in fact reforming education. The integration of nationally portable, industry-recognized credentials into degree programs will ensure the “product” from our educational system has real value in the workplace. These credentials greatly reduce the risk associated with hiring new employees — a decision I’ve heard manufacturers describe as “a million dollar bet” when the total expected investment in that worker is calculated.

The credentials will also help to professionalize our careers, give workers a defined education path to advancement within a company, and provide the security of a national industry certification that validates their skills for future employers.

But, focusing on the workforce does more than simply reduce the costs of your HR operation or provide some certainty in hiring: It helps U.S. firms maintain their performance edge.

Continuously producing high-value goods is not an easy process because, as you know, once a product has been on the market, competitors and imitators can find ways to make it for less. It requires the thing that manufacturers are telling us they strive for above all else: innovation.

Innovation has become the new catch-all term for finding and implementing the means to push the envelope and create new things with even greater value. But here’s the thing about innovation: There is no manual or formula that can make a machine innovate. It is almost entirely a human process. By increasing the overall quality of the workforce, manufacturers can increase their capacity to innovate and improve their ability to produce high-performance products.

Of course, innovation does not always happen spontaneously, so The Manufacturing Institute is also taking steps to create the support structure that can accelerate innovation in U.S. firms. These steps include the following:

1. Examining ways to expand the Application Service Center model demonstrated by Edison Welding Institute and the Fraunhofer USA centers to allow more small- and medium-sized manufacturers access to capital intensive equipment and labor;

2. Developing a partnership between the National Science Foundation and The Manufacturing Institute to place new technologies developed under their Small Business Innovation Research (SBIR) grants into existing manufacturers, creating a market for those technologies while providing smaller manufacturers with access to cutting-edge technology;

3. Supporting a group of land grant and state universities as they engage in regional economic development activities. Called Transformative Regional Engagement, this group is hoping to make the resources, research, and intellectual property of the universities available to area manufacturers to build clusters and regional economies in their states.

What our efforts in both innovation and the workforce have in common are that manufacturers cannot do it by themselves. Educational institutions at all levels must partner with industry if we are going to produce both the technical and engineering talent that our sector demands.

And the time is right to engage these institutions. Tighter state budgets are starting to dramatically impact their old revenue models. We can offer a different approach that leads to the attainment of a credential in less time and with a greater value in the workplace. Working with manufacturers can also more quickly move research from mind to market, increasing the value of university facilities and intellectual property.

The Need for Government Involvement

But perhaps the most important partner necessary to maintain a broad and strong manufacturing sector is the federal government.

There is a growing consensus in Washington regarding the need for a national innovation agenda. Several papers have appeared from some prominent think tanks, organizations, and corporate executives questioning the lack of a national manufacturing policy and proposing some
major steps to refocus the federal government on the manufacturing industry. For example, there are more than a dozen national laboratories focused on energy. Why can’t there be one that is specifically dedicated to R&D as it pertains to manufacturing? And what about the Manufacturing Extension Partnership, a very important program in theory that in practice is underfunded and prone to inconsistent services.

The idea of industrial policy has always been toxic in this country, and for good reason. But we must recognize that every other important country in the world is investing heavily in the manufacturing sector. And while we don’t want to pick winners and losers from Washington, we should seriously consider whether it is time to build a stronger infrastructure and strategies for manufacturing that allow more winners to emerge.

Unfortunately, none of this will matter if we continue to raise the cost of doing business in this country. It is these structural costs that threaten to choke off our economic recovery and push more production overseas.

Our most recent cost study shows U.S. manufacturing at a 17.6% cost disadvantage compared to our primary trading partners. At a time when manufacturing is facing unprecedented cost pressures from overseas, Congress has passed and is still considering several pieces of legislation that will dramatically increase the cost of doing business. I think it is fair to say that these are exactly what manufacturing does not need at this time.

The first and most obvious of these actions is health care. The Manufacturing Institute’s view has been that health care reform should first and foremost deal with the long-term cost structure that has led to a more than 100% increase in premiums over the last decade. This includes a focus on preventative care, proper implementation of health information technology, and alignment of incentives so that successful outcomes are rewarded.

Reasonable people can debate the changes we need in our health care system, but saddling employers with the costs of those changes is certainly not going to encourage them to hire new workers. And as manufacturers have to pass much of those costs on to consumers, it is going to make us less competitive against overseas competition.

The next is efforts by the Environmental Protection Agency to regulate carbon. If the United States is going to engage in serious efforts to reduce carbon dioxide emissions, the only way to do so is to dramatically increase the cost of energy. If this is done in concert with the rest of the world — and after all, climate change is a global concern — then there is no cost to our competitiveness. In fact, we may even benefit because of our ability to discover and implement creative new technologies.

But if over half the world’s population in East Asia and the sub-continent does not participate in emissions reduction, then we are simply adding a major new tax on business that will further encourage the offshoring of production without having any real impact on emissions.

What is important is promoting a national energy strategy that uses oil, natural gas, nuclear, and renewable energies together to meet our energy needs along with strong conservation and efficiency efforts to reduce costs and environmental impacts.

Couple these bills with the push for card check legislation and the lack of movement on free trade agreements, and Washington has created an environment of uncertainty and a potential for major increases in structural costs. This makes business very difficult, particularly for small- and mid-sized manufacturers already operating with razor thin margins.

Finally, let me return to why I believe manufacturing is critical to this country’s economic future. A common call from across the political spectrum is for greater investment in research and development in this country. But what most people envision here are scientists in white lab coats conducting research. What they fail to grasp is that the development part of R&D is often more critical than the research. It is in development where ideas are tested, refined, and tested again. And it is through development, and ultimately manufacturing, where ideas are commercialized and made into products.

A recent U.S. Commerce Department study aimed to understand the interdependence between research and development. What it found was that rather than manufacturing clustering around research, the opposite was occurring. Once a region or a country lost its development and production capabilities, its research soon followed because they were unable to use facilities to test and refine their work.

The message was pretty clear: Countries that allow their manufacturing sector to disappear in favor of the higher-end research and design functions, end up losing both.

The National Association of Manufacturers has released a policy roadmap titled Manufacturing Strategy for Jobs and a Competitive America. It details the policies and actions needed to make the United States the best country in the world for manufacturing goods, conduct research and development, and headquarter a company. We encourage the new Congress and the many new governors to take the steps needed to keep America manufacturing.
**COMING EVENTS**

**NOTE: A DIAMOND (♦) DENOTES AN AWS-SPONSORED EVENT.**


♦ JOM-16, 16th Int’l Conf. on the Joining of Materials and ICEW-7, 7th Int’l Conf. on Education in Welding. May 10–13. Lo-Skolens Conf. Center and Hotel, Helsignger, Denmark. Contact JOM Institute, Gilleleje, Denmark. Phone +45 48 35 54 58; jom_aws@postl0.tele.dk.

♦ AWS Weldmex. May 11–13, Cintermex, Monterrey, Mexico. Colocated with FABTECH Mexico and MetalForm Mexico. See the latest welding and cutting products, thermal spray, metal finishing and safety equipment, metalforming products, tool and...
die, metal stamping, forming and assembly, and a variety of bending and fabrication products, including laser and plasma cutting, coil processing, roll forming, plate and structural fabricating, saws and cut-off machines, rolling, press brakes, shears, punching, and tube and pipe equipment. Visit www.awsweldmex.com.


Educational Opportunities

Art Using Welding Technology Classes and Workshops. Miami, Fla. With artist and sculptor Sandra Garcia-Pardo. Meet the artist at www.sandragarciaart.com; or call (786) 547-8681.

CWI/CWE Preparation with Exam. AWS Certified Welding Inspector and AWS Certified Welding Educator, two-week-long classes beginning Jan. 17, Feb. 21, April 4, May 9, June 13, July...
Automotive Body in White Training for Skilled Trades and ASM Int'l Courses. Numerous classes on welding, corrosion, failure analysis, metallography, heat treating, etc., presented in Materials Park, Ohio, online, webinars, on-site, videos and DVDs. Visit www.asminternational.org, search for “courses.”


Boiler and Pressure Vessel Inspectors Training Courses and Seminars. Columbus, Ohio. Call (614) 888-8320 or visit www.nationalboard.org.

CWI/CWE Course and Exam. Troy, Ohio. This is a two-week preparation and exam program. For schedule, call Hobart Institute of Welding Technology (800) 332-9448, or visit www.welding.org.

CWI/CWE Prep Course and Exam and NDT Inspector Training. Courses. An AWS Accredited Testing Facility. Courses held year-round in Allentown, Pa., and at customers’ facilities. Call Welder Training & Testing Institute (800) 223-9884, info@wtti.edu; or visit www.wtti.edu.

CWI Preparatory and Visual Weld Inspection Courses. Classes presented in Pascagoula, Miss., Houston, Tex., and Houma and Sulphur, La. Call Real Educational Services, Inc. (800) 489-2890, info@realeducational.com.

Consumables: Care and Optimization. Free online e-courses presenting the basics of plasma consumables, designed for plasma operators, distributor sales and service personnel, etc. Visit www.hyperthermcuttinginstitute.com.

Crane and Hoist Training. Safety courses and operator training for users of overhead cranes and hoists. For schedules, contact Konecranes Training Institute, Springfield, Ohio; call (262) 821-4001; or visit www.konecranesamericas.com.

EPRI NDE Training Seminars. EPRI offers NDE technical skills training in visual examination, ultrasonic examination, ASME Section XI, and UT operator training. Call Sherryl Stogner (704) 547-6174, e-mail stogner@epri.com.

Environmental Online Webinars. Free, online, real-time seminars conducted by industry experts. For topics and schedule, visit www.augustmack.com.

Essentials of Safety Seminars. Two- and four-day courses are held at numerous locations nationwide to address federal and California OSHA safety regulations. Call American Safety Training, Inc. (800) 896-8867, or visit www.trainosha.com.


Firefighter Hazard Awareness Online Course. A self-paced, ten-module certificate course taught online by fire service professionals. Fee is $195. Call Industrial Scientific Corp. (800) 338-3287, or visit www.indsci.com.

Gas Detection Made Easy Courses. Online and classroom courses for managing a gas monitoring program from gas detection to confined-space safety. Call Industrial Scientific Corp. (800) 338-3287, or visit www.indsci.com.

Hellier NDT Courses. Hellier, 277 W. Main St., Ste. 2, Niantic, CT 06357; (860) 739-8950, FAX (860) 739-6732.

Inspection Courses on ultrasonic, eddy current, radiography, dye penetrant, magnetic particle, and visual at Levels 1–3. Meet SNT-TC-1A and NAS-410 requirements. Call TEST NDT, LLC, (714) 255-1500, or visit www.testndt.com.

INTEG Courses. Various courses for individuals seeking certification in nondestructive testing disciplines accredited by Natural Resources Canada to meet certifications to Canadian General Standards Board or Canadian Nuclear Safety Commission. Call The Canadian Welding Bureau, (800) 844-6790, or visit www.cwbgroup.org.


Laser Safety Training Courses. Courses based on ANSI Z136.1, Safe Use of Lasers, presented in Orlando, Fla., or at customer’s site. Call Laser Institute of America, (800) 345-3737, or visit www.laserinstitute.org.


NACE Int'l Training and Certification Courses. Call National Assoc. of Corrosion Engineers (281) 228-6223, or visit www.nace.org.

NDE and CWI/CWE Courses and Exams. Allentown, Pa., and at customers’ locations. Call Welder Training and Testing Institute, (800) 223-9884, or visit www.wtti.edu.

— continued on page 107
**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)

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<th>EXAM DATE</th>
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### 9-Year Recertification Seminar for CWI/SCWI

For current CWIs and SCWs needing to meet education requirements without taking the exam. The exam can be taken at any site listed under Certified Welding Inspector.

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### Certified Radiographic Interpreter (CRI)

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

### Certified Welding Sales Representative (CWSR)

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<td>Aug. 26</td>
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CWSR exams will also be given at CWI exam sites.

### Certified Welding Educator (CWE)

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

### Certified Robotic Arc Welding (CRAW)

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<tr>
<td>Feb. 7</td>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>(248) 391–8421</td>
</tr>
<tr>
<td>Feb. 14</td>
<td>Genesis–Systems, Davenport, IA</td>
<td>(563) 445–5688</td>
</tr>
<tr>
<td>Feb. 28</td>
<td>Lincoln Electric Co., Cleveland, OH</td>
<td>(216) 383–8542</td>
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<tr>
<td>March 7</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>(970) 225–7736</td>
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<td>April 25</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>(970) 225–7736</td>
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<td>May 2</td>
<td>ABB, Inc., Auburn Hills, MI</td>
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<td>Genesis–Systems, Davenport, IA</td>
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<td>Wolf Robotics, Ft. Collins, CO</td>
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<td>ABB, Inc., Auburn Hills, MI</td>
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### International CWI Courses and Exams

Please visit www.aws.org/certification/inter_contact.html

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**Important:** This schedule is subject to change without notice. Please verify your event dates with the Certification Dept. and confirm your course status before making your travel plans. For information, visit www.aws.org/certification, or call (800)705-443-9353, ext. 273, for Certification; or ext. 455 for Seminars. Apply early to avoid paying the Fast Track fee.
Q: We have a contract that requires us to produce a number of complete joint penetration fillet welds in ½-in.-thick 310 stainless steel plates. We first tried 0.045-in. flux cored E310T0-1 electrodes with CO₂ shielding gas, but the welds continually contained severe centerline cracking. After several attempts to put in the root pass failed, we tried E310T0-16 covered electrodes. Now we were able to put in the root pass with ⅞-in. electrodes, but attempts to complete the joints with ⅛-in. electrodes again resulted in centerline cracking. If we have to complete the joints with ⅛-in. electrodes, the time involved will be prohibitive. What can we do?

A: The nominal composition of 310 weld metal is 25% Cr, 20% Ni. The root of the problem is that this 310 weld metal (and base metal) composition is fully austenitic. Because it solidifies as 100% austenite, it is inherently susceptible to centerline solidification cracking. But “susceptible” does not mean that cracking is unavoidable.

There are several factors that can mitigate the tendency for cracking. One is to reduce restraint, but your restraint situation is governed by the requirement for complete joint penetration and the ½-in. thickness. Partial joint penetration may provide some reduction in the cracking tendency, and you could explore whether complete joint penetration is really required by your customer.

You have already discovered that small-diameter electrodes (low heat input) provide some relief from the cracking tendency. But there are at least three other things you can do to improve cracking resistance. Shielded metal arc welding (SMAW) with covered electrodes is well known as a way to mitigate solidification cracking tendencies. The E310-15 classification is better in this respect than the E310-16 that you have used.

The -15 coating type, normally formulated with large quantities of the minerals fluor spar (CaF₂) and marble (CaCO₃), produces metallurgically cleaner weld metal than the -16 coating type, normally formulated with large quantities of the mineral rutile (TiO₂). Both CaF₂ and CaO are metallurgically basic slag components, while TiO₂ is metallurgically acidic.

In addition, the -15 coating tends to produce convex bead profiles that are inherently more resistant to solidification cracking than the flat to slightly concave bead profile of the -16 coating. The convex shape of the -15 coating acts somewhat like the riser in a casting that supplies additional liquid metal to the solidifying weld centerline. It also produces a thicker weld throat than the -16 coating, which helps resist solidification cracking.

The -15 coating type has become largely the “forgotten man” among filler metal producers and fabricators. I think this is in part due to the tendency for a convex bead shape that welders think is ugly; however, this “ugly” bead shape is actually beautiful when there is a tendency for solidification cracking. It is in part also due to the harsher arc sound and more globular metal transfer that the -15 coating produces, along with coarser surface ripple and more spatter, than the -16 coating tends to produce.

Furthermore, the -15 coating type is generally limited to use with direct current electrode positive (DCEP) current, while the -16 coating type is equally usable with AC as well as with DCEP. The only welders who prefer the -15 coating type are pipe welders because the -15 coating type generally permits welding uphill without weaving. You will have to search for suppliers of E310-15 electrodes because many electrode producers do not produce this classification.

The second thing you can do, if you have the luxury of choosing from among more than one lot of electrodes, is to select from among the available lots those with the lowest total of sulfur and phosphorus. These two elements are notorious for their tendency to encourage solidification cracking in fully austenitic stainless steel weld metals.

Normally, low sulfur is easy to achieve in stainless steel weld metal because modern steel-making methods like argon-oxygen decarburization (AOD) tend to remove sulfur from the liquid metal. But low phosphorus is much more problematic because these same steel-making methods tend to not remove phosphorus. The AWS A5.4 specification (Ref. 1) sets maximum allowable sulfur and phosphorus at 0.03% each, or a total of 0.06% (actually 0.07% with rounding off rules applied to each element individually). However, experience teaches us that limiting the total P+S to 0.025%, or even less, produces much better resistance to solidification cracking in fully austenitic stainless steel weld metal.

The third thing you can do, again if you have the luxury of choosing from among more than one lot of electrodes, is to select from among these lots those with carbon content in the range of 0.08 to 0.15%.

Many technical reports from the BC (before computers) era tend to be overlooked nowadays. A report by Campbell and Thomas (Ref. 2), published in 1946, looks at a number of composition factors in 310 weld metal and comes to the above conclusions about the -15 coating type vs. the -16 coating type, about low sulfur and phosphorus, and about an optimum carbon range. You would do well to examine that report.

You should not be restricted to the ⅛-in. (2.4-mm) electrode diameter to successfully produce the complete joint penetration fillet welds in 310 stainless steel. You should be able to use at least the ⅝-in. (3.2-mm) and ⅜-in. (4.0-mm) sizes without solidification cracking issues if you follow the above suggestions. It will be essential to restrict welding to stringer beads, and to fill craters before breaking the arc, for optimum resistance to solidification cracking.

References

BY DAMIAN J. KOTECKI

Q&A

Dear Readers:

The Welding Journal encourages an exchange of ideas through letters to the editor. Please send your letters to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. You can also reach us by FAX at (305) 443-7404 or by sending an e-mail to Kristin Campbell at kcampbell@aws.org.
High Energy Beam Welding Standards and Featured Publications

Recommended Practices for Electron Beam Welding

Recommended Practices for Laser Beam Welding, Cutting, and Drilling

Standard Welding Terms and Definitions
Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying
**Beam Welding Standards**

**C7.1M/C7.1:2004, Recommended Practices for Electron Beam Welding**

Presents descriptions of electron beam welding equipment and procedures for welding a wide range of similar and dissimilar metals and thicknesses. Includes sections on safety, process fundamentals, equipment and maintenance, metallurgical and general process considerations, inspection and testing of welds, training and qualification of operators, weld process and procedure development, practical examples, and power curves for various alloys. 128 pages, 64 figures, 11 tables, (2004).

*Price: $92/$69*

**NEW EDITION: C7.2M:2010, Recommended Practices for Laser Beam Welding, Cutting, and Allied Processes**

Covers common applications of the process, including drilling and transformation hardening. Describes equipment and procedures. Practical information, including figures and tables, should prove useful in determining capabilities in the processing of various materials. 142 pages, 85 figures, 8 tables, (2010).

Order Code: C7.2

*Price: $100/$75*


Sister publication to C7.1, Recommended Practices for Electron Beam Welding, this standard discusses applicable specifications, safety, requirements, fabrication, quality examination, equipment calibration and maintenance, approval, and delivery of welds. Includes sample WPS and PQR forms, as well as a Nondestructive Evaluation Discontinuity Limits chart. 18 pages. (Reaffirmed 2003). C7.3

*Price: $49/$36*


Covers processing and quality control requirements for laser beam welding, 34 pages, 1 table. (2008).

*Price: $56/$42*

---

**Structural Steel Welding Standards**

**D1.1/D1.1M:2010, Structural Welding Code—Steel**

For everyone involved in any phase of welding steel structures—engineers, detailers, fabricators, erectors, inspectors, etc.—the new D1.1 spells out the requirements for design, procedures, qualification, fabrication, inspection, and repair of pipe, plate, and structural shapes that are subject to either static or cyclical stresses. U.S. Customary and SI units of measurement. 570 pages, 21 annexes, 171 figures, 78 tables, (2010).

*Price: $496/$372*


Covers arc welding of structural sheet/strip steels, including cold formed members, equal to or less than 3/16 in. (0.188 in./4.8 mm) nominal thickness and having a minimum specified yield point no greater than 80,000 psi (550 MPa). Applicable to welding of commonly used structural quality low-carbon hot rolled and cold rolled sheet and strip steel, with or without zinc coating (galvanized), to other structural steel sheets or to supporting structural steel members. Three weld types unique to sheet steel—arc seam, arc plug, and arc spot welds—are included. Includes sections on design, procedure and performance qualification, fabrication, inspection and stud welding as well as a commentary. 98 pages, 7 annexes, 44 figures, 11 tables, 3 forms (2008).

*Price: $120/$90*

**NEW EDITION: D1.4/D1.4M:2011, Structural Welding Code—Reinforcing Steel**


*D1.4

*Price: $116/$87*

**D1.5M/D1.5:2010, Bridge Welding Code**

Get the facts and code requirements for bridge building with carbon and low-alloy construction steels. Covers welding requirements of the American Association of State Highway and Transportation Officials (AASHTO) for welded highway bridges made from carbon and low-alloy construction steels. Chapters cover design of welded connections, workmanship, technique, procedure and performance qualification, inspection, and stud welding. Features the latest AASHTO revisions and nondestructive examination requirements, as well as a section providing a “Fracture Control Plan for Nonredundant Bridge Members.” Revisions include:

- Revised procedure, personnel, and test equipment inspection requirements
- New materials and hybrid joint provisions
- New guidance on electron beam and narrow-gap ESW

Approx. 456 pages, 17 annexes, 90 figures, 43 tables, 9 forms, commentary (2010). D1.5

*Price: $328/$246*

**D1.6/D1.6M:2007, Structural Welding Code—Stainless Steel**

Covers requirements for welding stainless steel structural assemblies/components (excluding pressure vessels or pressure piping) using gas metal arc welding, shielded metal arc welding, flux cored arc welding, submerged arc welding.

*Price: $48/$36*

---

**STRUCTURAL BUNDLES**

Save a bundle when you buy an AWS structural standards. Get 15% OFF the individual standards’ purchase prices.

**Bundle A:2011**

- D1.1/D1.1M:2010, Structural Welding Code—Steel
- A2.4:2007, Standard Symbols for Welding, Brazing, and Nondestructive Examination
- A3.0M/A3.0:2010, Standard Welding Terms and Definitions

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**BUNDLE A:2011**

*Price: $687/$515*

**Bundle B:2011**

- D1.1/D1.1M:2010, Structural Welding Code—Steel
- D5/D5M:2010, Bridge Welding Code

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**BUNDLE B:2011**

*Price: $1,241/$931*

**Bundle C:2011**

- A2.4:2007, Standard Symbols for Welding, Brazing, and Nondestructive Examination
- D5/D5M:2010, Bridge Welding Code

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**BUNDLE C:2011**

*Price: $405/$303*

**Bundle D:2011 (Seismic Bundle)**

- D1.1/D1.1M:2010, Structural Welding Code—Steel

**INDIVIDUAL PRICE**

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<td><strong>Total</strong></td>
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**BUNDLE D:2011**

*Price: $533/$400*

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and stud welding. Allows prequalified Welding Procedure Specifications for the austenitic stainless steels based on considerable experience with the most widely used stainless steels. Sections include design, procedure and performance qualification, fabrication, inspection, and stud welding. 292 pages, 14 annexes, 80 figures, 29 tables, (2007). D1.6 $200/$150

D1.7/D1.7M:2010, Guide for Strengthening and Repairing Existing Structures

Provides engineers and contractors with general direction and guidance on weld repairs, weld strengthening, and other procedures to correct problematic issues with existing structures made of steel (minimum yield strength of 100 ksi and minimum thickness of 3/8 inch), cast iron, and wrought iron. 52 pages, 4 tables, (2009). D1.7 $108/$81

D1.8/D1.8M:2009, Structural Welding Code—Seismic Supplement

A supplement to AWS D1.1, Structural Welding Code—Steel. Applicable to welded joints in seismic load resisting systems designed in accordance with the Seismic Provisions of the American Institute of Steel Construction, Inc. Covers additional controls on detailing, materials, workmanship, testing, and inspection necessary to achieve adequate performance of welded steel structures under conditions of severe earthquake-induced inelastic straining. Includes a commentary offering guidance on interpreting and applying this supplement. 124 pages, 9 annexes, commentary, 22 figures, 8 tables, (2009). D1.8 $132/$99

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These are the must-have references for engineers, structural designers, technologists, inspectors, welders, welding educators and others who need to understand this dynamic and evolving industry. Put all the facts at your fingertips and make sure you’re on the cutting edge with new and updated material. Here are five good reasons you should add these valuable editions to your library. The books represent:

• The largest body of knowledge on welding available anywhere.
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• Unparalleled authority—chapters are written by leading scientists, engineers, educators, and other technical and scientific experts. Everything is peer-reviewed for accuracy and timelines.
• The most valuable resource on welding on the market today, covering the entire spectrum of welding from science and technology, history, welding processes, and materials and applications.

Ninth Edition, Volume 1, Welding Science and Technology

Presents the latest developments in the basic science and technology of welding, and general descriptions of processes, continues with chapters on the physics of welding and cutting; heat flow; welding metallurgy; design; test methods; residual stress; welding symbols; testing and positioning; monitoring and control; mechanized, automated, and robotic techniques; economics; weld quality; inspection; qualification and certification; welding codes and standards; and safe practices. 932 pages, 17 chapters, 2 appendices, 530 illustrations, 168 tables, hardbound. 8” x 10”, (2001). WHB-1.9 $192/$144


Presents comprehensive information on welding and related processes. Contains detailed information on arc welding, power sources; shielded metal arc; gas tungsten arc; gas metal arc; flux cored arc; submerged arc; and plasma arc welding processes. Includes chapters on electrodes, welding; stud welding; oxyacetylene; brazing; flux; isolating; oxygen cutting; and cutting and gouging; 736 pages, 15 chapters, 260 line drawings, 100 photographs, 148 tables, hardbound. 8” x 10”, (2004). WHB-2.9 $192/$144


Over 600 pages of comprehensive information on solid-state and other welding and cutting processes. The book includes chapters on resistance spot and seam welding, projection welding, flash and upset welding and high-frequency welding. In addition to a chapter on friction welding, a new chapter introduces friction stir welding. The most recent developments in beam technology are discussed in the greatly expanded chapters on laser beam welding and cutting and electron beam welding. A diverse array of processes are presented in chapters on the ultrasonic welding of metals, explosion welding, diffusion welding and diffusion brazing, adhesive bonding and thermal and cold spraying. The last chapter covers various other welding and cutting processes, including modernized water jet cutting, 669 pages, 15 chapters, 3 appendices, 438 illustrations, 59 tables, hardbound. 8” x 10”, (2007). WHB-3.9 $192/$144


Extensively revised and updated from the eighth edition, this comprehensive volume had more than 50 experts in materials and materials applications assure its accuracy and the currency of its content. It is a great reference source for engineers, educators, welding supervisors, and welders. Covers carbon and low-alloy steels; high-alloy steels; coated steels; tool and die steels; stainless and heat-resistant steels; clad and dissimilar metals; surfacing; cast iron; maintenance and repair welding; underwater welding and cutting. Includes more than 500 tables, charts, and photos. 10 chapters, hardbound. 8” x 10”, (2010). WHB-4.9 $192/$144


Covers nonferrous metals, plastics, composites, and ceramics; specialized topics on maintenance and repair welding; underwater welding and cutting. Includes applications of the specific metals and processes, weldability, safety practices. Best copy available, 536 pages, 10 chapters, softbound. 8” x 10”, (1996). WHB-3.8 $160/$120

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A2.4:2007, Standard Symbols for Welding, Brazing, and Nondestructive Examination
Establishes a method of specifying certain welding, brazing, and nondestructive examination information by means of symbols. Contains detailed information and examples for the construction and interpretation of these symbols. This system provides a means of specifying welding or brazing operations and nondestructive examination, as well as the examination method, frequency, and extent. 128 pages, (2007). $148/$111

A3.0M/A3.0:2010, Standard Welding Terms and Definitions
Alphabetical glossary of over 1,400 standard terms and definitions for welding, brazing, soldering, resistance welding, etc., as well as hybrid processes. Each term has one clearly applicable definition, accurately reflecting the term’s use in the joining world. Includes figures to illustrate the use of terms. For completeness, nonstandard terms are also included. Contains a Master Chart of Welding and Allied Processes, and the Joining Method Chart. 160 pages, 62 figures, 5 tables (2010). $164/$123

Addresses which examination method — visual, liquid penetrant, magnetic particle, radiographic, ultrasonic, electromagnetic (eddy current), or leak testing — best detects various types of discontinuities. Note: Does not address acceptance criteria. 64 pages, 30 figures, 4 tables, (2009), fourth edition. $104/$78

B1.11:2000, Guide for the Visual Examination of Welds
Provides guidance on visual examination of welds, including sections on prerequisites, fundamentals, surface condition, and equipment. Sketches and color photographs illustrate common weld discontinuities. 48 pages, 3 annexes, 48 figures, (2000). $104/$78

Covers all fusion welding processes and an exhaustive array of materials used in metal fabrication. Specifies requirements for the qualification of welding procedures, and for performance qualification of welders and welding operators for manual, semiautomatic, mechanized, and automatic welding. 298 pages, 43 figures, 25 tables, 5 forms (2009). $216/$162

B4.0:2007, Standard Methods for Mechanical Testing of Welds
Describes the most common mechanical test methods applicable to welds and welded joints. Each test method gives details concerning specimen preparation, test parameters, testing procedures, and suggested report forms. Acceptance criteria are not included. Three new weldability tests (WIG, tung, and GBOG) and resistance weld tests have been included in this new edition. (Note: Joint tests for brazements are covered in AWS A2.4M/A2.4:2010, U.S. Customary Units. 152 pages, 97 figures, (2007). $104/$78

D1.2/D1.2M:2008, Structural Welding Code—Aluminum

NEW EDITION! D3.6M:2010, Underwater Welding Code
Covers the requirements for the underwater welding of structures or components in wet and dry environments at one-atmosphere and ambient atmospheres. Includes qualification and inspection requirements. CALL FOR PRICE

Covers arc and brazing welding requirements for nonstructural sheet metal fabrications using commonly welded metals available in sheet form up to and including 3 gauge, or 6.4 mm (0.250 in.). Applications of the code include heating, ventilating, and air conditioning systems, food processing equipment, architectural sheet metal, and other nonstructural sheet metal applications. Sections include procedure and performance qualification, workmanship, and inspection. Nonmandatory annexes provide useful information on materials and processes. Not applicable when negative or positive pressure exceeds 30 kPa (5 psi). 70 pages, 29 figures, 10 tables, (2006). $72/$54

Specifies requirements for welding of all principal structural weldments and all primary welds used to manufacture cranes for industrial, mill, powerhouse, and nuclear facilities. Also applies to other overhead material-handling machinery and equipment that support and transport loads within the design rating, vertically or horizontally, during normal operations. Additionally, when agreed upon between the owner and manufacturer, it may apply to loading caused by abnormal operations or environmental events, such as seismic loading. All provisions apply equally to strengthening and repairing of existing overhead cranes and material handling equipment. Contains figures and tables with prequalified joint details, allowable stress ranges, stress categories, and nondestructive examination techniques. Does not apply to construction or crawler cranes or welding of rails. 150 pages, 60 figures, 21 tables (2005). $104/$78

D17.1:2001, Specification for Fusion Welding for Aerospace Applications
Specifies general welding requirements for welding aircraft and space hardware. Includes fusion welding of aluminum-based, nickel-based, iron-based, cobalt-based, magnesium-based, and titanium-based alloys using arc and high energy beam welding processes. Includes sections on design of welded connections, personnel and procedure qualification, fabrication, inspection, repair of existing structures and nonflight hardware acceptance. Additional requirements cover repair welding of existing hardware. 94 pages, 5 annexes, commentary: 47 figures, 14 tables, (2001). $160/$120

This invaluable training reference helps inspectors, engineers, and welders evaluate the difference between discontinuities and unacceptable defects. 254 pages 18 chapters, index: 106 figures, 16 tables, 61/2" x 9", (2000), third edition. $76/$57

WIT-T:2008, Welding Inspection Technology
For at-home study, this official reference textbook for the three-day AWS core seminar for CWI exam preparation is readable, informative, and comprehensive. 329 pages, 10 chapters, 379 figures and photographs, (2008). $272/$204

Brazing Handbook
A comprehensive, organized survey of the basics of brazing, processes, and applications. Addresses the fundamentals of brazing, brazement design, brazing filler metals and fluxes, safety and health, and many other topics. Includes new chapters on induction brazing and diamond brazing. A must-have for all brazers, brazing engineers, and students. 749 pages, 36 chapters, 3 appendices, 308 figures, 116 reference tables, fifth edition, (2007). $136/$102

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Venue: Hotel Le Royal Meridian, Chennai

Conference Theme:
“Global trends in Joining, Cutting and Surfacing Technology”

&
6th International Welding Technology Exhibition
WELD INDIA 2011
21-23 July, 2011
Venue: Chennai Trade Centre

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- Manufacturers, Suppliers & Traders of welding consumables, welding & cutting equipment & automation products.
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Annual FABTECH International & AWS Welding Show
Chicago, IL - November 13-16, 2011

Submission Deadline: March 25, 2011
(Complete a separate submittal for each paper to be presented.)

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Answer the following about this paper

Original submittal? Yes □ No □  Progress report? Yes □ No □  Review paper? Yes □ No □  Tutorial? Yes □ No □

What are the welding/Joining processes used?
What are the materials used?
To what industry segments is this paper most applicable?
Has material in this paper ever been published or presented previously? Yes □ No □

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Is this a graduate study related research? Yes □ No □
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Keywords: Please indicate the top four keywords associated with your research below

Guidelines for abstract submittal and selection criteria:
- Only those abstracts submitted on this form will be considered. Follow the guidelines and word limits indicated.
- Complete this form using MSWord. Submit electronically via email to mventurat AWS.org

Technical/Research Oriented
- New science or research.
- Selection based on technical merit.
- Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes.
- Preference will be given to submittals with clearly communicated benefit to the welding industry.

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- Innovation in welding education at all levels.
- Emphasis is on education/training methods and their successes.
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Technical Approach, for technical papers only (100 words max.) – Explain the technical approach, experimental methods and the reasons why this approach was taken.

Results/Discussion (300 words max.) – For technical papers, summarize the results with emphasis on why the results are new or original, why the results are of value to further advance the welding science, engineering and applications. For applied technology and education papers, elaborate on why this paper is of value to the welding community, describe key aspects of the work developed and how this work benefits the welding industry and education.

Conclusions (100 words max.) – Summarize the conclusions and how they could be put to use – how and by whom.

NOTE: Abstract must not exceed one page and must not exceed the recommended word limit given above

Note: The Technical Program is not the venue for commercial promotions of a company or a product. All presentations should avoid the use of product trade names. The Welding Show provides ample opportunities for companies to showcase and advertise their processes and products.

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MUST BE RECEIVED NO LATER THAN MARCH 25, 2011
Friends and Colleagues:

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.

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:

- 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, 2011. The committee looks forward to receiving these nominations for 2012 consideration.

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee
AWS Elects National and District Officers for 2011

John L. Mendoza
president

The American Welding Society elected its incoming slate of national officers Nov. 2 during FABTECH, held in Atlanta, Ga. The officers take their posts on Jan. 1, 2011.

John L. Mendoza was elected president. Mendoza, a past District 18 director, is a Certified Welding Inspector, Certified Welding Educator, and a journeyman welder qualified to ASME Section IX in SMA and GTA welding. With 34 years of experience at CPS Energy, he is currently with Lone Star Welding in San Antonio, Tex.

William A. Rice Jr. was elected to his third term as a vice president. Rice serves as a part-time CEO for OKI Bering Supply, and is a member of the boards of trustees for several health and financial organizations in West Virginia. Rice worked for Airgas from 1993 to 2001, where he served as its president and COO. From 1971 to 1992, he was president of Virginia Welding Supply Co. and president of several other welding-related companies.

Nancy C. Cole has been elected to her second term as a vice president. She is an AWS Fellow, a Life Member, and a registered Professional Engineer in the state of Tennessee. She served as chair of the AWS Technical Activities, Fellows, and C3 Brazing and Soldering Committees. Cole has worked at ABB Combustion Engineering and, before forming her own company, she was program manager and contract manager at Oak Ridge National Laboratories.

Dean R. Wilson was elected to his first term as a vice president. He is vice president, welding business development, at Jackson Safety Products where he has worked since 2007. From 1987 to 2007, he served as president, CEO, and owner of Wilson Industries, Inc., in Pomona, Calif., a manufacturer of industrial safety-related products.

Nancy C. Cole
vice president

Director-at-Large
Tony Anderson

Tony Anderson was elected to his first term as a director-at-large. He currently serves as director of aluminum technology at ITW Global Welding Technology Center. Previously, he was corporate technical training manager for ESAB North America. He is an AWS Certified Welding Engineer, Certified Welding Inspector, and Certified Welding Educator. He has chaired a number of AWS technical committees on aluminum.

Reelected Director-at-Large
David L. McQuaid

David L. McQuaid was reelected to his second term as a director-at-large. He heads the consulting firm, D. L. McQuaid and Associates, Inc., which he founded in 1999. He has chaired the AWS D1 Structural Welding Committee and the Technical Activities Committee. At American Bridge Division of U.S. Steel Corp., he served as senior welding engineer and corporate applications engineer. In 2009, McQuaid was presented the American National Standards Institute (ANSI) Finegan Standards Medal for his outstanding work on standards.

Director-at-Large
Tony Anderson
vice president

David L. McQuaid
director-at-large
Harland W. Thompson  
District 2 director

Steve Mattson  
District 5 director

Joe A. Livesay  
District 8 director

Robert P. Wilcox  
District 11 director

Elected District 2 Director  
Harland W. Thompson

Thompson is senior project engineer and welding supervisor for Underwriters Laboratories (UL), Inc., in Melville, N.Y. He received his degrees in business management at Lyndon State College, and industrial engineering from the University of Vermont. Prior to joining UL in 2006, he worked in engineering and quality assurance positions at Belle Transit Div., Bohemia, N.Y.; the Long Island Rail Road; Breda Transportation, Inc., San Francisco, Calif.; Thompson Transit Services, Inc., Ronkonkoma, N.Y.; and LTK Engineering Services in Blue Bell, Pa.

Reelected District 5 Director  
Steve Mattson

Mattson began his career in the welding industry in 1986 after serving in the military. He started a welding equipment service and repair facility business in Jacksonville, Fla., that has operated for more than 20 years. Mattson has been active in the North Florida Section for more than 20 years where he has served in all executive positions. Currently, he serves as its chairman and secretary.

Reelected District 8 Director  
Joe A. Livesay

Livesay served in the U.S. Navy as a hull technician, then continued his studies at Tennessee Technological University and worked as a welder at the Hartsville, Tenn., nuclear power plant, a fitter-welder in Louisiana offshore operations, and 13 years at Crossville Ceramic. An AWS Certified Welding Educator, he taught evening welding classes at the Tennessee Technology Center. He has been active in AWS and has helped implement the welding accreditation program for the state of Tennessee.

Elected District 11 Director  
Robert P. Wilcox

An AWS member since 1974, Wilcox has served in many Detroit Section officer positions including chair. He received his bachelor’s degree at Spring Arbor College and a MS at Central Michigan University. He has worked in the automobile industry as a cost estimator, buyer, and quality manager. Wilcox serves on the advisory committees for William D. Ford Vocational High School and Schoolcraft Community College. Currently, he owns and operates Warriors of Faith Martial Arts Academy where he conducts classes in self-defense.

Elected District 14 Director  
Robert L. Richwine

An AWS Distinguished Member, active in the Indiana Section, Richwine has served as assistant District 14 director for the past three years. In 1994, he joined Ivy Tech State College teaching courses in welding, plumbing, pipelining, blueprint reading, and metallurgy. He was promoted to program chair in 1997. Among his many District awards are CWI of the Year, Meritorious, Private Sector Educator, and the District Director Award. He has received the Mid-West Team Welding Tournament’s Clifford Hunt Award for his work in education.

Reelected District 17 Director  
J. Jones

Jones has worked 27 years as a welding instructor with industry, secondary, and higher-education institutes. He is currently a technical sales manager for Region 300 of Thermadyne Industries. He later received a bachelor’s degree and his Texas Lifetime Teaching Certificate in vocational trades. He contributed to the AWS Welding Handbook, ninth edition, where he authored welding processes. He has held Section officer positions and worked on the 2005 AWS Welding Show Committee.

Reelected District 20 Director  
William A. Komlos

Komlos, a Senior Certified Welding Inspector and a Certified Welding Educator, is president of Arc Tech, LLC, Salt Lake City, Utah. Previously, he worked as a welding engineer with Autoliv ASP, and as project manager and quality assurance manager for Mark Steel Corp. He taught welding at Salt Lake Community College, and worked at United Precision Machine and Engineering Co. for six years. Komlos served on the AWS B1 Committee on Nondestructive Examination of Welds as first vice chair for four years. He holds an MBA and a master’s in civil engineering.
Shanghai Institute of Standardization Officials Visit AWS Headquarters

Shown (from left) are Jeff Kennedy, Wang Enshan, Ray Shook, Andrew Davis, Yang Jing, Niu Gang, Qin Yuqing, and Xie Lin.

Five representatives from the Shanghai Institute of Standardization (SIS) visited AWS headquarters in Miami, Fla., Nov. 16 to discuss business interests with AWS and World Engineering Exchange (WEX). The SIS officials included Wang Enshan, Discipline Inspection Committee Secretary; Yang Jing, senior engineer and vice curator, Standards Library; and engineers Niu Gang, Qin Yuqing, and Xie Lin. Hosting the meetings were Jeff Kennedy, WEX vice president of operations; Andrew Davis, managing director, AWS Technical Services; and Ray Shook, AWS executive director.

Actions of Districts Council

On Oct. 31, 2010, after due consideration, Districts Council made the following decisions.

The AWS Saudi Arabia International Section and the AWS Western Area Career and Technology Center Student Chapter (District 7) were approved for reinstatement.

Approved for AWS Student Chapter charters were the Savannah Technical College and Space Coast Student Chapters (District 5); North Dakota State College of Science Student Chapter (District 15); Wharton County Jr. College Student Chapter (District 18); and the Walla Walla Community College Student Chapter (District 19).

Approved the name change from AWS Regional Technical Institute Student Chapter to AWS Academy for Arts, Careers, and Technology Student Chapter (District 22).

The AWS Lima High School Student Chapter (District 7) was approved for disbandment.

Avery Seaman Jr. (center, photo at right) received his Life Member certificate for 35 years of service to the Society on October 27 from Rhenda Kenny, director, AWS Member Services; and Ray Shook, AWS executive director. Seaman was at AWS headquarters for a Gases and Welding Distributors Association (GAWDA) business meeting. Since 1985, Seaman has served as president of Corp Brothers, Inc., Providence, R.I. He served as GAWDA president for the 2005–2006 term.

Singapore Welding Society President Addresses Board

Ang Chee Pheng (white tie), president, Singapore Welding Society, addressed the AWS board members in November. Shown with him are (from left) 2010 AWS President John Bruskotter, 2011 AWS President John Mendoza, and Ray Shook, AWS executive director.

GAWDA Past President Achieves AWS Life Member Status

Shown (from left) are Ray Shook, Avery Seaman Jr., and Rhenda Kenny at AWS headquarters in Miami, Fla.
Official Interpretations: C3.7, D1.1, D1.3, D1.5, D17.1

C3.7, Specification for Aluminum Brazing
Subject: Temperature Uniformity Requirements
Code Provision: Page 4, Subclause 5.3.2 (Temperature Uniformity Requirements)
Inquiry: Do salt baths for brazing aluminum having a solidus of less than 1120°F have to meet ±5°F, SAE/AMS 2750 Pyrometry, Class 1 temperature uniformity requirement?
Response: Yes.

D1.1, Structural Welding Code — Steel
Subject: Ceramic Backing and Welder Qualification
Code Provision: Clause 4
AWS Log: D1.1-06-I10b
Inquiry 1: If the WPS clearly states that the ceramic backing to be used will be removed, with backgouging to follow and a back weld, then could this WPS be deemed prequalified?
Response 1: Yes, provided all conditions for a prequalified weld are met. Backing other than steel is not a prequalified substitute where steel backing is required.

Inquiry 2: Regarding welder qualifications, if a welder is qualified in the FCAW-S process using an E70 series electrode (example E71T-11), is he/she qualified to use other E70 (FCAW) series electrodes (example E71T-8)?
Response 2: Yes.

Inquiry 3: Is that same welder also qualified to use FCAW-G (example E71T-1)?
Response 3: Yes.

Subject: Single-V-Groove Butt Joints and Groove Type Qualification
Code Provision: Table 4.5 Variable Nos. 31 and 32 and Subclause 4.9
AWS Log: D1.1-06-I11b
Inquiry 1: Does a WPS qualified using a single-V-groove CJP butt joint qualify for all other joints in conformance with 3.12 or 3.13 regardless of joint design, except for square groove joints as listed in essential variable 32, even if they require CVN testing?
Response 1: Yes.

Inquiry 2: Does the requirement of Section 4.9.1.1 supersede the essential variable 31 and require the WPS be qualified with the same groove configuration to be used in construction as written in the code?
Response 2: Yes, for nontubular connections qualified by test.

Inquiry 3: Is it acceptable to allow previously qualified single-V-groove CJP butt joints to qualify single-bevel CJP T and corner joints?
Response 3: Yes, except for CJP groove welds for nontubular connections (see 4.9.1.1).

Subject: Sample Forms and Required Information
Code Provisions: Clauses 3, 4, Annex N
AWS Log: D1.1-06-I12b
Inquiry 1: What is the minimum required information required by the code for WPS, PQR and Welder Qualification Test Records?
Response 1: Minimum WPS requirements are listed in Clauses 3.6, 4.6, and 7.6. Minimum information required for welders, welding operators, or tack welders are listed in Clause 4.22. Additional information may be needed to fully document the requirements of the specific application. The Contractor is responsible for the content and style of the WPS/PQR and Welder Qualification form. Annex N forms are a guide only and convey no code-mandated use.

Inquiry 2: Is it acceptable to list base metals, joint designs and fit-up tolerances by making reference to code groupings and joint designs?
Response 2: Yes.

Subject: Other than Steel Backing and Prequalified Joints
Code Provision: Subclauses 2.17, 5.10
AWS Log: D1.1-08-I02
Inquiry: Can the use of backing “other than” steel be considered prequalified where backgouging and welding are performed on the second side?
Response: Yes, provided all conditions for a prequalified weld are met. Backing other than steel is not a prequalified substitute where steel backing is required.

D1.3, Structural Welding Code — Sheet Steel
Subject: Exposed Moisture
Code Provision: Subclause 5.1(2)
AWS Log: D1.3-08-I08b
Inquiry: May tack welding be performed when base metals are exposed to moisture (e.g., snow, rain, etc.)
Response: No, see Subclause 5.2.

Subject: Rust and Moisture
Code Provision: Subclause 5.2
AWS Log: D1.3-08-I09b
Inquiry: The second sentence in Subclause 5.2 reads: “Surfaces to be welded and surfaces adjacent to a weld shall also be free from loose or thick scale, slag, rust, moisture, grease, or other foreign material that would prevent proper welding or produce objectionable fumes.” When applying this sentence specifically to rust and moisture, may we perform production welding (i.e., arc spot welding to structural steel) in the presence of rust and moisture so long as there isn’t enough rust and moisture to prevent proper welding?
Response: No.

D1.5, Bridge Welding Code
Subject: Yield Strength and Filler Metal Qualification
Code Edition: D1.5M/D1.5:2008
Code Provision: Tables 4.1 and 4.2
AWS Log: D1.5-08-I06
Inquiry: For WPS Qualification, must Yield Strength (0.2% offset) be used to comply with the requirements for Yield Strength in the D1.5 code?
Response: No. Yield strengths established by the all weld metal tension test have multiple allowable methods for determining yield strength per ASTM A370 or AWS B4.0 (Subclause 3.18.4).

D17.1, Specification for Fusion Welding for Aerospace Applications
Subject: Qualified Thickness Range
Code Provision: Paragraph 4.3.3.1
AWS Log: D17.1-01-I04
Inquiry: Paragraph 4.3.3.1 (1) defines the qualified thickness range based on a test weld thickness of t. It also defines that two test weds qualify welds with intermediate thickness. It is, however, unclear on the qualification range when two unequal thicknesses are used in a fillet test weld. This can be interpreted in several different ways. Take the following for example:

a.) 0.67t of thinner member to 4t of the thicker member
b.) 0.67t to 4t of the thinner member
c.) Range of thinner member to thicker member thicknesses

Proposed reply: Define qualified thickness range if unequal thickness members are used in fillet weld tests for welder qualifications.
Response: The answer is 0.67t to 4t of the thinner member.

Subject: Special Application Qualification Range
Code Provision: Paragraphs 4.3.7.5, 4.3.3.1
AWS Log: D17.1-01-I05
Inquiry: When the “Special Application” provision of paragraph 4.3.7.5 is invoked, can the provisions of paragraph 4.3.3.1 “Qualified Thickness Range” (0.67t – 4)T be applied?
Response: No.
New Standard Project

Development work has begun on the following revised standard. Affected individuals are invited to contribute to its development. To participate, contact John Gayler, (800/305) 443-9353, ext. 472. Participation on AWS Technical Committees and Subcommittees is open to all persons.

B5.16/20XX, Specification for the Qualification of Welding Engineers. This specification establishes the requirements for qualification of welding engineers employed in the welding industry. It defines the minimum experience, examination, application, qualification, and requalification requirements and methods. Specified is a method for engineers to establish a record of their qualification and abilities in welding industry work such as development of procedures, processes controls, quality standards, problem solving, etc. Stakeholders: Welding engineers, those employing welding engineers, colleges that offer welding engineering degrees, those working with or contracting welding engineers, welding industry, structural steel, marine, aerospace, etc.

Standards for Public Review


AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. A draft copy of the above standard may be obtained from Rosalinda O'Neill, roneill@aws.org, telephone (800/305) 443-9353, ext. 451.

ISO/DIS 13588, Nondestructive testing of welds — Ultrasonic testing — Use of (semi-) automated phased array technology

ISO/DIS 14174-2, Welding consumables — Fluxes for submerged arc welding and electrodes welding — Classification

ISO/DIS 16834, Welding consumables — Wire electrodes, wires, rods, and deposits for gas shielded arc welding of high-strength steels — Classification

ISO/DIS 17636-2, Nondestructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors

ISO/DIS 21952, Welding consumables — Wire electrodes, wires, rods, and deposits for gas shielded arc welding of creep-resisting steels — Classification

ISO/DIS 24598, Welding consumables — Solid wire electrodes, tubular cored electrodes, and electrodes-flux combinations for submerged arc welding of creep-resisting steels — Classification

Copies of the above Draft International Standards are available for review and comment through your national standards body. The United States contact is ANSI, 25 W. 43rd St., Fourth Fl., New York, NY 10036; or call (212) 642-4900. In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis, adavis@aws.org; or call (305) 443-9353, ext. 406.

Technical Committee Meetings

All AWS technical committee meetings are open to the public. To attend a meeting, call the secretary at the extension listed. Telephone (305) 443-9353.


Feb. 24, C1 Committee on Resistance Welding. Palm Beach Gardens, Fla. Call Annette Alonso, ext. 299.

Feb. 25, J1 Committee on Resistance Welding Equipment. Palm Beach Gardens, Fla. Call Annette Alonso, ext. 299.

Nominate Candidates for M.I.T. Masubuchi Award

The deadline for submitting nominations for the 2012 Prof. Koichi Masubuchi Award is Nov. 2, 2011.

This award, including an honorarium of $5000, is presented each year to one person, 40 years old or younger, who has made significant contributions to the advancement of materials joining through research and development.

The nomination package should include the candidate’s background, experience, publications, honors, and awards, plus at least three letters of recommendation from fellow researchers. E-mail your nomination package to Todd A. Palmer, assistant professor, The Pennsylvania State University, tap103@psu.edu.

Bridge Welding Code Updated

AASHTO/AWS D1.5M/D1.5:2010, Bridge Welding Code, has been revised to update the code provisions based on the needs of the American Association of State Highway and Transportation Officials (AASHTO). The code was prepared by the AASHTO/AWS Bridge Welding Committee operating as a subcommittee of the AWS Structural Welding Committee. The Committee is comprised of representatives from the AWS Structural Welding Committee and the AASHTO Technical Committee for Welding. The list price for the 478-page code is $264, $198 for AWS members.

To order, visit www.awspubs.com or call World Engineering Exchange (WEX) (800) 935-3464.

Errata D17.1:2001

Specification for Fusion Welding for Aerospace Applications

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


Page 9. Table 4.3, Revise Footnote (1) to read: A groove weld does not qualify for fillet welds in base metal ≤ 0.063 in. in thickness.

Page 71. Under B3. Procedure revised to read as follows: Managing Director of Technical Services.

Page 7. Clauses 4.3.7.6 and 4.3.7.7 should be subordinate to Clause 4.3.7.5 and revised as follows:

4.3.7.5 Special Applications. When none of the test welds described above are applicable to a given production weld, a special welder or welding operator qualification limited to the specific application may be achieved with a test weld consisting of the given production weld or a test weld representative of the given production weld.

1) Qualification Limitations. The qualification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, base metal thickness, welding position, base metal form, type of weld, and the other welding conditions of 4.3.6.

2) Acceptance Criteria. The required inspection, examination, and acceptance criteria shall be consistent with 4.3.8 or with production part criteria.

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

Pages 62 and 63, Figures B.5A and B.5B — Metric values in both figures have been corrected to reflect proper conversions, as shown at left.

Page 64, Figure B.5C — Metric values in figure corrected to reflect proper conversions as shown at left.

Contribute Your Knowledge to These Technical Committees

Marine Construction
The D3 Committee for Welding in Marine Construction to contribute to the development of D3.5, Guide for Steel Hull Welding; D3.6, Specification for Underwater Welding; D3.7, Guide for Aluminum Hull Welding; and D3.9, Specification for Classification of Weld-Through Paint Primers. Contact B. McGrath, bmcg_mtime@aws.org, ext. 311.

Mechanical Testing of Welds
The B4 Committee for Mechanical Testing of Welds to contribute to B4.0, Standard Methods for Mechanical Testing of Welds. Contact B. McGrath, bmcg_mtime@aws.org, ext. 311.

Surfacing Industrial Mill Rolls

Magnesium Alloy Filler Metals
A5L Subcommittee on Magnesium Alloy Filler Metals to assist in the updating of AWS A5.19-92 (R2006), Specification for Magnesium Alloy Welding Electrodes and Rods. Contact R. Gupta, gupta@aws.org, ext. 301.

Robotic and Automatic Welding

Thermal Spraying

Labeling and Safe Practices
SH4 Subcommittee on Labeling and Safe Practices to update AWS F2.2, Lens Shade Selector; AWS F4.1, Safe Practices for the Preparation of Containers and Piping for Welding and Cutting. S. Hedrick, steveh@aws.org, ext. 305.
A Presidential Reunion in Galveston

Shown (from left) are John Bartley, Patty Bartley, Leslie Kvidahl, Lee Kvidahl, Sandi Landry, Elsie Howden, and David Howden.

The occasion of John Hartley’s 80th birthday last September brought together three AWS past presidents in Galveston, Tex. Bartley served as AWS president for the 1991–1992 term. Joining Bartley and his wife, Patty, and their daughter, Sandi Landry, for the occasion were Lee Kvidahl and wife, Leslie; and Dave Howden and his wife, Elsie. Kvidahl served as AWS president for the 1993–1994 term, and Howden was AWS president for the 1994–1995 term.

Member-Get-A-Member Campaign

Listed are the members participating in the June 1, 2010–May 31, 2011, Member-Get-A-Member (MGM) campaign. These data are for Nov. 22, 2010. For campaign rules and the prize list, see page 85 in this Welding Journal or visit the AWS campaign Web site www.aws.org/mgm. Call the AWS Membership Dept. (800/305) 443-9353, ext. 480, for information on your status.

Winner’s Circle
Sponsored 20+ new Individual Members, per year, since 6/1/1999. The superscript shows the number of years the member has achieved this status if more than once.
J. Compton, San Fernando Valley — 7
E. Ezell, Mobile — 7
J. Merzthal, Peru — 2
G. Taylor, Pascagoula — 2
L. Taylor, Pascagoula — 2
B. Mileska, Houston — 2
W. Shreve, Fox Valley — 2
M. Karagoulis, Detroit — 2
S. McGill, NE Tennessee — 2
B. Chin, Auburn — 2
T. Weaver, Johnstown/Altoona — 2
G. Woerner, Johnstown/Altoona — 2
R. Wray, Nebraska — 2
M. Haggard, Inland Empire — 2
S. Esders, Detroit — 2

President’s Roundtable
Sponsored 9–19 new Individual Members
G. Kirk, Pittsburgh — 11

President’s Club
Sponsored 3–8 new Individual Members
M. Pelegrino, Chicago — 8
M. Tryon, Utah — 8
E. Ezell, Mobile — 7
R. Dawson, Western Carolina — 4
J. Hopwood, Iowa — 4
D. Seyer, Niagara Frontier — 4
H. Cable, Pittsburgh — 3
C. Crumpton, Florida W. Coast — 3
R. Ellenbecker, Fox Valley — 3
J. Hope, Puget Sound — 3
W. Sartin, Long Beach/Or. Cty. — 3
W. Sturge, New York — 3

President’s Honor Roll
Sponsored 2 new Individual Members
M. Allen, Charlotte — 2
D. Berger, New Orleans — 2
R. Fuller, Florida W. Coast — 2
G. Hamilton, Houston — 2
J. Hill, Nebraska — 2
J. Kline, Northern New York — 2
A. Laabs, Lakeshore — 2
T. Palmer, Columbia — 2
W. Wall, Auburn — 2
S. Witkowski, Houston — 2
D. Wright, Kansas City — 2

Student Sponsors
Sponsored 3+ new Student Members
M. Pelegrino, Chicago — 69
D. Berger, New Orleans — 27
J. Carney, W. Michigan — 25
G. Gammill, NE Mississippi — 25
S. Siviski, Maine — 22
V. Facchiano, Lehigh Valley — 20
A. Baughman, Stark Central — 19
E. Melin, affiliated — 18
G. Smith, Lehigh Valley — 18
T. Buchanan, Mid-Ohio Valley — 17
D. Schnalzer, Lehigh Valley — 17
K. Cox, Palm Beach — 17
M. Haggard, Spokane — 16
H. Hughes, Mahoning Valley — 16
S. Robeson, Cumberland Valley — 16
D. Saunders, Lakeshore — 16
G. Seese, Johnstown-Altoona — 16
T. Shirk, Tidewater — 15
C. Schiner, Wyoming Section — 14
W. Davis, Syracuse — 13
C. Donnell, New Jersey — 13
J. Goodson, New Orleans — 12
G. Kirk, Pittsburgh — 11
K. Karwoski, Milwaukee — 10
R. Wahrman, Triangle — 10
J. Ciaramitaro, N. Central Florida — 9
S. Ulrich, St. Louis — 9
A. Badeaux, Washington, D.C. — 8
J. Boyer, Lancaster — 8
T. Moore, New Orleans — 8
W. Wilson, New Orleans — 8
R. Hutchinson, Long Beach/Or. Cty. — 7
J. Kline, Northern New York — 7
G. Siepert, Kansas — 7
D. Wright, Kansas City — 7
T. Palmer, Columbia — 6
D. Zabel, SE Nebraska — 6
D. Badeaux, Washington, D.C. — 6
D. Kowalski, Pittsburgh — 4
S. Mackenzie, Northern Michigan — 4
C. Warren, N. Central Florida — 4
M. Anderson, Indiana — 3
S. Colton, Arizona — 3
J. Gerdin, Northwest — 3
J. Meyer, San Francisco — 3
S. Miner, San Francisco — 3
G. Rilla, L.A./Inland Empire — 3
J. Seitzer, York-Central Pa. — 3
T. Smeltzer, San Francisco — 3
J. Sullivan, Mobile — 3
B. Wenzel, Sacramento — 3
New AWS Supporters

New Sustaining Company
Metalsa S.A. de C.V.
Carr. Miguel Aleman Km. 16.5 #100
Monterrey, Nuevo Leon, Mexico
Representative:
Carlos A. Cardenas Elizondo
Metalsa manufactures metallic structures for heavy trucks, buses, light trucks, and passenger cars. The company employs more than 2500 workers with locations in Argentina, Australia, Brazil, Canada, Germany, India, Japan, Mexico, the United States, and United Kingdom. It is well known for its high-quality products, workmanship, and service customized for each client.

Supporting Company
NCAD Products, Inc.
PO Box 622188, Oviedo, FL 32762

Affiliate Companies
Diversified Metalworks
332 W. Brenna Ln., Orange, CA 92867

Glauber Equipment Corp.
1600 Commerce Pkwy.
Lancaster, NY 14086

Hefco Enterprises, Inc.
PO Box 330, Fresno, TX 77545

Istanbul Naval Shipyard
Istanbul Tersanesi Komutanligi
Pendik Istanbul 34890, Turkey

Southwest Steel Fab, Inc.
PO Box 275, 2520 Scheidt Ln.
Bonner Springs, KS 66012

Steel America
400 E. Indian River Rd.
Norfolk, VA 23523

Shijiazhuang Shiqiao Electric
Welding Material Co., Ltd.
S. St. Shengli, Shijiazhuang
Hebei 050225, China

Valiant International
1511 E. 14 Mile Rd., Troy, MI 48083

Welding Distributor
Böhler Welding Group Nordic AB
Box 501, Avesta, Kopparalen 77427, Sweden

Educational Institutions
Ecole de Technologie Supérieure/Bibliothèque
1100 Rue Notre Dame Ouest
Montreal, QC H3C 1K3, Canada

El Campo High School
600 W. Norris Ave.
El Campo, TX 77437

Naugatuck Valley Community College
750 Chase Pkwy., Waterbury, CT 06708

Northern Tier Career Center
RR 1, Box 157A, Towanda, PA 18848

Portland Arts & Technology High School
196 Allen Ave., Portland, ME 04103

AWS Member Counts
December 1, 2010

Grades
Sustaining ........................................ 512
Supporting ........................................ 296
Educational ........................................ 560
Affiliate ............................................. 467
Welding Distributor ............................. 48
Total Corporate ................................. 1,883
Individual ........................................ 55,571
Student + Transitional ...................... 10,473
Total Members* ................................. 66,044

* Includes reinstatement of international members.

District Director Award Recipients Named

Roy Lanier, District 4 director, has nominated the following members for the District Director Award.

David Schaefer — Carolina
Ray Sosko — Carolina
Randy Owens — Carolina
Gary Stillner — Charlotte
Carl Yaeger — Northeastern Carolina
Wayne Johnson — SW Virginia
Stewart Harris — Triangle
Paul Hebert — Tidewater

Honorary Meritorious Awards

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

William Irrgang Memorial Award
Sponsored by The Lincoln Electric Co. in honor of William Irrgang, the award, administered by AWS, is given each year to the individual who has done the most over the past five years to enhance the Society’s goal of advancing the science and technology of welding. It includes a $2500 honorarium and a certificate.

National Meritorious Certificate Award
This certificate award recognizes the recipient’s counsel, loyalty, and dedication to AWS affairs, assistance in promoting cordial relations with industry and other organizations, and for contributions of time and effort on behalf of the Society.

George E. Willis Award
Sponsored by The Lincoln Electric Co. in honor of George E. Willis, the award, administered by AWS, is given each year to an individual who promoted the advancement of welding inter- nationally by fostering cooperative participation in technology transfer, standards rationalization, and promotion of industrial goodwill. It includes a $2500 honorarium and a certificate.

Honorary Membership Award
The honor is presented to a person of acknowledged eminence in the welding profession, or to one who is credited with exceptional accomplishments in the development of the welding art, upon whom the Society deems fit to confer an honorary distinction. Honorary Members have full rights of membership.

International Meritorious Certificate Award
This honor recognizes recipients’ significant contributions to the welding industry for service to the international welding community in the broadest terms. The awardee is not required to be an AWS member. Multiple awards may be given. The award consists of a certificate and a one-year AWS membership.
District 1
Thomas Ferri, director
(508) 527-1884
thomas_ferri@thermadyne.com

BOSTON
November 9
Activity: The Section members toured Gilchrist Metal Fabricating Co., in Hudson, N.H. Stewart and Jack Gilchrist conducted the program.

November 12
Activity: Tom Ferri, District 1 director, presented the District Educator of the Year Award to Fred Hein. Hein teaches welding at Greater Lowell Technical High School in Tyngsboro, Mass.

District 2
Harland W. Thompson, director
(631) 546-2903
harland.w.thompson@us.ul.com

LONG ISLAND
November 11
Activity: The Section members met at The Nook Restaurant in Wantagh, N.Y., to discuss state and local permits required to run a welding business and view the Lincoln Electric welding safety video. Attending the meeting were Chair Brian Cassidy, District 2 Deputy Director Harland Thompson, Sal Spallino, Ray O’Leary, Tom Gartland, and Alex Duschere.

District 3
Michael Wiswesser, director
(610) 820-9551
mike@welderinstitute.com

District 4
Roy C. Lanier, director
(252) 321-4285
rlanier@email.pittcc.edu

District 5
Steve Mattson, director
(904) 260-6040
steve.mattson@yahoo.com

ATLANTA
October 19
Speaker: Kevin Ledford, branch chief of field inspection services
Affiliation: Georgia DOT Field Services Topic: Welder qualifications for DOT field services
Activity: Following the talk, Ledford conducted a tour of the testing facility. The meeting was held in Forest Park, Ga.
Florida West Coast Section members are shown at the November meeting.

Shown at the North Florida Section program are (from left) District 5 Director Steve Mattson, speaker Mark Burke, and Jim Issa from Lincoln Electric.

**FLORIDA WEST COAST**

**November 10**
Speaker: Ben Stroup, sales representative
Affiliation: The Lincoln Electric Co.
Topic: The VRTEX® 360 virtual reality arc welding training system
Activity: Mel M. Schwartz received his AWS Gold Member certificate commemorating 50 years of service to the Society. The program was held at Frontier Steakhouse in Tampa, Fla.

**NORTHERN NEW YORK**

**October 2**
Activity: The Section members toured Welding & Brazing Services, Inc. Carter Cook, general manager, described the field repair work the company does in field repair using welding and brazing, robots, and induction heating. The facility, located in East Worcester, N.Y., was recently certified as an AWS Accredited Test Facility.

**District 6**
Kenneth Phy, director
(315) 219-5297
kenneth.phy@gmail.com

**District 7**
Don Howard, director
(814) 269-2895
howard@ctc.com

**SOUTH FLORIDA**

**October 19**
Speaker: Mark Burke
Affiliation: Indalco, Inc.
Topic: Manufacturing aluminum welding wires
Activity: District 5 Director Steve Mattson attended this program, held in Hollywood, Fla.

**SOUTHERN NEW YORK**

**October 21**
Speaker: Phillip Nidd, team leader of asset risk management
Affiliation: DNV Columbus
Topic: E-mails, litigation, and the electronic paper trail
Activity: This program was a joint meet-
Elisha Ramsey, welding instructor at Fulton County Vo Tech, presents a speaker gift to Greg Walters during the Johnstown-Altoona Section’s tour of Mellott Co. in October.

ing of the Columbus Section with the local chapters of SWE, ASME, ASM International, AIAA, and NACE. The event was held in Columbus, Ohio.

DAYTON
OCTOBER 12
Speaker: Anthony Ananthanarayanan
Affiliation: Innovative Weld Solutions
Topic: Improvements in the weldability of heat-treated aluminum alloys
Activity: James Grant received his Life Membership certificate for 35 years of service to the Society.

NOVEMBER 9
Speakers: Steve Roth, Gary Ward
Affiliation: Southern Ohio Forge and Anvil Association
Topic: Forge welding
Activity: Following the talks, Roth and Ward demonstrated several forge welding techniques and fabricated a decorative piece and a knife blade for the Dayton Section members. Attendees were given an opportunity to work with forge welding.

JOHNSTOWN-ALTOONA
SEPTEMBER 28
Activity: The Section members met at Small Tube Products Co., in Duncansville, Pa., to study the production of tubes fabricated from copper, brass, stainless steel, and other metals. Mike Hormell, maintenance manager, conducted the tour for 64 members, students, and guests. Don Howard, District 7 director, attended the program.

OCTOBER 19
Activity: The Johnstown-Altoona Section members met at Mellott Co. in Warfordsburg, Pa., to tour the facility. Greg Walters, operations manager, conducted the program for 31 attendees.

District 8
Joe Livesay, director
(931) 484-7502, ext. 143
joe.livesay@ttcc.edu

District 9
George Fairbanks Jr., director
(225) 473-6362
fits@bellsouth.net

Baton Rouge
OCTOBER 21
Speaker: George Fairbanks, District 9 director
Affiliation: Fairbanks Inspection & Testing Services, Inc.
Topic: D1.1 prequalification procedure
Activity: Chairman Davis Rayborn thanked the Section’s sponsor, Performance Contractors, for providing the venue and the dinner for this program.
Shown at the Baton Rouge Section program are (from left) District 9 Director George Fairbanks, Barry Carpenter, Chair Davis Rayborn, and Jerome Mabile, QA director at Performance Contractors.

Speaker George Fairbanks (left), District 9 director, is shown with Davis Rayborn, Baton Rouge Section chairman.

Shown at the September Mobile Section program are (from left) speaker Bob Henson, Chair Jackie Morris, and George Fairbanks, District 9 director.

Shown at the September Mobile Section program are (from left) speaker Bob Henson, Chair Jackie Morris, and George Fairbanks, District 9 director.

Shown at the September Mobile Section program are (from left) District 9 Director George Fairbanks, Barry Carpenter, Chair Davis Rayborn, and Jerome Mabile, QA director at Performance Contractors.

MOBILE

SEPTEMBER 9
Speaker: Bob Henson, technical director
Affiliation: Harris Products Group
Topic: Brazing and soldering methods
Activity: Big winners for the evening were Charles Boundurant who took the student door prize home, Michael Zoghby garnered the door prize, and Wallace Bourque won the 50/50 split-the-pot raffle.

OCTOBER 21
Activity: Michael Orr led the Mobile Section members on a tour of the GE Energy facility in Pensacola, Fl.

NOVEMBER 11
Speakers: Jim Kovach, Phil Wickersham
Affiliation: ESAB Welding and Cutting
Topic: 20 welding questions
Activity: This was an audience participation presentation held at Saucy Q Bar B Que in Mobile, Ala., for 34 attendees. District 9 Director George Fairbanks attended the program, hosted by Jackie Morris, chairman.

MORGAN CITY

SEPTEMBER 7
Activity: The Section held an executive committee meeting to plan joint meetings with the Acadiana, Baton Rouge, and New Orleans Sections. The meeting was held at Atchafalaya Country Club in Morgan City, La., led by Renee Landry, Section secretary and an educator at Morgan City High School. District 9 Director George Fairbanks attended the program.

OCTOBER 19
Activity: The Morgan City Section members met at Oceaneering International in Morgan City, La. District 9 Director George Fairbanks attended the program. Mark Campbell presented an overview of how the company became involved with manufacturing its own deep-sea remotely operated vessels (ROVs), then led a tour of the manufacturing facility, training area, and the Millennium® ROV.

NEW ORLEANS

OCTOBER 19
Speaker: Robbie LaChute
Affiliation: Dynamic Industries
Topic: Fabrication and safety tips
Activity: The meeting was sponsored by Dynamic Industries for 79 attendees, including 41 students. The program was held at Boomtown Casino in Harvey, La.
Morgan City Section members are shown at the executive meeting held in September.

New Orleans Section officers and Dynamic Industries sponsors are shown at the October program.

Shown at the New Orleans Section program are Chair D. J. Berger, speaker Robbie LaChute, and Vice Chair Aldo Duron.

Shown at the Mobile Section November program are (from left) Chair Jackie Morris, speakers Jim Kovach and Phil Wickersham, and George Fairbanks, District 9 director.

Shown at the Mahoning Valley Section program are (from left) Chair Kenny Jones, speaker Murphy Lewis, and Brandon Smith, CCCTC Student Chapter chair.

Morgan City Section members are shown during their tour of the Oceaneering International facilities in October.
Shown at the Central Michigan Section program are (from left) Jeff Haynes, speaker Vern Mesler, Roy Bailiff, Chair Bill Eggleston, Cathie Lindquist, Scott Poe, Bill Mumford, and Jeff Grossman.

Mark Hollenbank (right) receives the CWI of the Year Award from Kenny Jones, Mahoning Valley Section chairman.

District 11
Robert P. Wilcox, director
(734) 721-8272
rmwilcox@wowway.com

Central Michigan Section Chair Bill Eggleston (left) is shown with Jeff Seelye, past chair.

Central Michigan Section
October 26
Speaker: Vern Mesler, project manager
Affiliation: Historic Bridge Park, Calhoun County, Mich.
Topic: Discussion of projects currently in progress to restore nine historic sites
Activity: Jeff Grossman, Section secretary, received his AWS Life Member certificate for 35 years of service to the Society. The program was held at Tony M’s Restaurant in Lansing, Mich.

District 12
Daniel J. Roland, director
(715) 735-9341
droland@marinettemarine.com

Lakeshore
November 11
Activity: The Section members met at the Manitowoc Cranes Port Washington Plant to tour the facility and study the manufacture of crawler frames, car bodies, and adapter frames. A highlight was seeing the Cloos welding robotic cell in operation. The guides included Chris Monday, robot operator, and James Tucker, welding technician.

Madison-Beloit
October 13
Activity: The Section members worked with instructors and students to present a welding education open house at Madison Area Technical College in Madison, Wis. The students and their families were given an opportunity to tour the college and operate some of the new equipment received.

MAHONING VALLEY
October 21
Speaker: Murphy Lewis, president
Affiliation: Murphy’s Consultants, Inc.
Topic: Impact of drugs in the workplace
Activity: Mark Hollenbank received the CWI of the Year Award from Vern Mesler, Section chairman. The program was held at the Columbiana County Career and Technical Center (CCCTC) in Lisbon, Ohio. The more than 50 attendees included members of the CCCTC Student Chapter, headed by Chair Brandon Smith.

SAGINAW VALLEY
October 28
Activity: About 45 Section members and guests toured Glastender, Inc., in Saginaw Mich., to study the manufacture of commercial bar and restaurant equipment. Keith Arnold, plant manager, and his staff led the 90-min tour. Attending the event were welding instructors and students from Mott Community College, Bay Arenac Career Center, Delta College, and Baker College. Prior to taking the tour, the Section held a brief meeting where the students were told about the AWS welding scholarship program.

DETROIT
November 11
Speaker: Ed Warzyniec, technical service and automation manager
Affiliation: Airgas Great Lakes
Topic: The value of technical interaction between customer and supplier
Activity: The program was held for 29 attendees at the Ukrainian Cultural Center in Warren, Mich.

NORTHWEST OHIO
November 9
Activity: The Section members met at G. L. Heller Co., Inc., in Whitehouse, Ohio, to study its manufacturing operations. The machine shop performs general and CNC machining to produce machinery parts. Featured on the tour were water jet cutting operations and various machining and drilling stations. Gary Heller, owner, conducted the program.
Shown at the Milwaukee Section program are (from left) Russ Dudar, Brian Stephens, Tom Jobs, Larry Market, Carl Senak, presenter Eric Isbister, Melissa and Pauline Emerson-Froebe, Jose Domenech, and Richard Cortez.

Attending the Racine-Kenosha Program are (from left) Ken Karwowski, Jeff Wink, Alex Wagner, Sam Hatchett, Bob Hatchett, Andy Herman, Mrs. Herman, Mike Stubbs, and Chairman Dan Crifase.

from Miller Electric and Lincoln Electric. Rob Stinson from Lincoln and Bryan Kwapis from Miller answered questions for the attendees. Tony Stute, a CWI and an instructor at the college, presented a talk on welder certification in Wisconsin. Don Schmidt and Rick Maier received their AWS Silver Membership Certificates for 25 years of service to the Society.

**MILWAUKEE**
**OCTOBER 21**
Activity: The Section members met at GenMet Corp in Mequon, Wis., for a tour of the facility. Eric Isbister, CEO, presented a talk on just-in-time and lean manufacturing, then conducted the tour for 65 attendees.

**RACINE-KENOSHA**
**OCTOBER 26**
Activity: The Section members toured the Super-Value Distribution Center in Pleasant Prairie, Wis. Jeff Wink, warehouse manager, and Mike Stubbs, warehouse superintendent, conducted the program. Several Gateway Technical College welding students attended the tour.

**District 13**
W. Richard Polanin, director
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Students Mike Lemon (left) and Trevor Listol learned about welding at the Madison Area Technical College open house.

Chris Monday (left) and James Tucker conducted the Lakeshore Section members on a tour of the Manitowoc Cranes facility.

Ed Warzyniec addressed the Detroit Section members in November.

Shown (from left) are Madison-Beloit Section Chair Ben Newcomb, Don Schmidt, and Rick Maier during the presentation of their Silver Membership Award certificates.
Chicago Section board members are shown at the November meeting. From left are Cliff Iftimie, Hank Sima, Marty Vondra, Vicky Landorf, Chair Chuck Hubbard, Eric Purke, and Eric Krauss.

Shown at the Chicago Section program are (from left) ASNT Chair John Zafer, speaker Stuart Kleven, and Chair Chuck Hubbard.

Shown at the Chicago Section program November 17 are (from left) James Greer, speaker Lyle Hill, and Chair Chuck Hubbard.

Chicago Chair Chuck Hubbard (left) presents Jim Greer a distinguished service award November 17.

Speaker Pat Garten (left) chats with Gary Tucker, Indiana Section chairman.

CHICAGO
OCTOBER 20
Speaker: Stuart Kleven, quality engineer
Affiliation: Alloyweld Inspection Co.
Topic: A review of AWS D17.1, Specification for Fusion Welding for Aerospace Applications
Activity: Members of the local chapter of ASNT, John Zafer, chairman, attended this program. The meeting was held at Bohemian Crystal Restaurant in Chicago, Ill.

NOVEMBER 9
Activity: The Chicago Section held a board meeting at Papa Passaro’s Family Restaurant in Westmont, Ill. The participants included Chair Chuck Hubbard, Cliff Iftimie, Hank Sima, Marty Vondra, Vicky Landorf, Eric Purke, and Eric Krauss.

NOVEMBER 17
Activity: The Chicago Section met at Bohemian Crystal Restaurant. Lyle Hill, MTH Industries, presented his talk, “Building the Bean,” concerning taking on ground-breaking projects. James Greer, an AWS past president, received an award for his distinguished service to the Section and his service as chairman 2009–2010.

District 14
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INDIANA
OCTOBER 20
Speaker: Pat Garten, owner
Affiliation: Sutton-Garten Co.
Topic: The history of Sutton-Garten Co., a supplier of welding supplies and gases
Activity: The talk was preceded by a business meeting held in Indianapolis, Inc.

District 15
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SASKATOON
APRIL 9
Activity: The Section participated in a seminar held by the University of Saskatchewan Dept. of Mechanical Engineering. The presenter was Shufang Shen who addressed the topic, effects of heat input on fatigue properties of submerged arc welded ASTM A709 Grade 50 steel.

District 16
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dlandon@vermeermfg.com
NEBRASKA
OCTOBER 21
Speaker: Bruce Gregory, technical sales representative
Affiliation: The Lincoln Electric Co.
Topic: The VRTEX® 360 virtual reality arc welding training system
Activity: Gregory demonstrated the equipment and offered the attendees an opportunity to try their skills welding in the virtual environment.

District 17
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jjones@thermadyne.com

EAST TEXAS
OCTOBER 21
Speaker: Johnny Harvill, technical representative
Affiliation: The Lincoln Electric Co.
Topic: Advancements in submerged arc and robotic welding technologies
Activity: The meeting was held at Papacita’s Restaurant in Longview, Tex.

OKLAHOMA CITY
NOVEMBER 11
Speaker: Dwight Haworth, multiprocess specialist
Affiliation: Airgas
Topic: Introduction to powder alloy welding
Activity: Instructors and students from Caddo-Kiowa and Canadian Valley Technology Centers attended the program, which included demonstrations of the powder alloy welding process.

TULSA
OCTOBER 21
Speaker: Bill Byrd, sr. welding engineer
Affiliation: ED Williamson Services, Inc.
Topic: Welding in-service pipeline welding
Activity: The event was held in Tulsa, Okla.
Attendees are shown at the Spokane Section program.

Spokane Section Chair Phil Zammit (left) presents Lonnie Benn his Life Membership certificate.

Patricio Mendez (left) is shown with speaker YuMing Zhang at the Alberta Section meeting in March.

Ankit Vajpayee (left) and David Topp were the featured speakers at the Alberta Section event in February.

**District 18**
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**District 19**
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**ALBERTA**
February 1
Activity: The Section spearheaded and formed the Edmonton Association of Technical Societies (EATS) consisting of nine local technical societies including ASM International, ASME, ASQ, AWS, CScHdE, CWA, NACE, SME, and STLE. This first meeting focused on nondestructive testing with 80 attendees. The first speaker was Ankit Vajpayee from Russell NDE Systems, who spoke on advancements in remote field technology (RFT). The second speaker was David Topp from TSC Inspection Systems who discussed the application of the alternating current field measurement technique to weld inspection. The event was held at Alberta Innovates, Technology Futures Building, Edmont, Alb., Canada.

**March 17**
Speaker: YuMing Zhang
Affiliation: University of Kentucky
Topic: Sensing and control of welding processes
Activity: The event was held at the University of Alberta Faculty Club in Edmonton, Alb., Canada.

**SPOKANE**
October 20
Speaker: Tom Goonan
Affiliation: Eutectic
Topic: Welding cast iron
Activity: Chair Phil Zammit presented Lonnie Benn his AWS Life Member certificate for 35 years of service to the Society. Welding instructor Shawn McDaniel from Big Bend Community College, Moses Lake, attended the event with his students. The program was held at Cathay Inn Restaurant in Spokane, Wash.

**District 20**
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bkoz@arctechllc.com

**IDAHO/MONTANA**
October 22
Activity: The Section members toured Yellowstone Log Homes in Rigby, Idaho, to study the manufacture of prefabricated log homes. David Youngstrom, co-owner of the company, conducted the tour.

**District 21**
Nanette Samanich, director
(702) 429-5017
nan07@aol.com

**District 18**

**District 19**

**District 20**

**District 21**
Shown at the Sierra Nevada Section program are (standing, from left) Pat Wilke, Michael Christian, Jacob Gill, Robert Stave, Chair Scott Holcomb, Andrew Pelissner, John Rich, Taylor Hayes, Robert Pace, James Cooney, Jeff Sawtell, Gaylord Rodeman, Eric McAuliffe, speaker David Kilburn, Kurt Reinschmidt, and Scott Walsh, and (front, from left) Ted Scott and Robin Howard.

District 22
Dale Flood, director
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d.flood@tritool.com

SACRAMENTO VALLEY
October 13
Speaker: David Kilburn, technical sales representative
Affiliation: The Lincoln Electric Co.
Topic: A history of welding and the development of safety procedures for welders
Activity: The meeting was held at Consumnes River College in Sacramento, Calif.

SAN FRANCISCO
September 27
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Your education in welding
Activity: The meeting was held for the students and staff at Las Positas College in Livermore, Calif. Scott Miner, welding department coordinator, conducted a tour of the college for Bruskotter and Dale Flood, District 22 director.

SIERRA NEVADA
October 6
Speaker: David Kilburn
Affiliation: The Lincoln Electric Co.
Topic: Hardfacing
Activity: Following the lecture, Kilburn conducted a hands-on session in the Truckee Meadows Community College welding shop for the attendees to try the various hardfacing electrodes and techniques. The program was held at the college in Reno, Nev.

AWS President John Bruskotter discussed the importance of education for welding students at the San Francisco Section program.
Order by December 31, 2010

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Welding is the most vital and fundamental manufacturing process in the construction of ships and metal hull boats. Attendees will learn the progress of new and innovative developments, as well as the potential value and impact to the industry. The conference will also address the critical importance of welding in the shipbuilding industry by providing current information on new and emerging technologies being developed for shipbuilding applications.

Conference on Preventing Weld Failures
June 14, 15
New Orleans, La.

Management continues to point fingers at the engineers in the weld shop: “How come that weld failed? What are you going to do to prevent it from happening again?” Finding the answers to the questions is not as easy as it seems. For help on this matter, come to this conference. There will be presentations on two of the most critical problems: postweld heat treating and dissimilar metal welding. It will be a useful mix of the valuable existing technologies and some of the new technologies coming on the scene. Topics like Six Sigma, lean manufacturing, several of the newer NDE inspection methods, and new software that can be put to practical use will be discussed.

Corrosion-Resistant Alloys and the New Chrome-Moly Steels
August 16, 17
Charlotte, N.C.

This double-barreled two-day conference in Charlotte will be something a little different in AWS conferences. Day one will be all about the newer corrosion-resistant alloys and will cover such materials as the growing body of duplex stainless steels, the nickel-based alloys, and titanium. The duplex grades are beginning to replace the austenitic stainless steels in some applications and there is much to learn about welding them. Even newer is the introduction of less-expensive duplex alloys, so much needs to be learned about these as well. There’s also a new titanium alloy that could replace the popular 6Al-4V grade. It too will be on the program. Cladding is also playing an increasingly important role in the whole matter.

Day two will be devoted to another hot topic in welding, the new chrome-moly steels such as the 91, 92, and 911 grades. There are benefits with those, but there is still much to learn. It’s a market cut out for the low-hydrogen consumables. Fabrication is tricky. Great attention must be paid to heat treating and dissimilar metal welding. Also discussed will be the material that to some is an old nemesis, 4130 chrome-moly steel.

Aluminum lends itself to a wide variety of industrial applications because of its light weight, high strength-to-weight ratio, corrosion resistance, and other attributes. However, because its chemical and physical properties are different from those of steel, welding aluminum requires special processes, techniques, and expertise.

A distinguished panel of aluminum-industry experts will survey the state of the art in aluminum welding technology and practice. The conference will also provide opportunities for you to network informally with speakers and other participants, as well as visit an exhibition showcasing products and services specifically for the aluminum welding industry.

2011 FABTECH Conference Schedule
Chicago, Ill.

National Welding Education Conference
November 13

Presented by the National Center for Welding Education and Training (Weld-Ed), this conference is designed to bring together educators for professional development and networking opportunities. Weld-Ed’s focus is on the preparation of welders, welding technicians, and welding engineers to meet the needs of industry. This conference will include presentations on topics such as Weld-Ed accomplishments in the last year, the partnership between Weld-Ed and AWS, welding industry workforce needs, recruitment tips and tools for educators, competency models, externship programs for educators, tips on partnering with other secondary and postsecondary schools, welding education trends, curriculums, materials science education and applications, distance learning updates, new technology applications, and presentations from welding educators who will share their best practices.

ABCs of Welding Engineering
November 14

8th Conference on Weld Cracking
November 15

The most perplexing problem in the welding industry has to be weld cracking. This conference is for those who want to get a handle on weld cracking situations.

For more information, please contact the AWS Conferences and Seminars Business Unit at (800) 443-9353, ext. 264. You can also visit the Conference Department at www.aws.org/conferences for upcoming conferences and registration information.
In 2011, WEMCO and RWMA will once again co-locate their annual meetings.

On February 24-26, 2011 WEMCO and RWMA will host their independent meetings and work groups at the PGA National Resort and Spa, in Palm Beach Gardens, Fla. Both committees have agreed to collaborate on a very relevant theme — “Opportunities in the Energy Sector.” Join us as we gain insight on this topic from first-class business speakers, key industry leaders, enlightening presentations, and dynamic business forums.

The cost to attend this 3-day annual event is:
- WEMCO and RWMA Members: $675
- WEMCO and RWMA Spouses: $285

Negotiated rate at the PGA National Resort and Spa: WEMCO and RWMA have negotiated a rate of $179 per night for all attendees. However, rooms are limited—first-come, first-served!

Register Today!
For more information on WEMCO and RWMA or to register for the annual meetings contact:
Susan Hopkins
to susan@aws.org or 800-443-9353, ext. 295

This Year’s Theme:
“OPPORTUNITIES IN THE ENERGY SECTOR”

With the country’s continued demand for oil and natural gas, America has started to ask:

Is there a better way?
Absolutely. The United States is now focusing on natural, nuclear and renewable energy as alternatives. The nuclear energy sector is a key player in the energy industry. Old, unfinished plants are now being completed, and new ones are being built. In addition, energy sources such as sun, wind and tide are gaining strength. Next on many of our minds was:

“How will this affect the welding industry tomorrow?”

With the economy focusing on “green” jobs and technology, the employment outlook is bright for workers possessing skills in various welding processes. Competent and experienced welders, as well as welding equipment/products manufacturers will be critical to the creation of the green infrastructure in the coming years.

Will your company be a part of this new movement?
It is inevitable that this is the direction of the future. Countries such as Israel and Brazil are already making significant developments in this field. Now it’s time for WEMCO and RWMA to enlighten their members as well.
Operation Principles for Electron Beam Welding

The heart of the electron beam welding process is the electron beam gun/column assembly. Figure 1 shows a simplified representation of the gun column. Electrons are generated by heating a negatively charged emitting material to its thermionic emission temperature range, which causes electrons to “boil off” the emitter (or cathode/filament) and to be electrostatically accelerated toward the positively charged anode. The precisely configured grid (bias cup) surrounding the emitter provides an electrostatic field geometry that accelerates the electrons and shapes them into the beam. The beam exits the region of the gun through an opening in the anode.

In a diode (cathode-anode) gun, the beam-shaping electrode and emitter are both at the same electrical potential, and together are referred to as the cathode. In a triode (cathode-grid-anode) gun (Fig. 1), the emitter and beam-shaping electrode are at different potentials; consequently, the beam-shaping electrode can be biased to a slightly more negative value than the emitter to control the flow of the beam current. In this case, the emitter is called the cathode (or filament) and the beam-shaping electrode is called the grid. In both cases, the anode is incorporated into the electron gun, so beam generation (acceleration and shaping) is accomplished independently of the workpiece.

As it exits the gun, the beam of electrons is accelerated to speeds in the range of 30–70% of the speed of light when gun voltages in the 25–200-kV range are employed. The beam then continues on toward the workpiece. Once the beam exists the gun, it gradually broadens as travel distance increases — Fig. 1. This divergence results from the fact that all electrons in the beam have some radial velocity due to their thermal energy, and all experience some degree of mutual electrical repulsion. Small effects are also created by the interaction of electrons with the remaining gas atoms and molecules in the beam path. While electrons at much higher energy levels will charge the particles, causing a self-focusing effect, the lower energy levels used in welding do not cause this phenomenon to occur. Therefore, to counteract this inherent divergence effect, an electromagnetic lens system is used to converge the beam and focus it into a small spot on the workpiece. The divergence and convergence angles of the beam are relatively small, which gives the concentrated beam a usable focal range extending over a distance of about 25 mm (1 in.).

In practice, the following variables control the rate of energy input to the weld:

1. Beam current — the number of electrons per second impinging upon the workpiece
2. Beam accelerating voltage — the magnitude of velocity of these electrons
3. Focal beam spot size — the degree to which this beam is concentrated at the workpiece
4. Welding speed — the travel speed at which the workpiece or electron beam is being moved.

The maximum beam accelerating voltages and currents achievable with commercially available electron beam gun/column assemblies ranges from 25 to 200 kV for the gun and 1 to 1000 mA (milliampere) for the current. These systems produce electron beams that can be focused to minimum diameters of 0.25–0.76 mm (0.01–0.03 in.). The resulting power level attainable can reach as high as 100 kW. Power density can reach values of $1.55 \times 10^4 \text{ W/mm}^2$ ($10^7 \text{ W/in.}^2$). These power densities are higher than those possible with arc welding processes and are similar to those achievable with laser beam welding.

The potential welding capability of an electron beam system is indicated by the maximum power density that the system is capable of delivering to the workpiece. This comparison factor depends on the maximum beam power (current x voltage) and the minimum focal spot size the system can attain.

As illustrated in Fig. 2, at power densities on the order of $1.55 \times 10^2 \text{ W/mm}^2$ ($10^5 \text{ W/in.}^2$) and greater, the electron beam can instantly penetrate into a solid workpiece or a butt joint and form a vapor cavity, called a keyhole, which is surrounded by molten metal. This molten metal flows around the keyhole as the beam advances along the joint and solidifies at the rear to form weld metal. In keyhole applications, joint penetration is much deeper than it is wide and a very narrow heat-affected zone is produced. For example, the width of a weld in a butt joint in 13 mm (0.5 in.) thick steel may be as small as 0.8 mm (0.030 in.) when made in vacuum.

Because the electron beam weld resulted from a keyhole formed by the beam, the angle of incidence at which the beam impinges on the surface of a workpiece can affect the final angle at which the keyhole is produced with respect to that surface. The angle of incidence also affects the resulting weld metal zone.
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NEW LITERATURE

**Book Explores Aspects of the History of Welding**

Welding — A Journey to Explore Its Past, by André A. Odermatt, president and chairman of the board of Hobart Institute of Welding Technology, aims to give the reader some basic knowledge of a few aspects of the history of welding and its problems as well as its contributions to society. It ranges from antiquity to modern times, and brazing and forging to gas and electric welding. The book takes the reader on a journey to China, the Middle East, Russia, European countries, and the New World, plus to the areas where the welding industry was founded — around the Mediterranean, Caspian, Black, and Red Seas and the Arabian Gulf. The 184 page book, available in soft- and hardcover editions, may be ordered by phone or from the Web site.

Hobart Institute of Welding Technology  
www.welding.org/c-22-general-welding-books.aspx  
(800) 332-9448, ext. 5433

**Hazardous Materials Regulations Expanded**

The latest regulations covering HazMat issues are combined with useful extras in the DOT/PHMSA Hazardous Materials Regulations, Oct. 2010 edition. The 600-page text is available as a softcover book and in CD format. The document uses the RegLogic® two-color graphical approach to simplify navigating and reading the documents. These regulations are issued by the Department of Transportation, Pipeline and Hazardous Materials Safety Administration, to govern the packaging and transportation of hazardous materials by highway, rail, vessel, and air. Included are 49 CFR A, Hazardous Materials and Oil Transportation; 49 CFR B, Oil Transportation; 49 CFR C, Hazardous Materials Regulations; Enhancing Security against Terrorism; Hazardous Materials Incident Report; Quick-Find Index™; regional office location listings; and a government organizational chart.

MANCOMM  
www.mancomm.com  
(800) 626-2666

**Grinding and Finishing Guide Updated**

The Grinding and Finishing Solutions Guide showcases the company’s lines of flap discs, deburring, weld blending, and finishing products. The new Saber Tooth™ flap disc features a ceramic cloth that provides cool and fast cutting action on aluminum, stainless steel, Inconel®, titanium, and other hard-to-grind metals. Other product lines featured are the original Tiger® disc, a new trimmable Tiger® disc, the economical Vortec Pro™ line, BigCat™ high density discs, and BobCat™ discs for use with air and electric right-angle die grinders. Included are selection guides for abrasive flap disc type, backing type, and grain type to meet specific needs.

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— continued on page 98
The AWS and WEMCO are proud to announce the 2010 Image of Welding Award Winners

Mike Dammann
Large Business Winner
PSEG Fossil
Newark, NJ

James Brantley
Educator Winner
Miami-Dade
Public Schools
Miami, FL

Colleen Grub
Small Business Winner
Colmac Coil Manufacturing, Inc.
Colville, WA

Tim Green
Educational Facility Winner
Gadsden State Community College
Gadsden, AL

Bill Myers
AWS Section Winner
North Central Florida Section

Robert Richwine
Individual Winner
Chesterfield, IN

The American Welding Society (AWS) and The Welding Equipment Manufacturers Committee (WEMCO) are extremely proud to present this year's recipients of the prestigious IMAGE of WELDING Awards.

The awards recognize individuals, educators, education facilities, small & large businesses, and AWS Sections for their respective contributions to promoting and enhancing the welding industry.

Our congratulations to the class of 2010.

For Info go to www.aws.org/ad-index
NEW LITERATURE
— continued from page 96

Construction Math
Released in Extreme-Duty Format

The Construction Math Quick Check: Extreme Duty Edition identifies the mathematical formulas that are most commonly used in the construction industry and simplifies them using a clear step-by-step approach. The guide covers basic conversions, percentages, volume calculations, framing calculations, and clarifies complicated calculations with detailed charts and tables. The 42-page extreme-duty format is SVi x V2, with laminated pages and a durable binding to withstand the rigors of toolbox and job site conditions. The list price is $14.95.

DeWALT®
www.dewalt.cengage.com/QuickCheckSeries.aspx
(800) 433-9258

Palm-Sized Green Laser System Pictured

A four-page, full-color brochure details the Explorer® XP 532-5, a 6.6-lb, 5-W green laser head and power supply combined into a single hand-holdable package. Presented are a verbal description of the unit, technical specifications, multiple dimensioned drawings showing connectors and parts locations, and three graphs: average power vs. pulse repetition frequency; pulse energy vs. pulse rate frequency; and pulse peak power vs. pulse rate frequency. The literature can be downloaded from the Web site.

Spectra-Physics®
www.newport.com/spectra-physics
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CD Presents Dust-Collection Technology

A new product/engineering CD provides a comprehensive electronic catalog of the company’s air-pollution control solutions. Displayed are its complete lines of dust- and fume-collection equipment and technology. In-depth information is presented on dust collectors for all types of applications, including the Gold Series® cartridge collectors featuring the latest HemiPleat® filter technology. Included are product literature, technical data, application guidelines, photos, drawings, and PowerPoint presentations for key products. The CD also contains a library of technical papers and case studies on dust collection topics. No installation is required to run the Windows®-based menu program. Visit the Web site to order the CD.

Camfil Farr APC
www.farrapc.com/product-ed
(800) 479-6801

Full-Line Instrumentation Catalog Updated

The company’s full-line electrical and instrumentation product catalog has been updated to include 45 new product families and 245 additional pages of information. The major lines include industrial fittings, control apparatus, enclosures, lighting, plugs, receptacles, wireless solutions, and solar power sources. Added are corrosion-resistant products throughout each product line. Transition pages highlight information on new products, as well as notable changes to the product line since the catalog’s last printing. To order, visit the Web site or call.

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For info go to www.aws.org/ad-index
The 143-page 2011 Equipment Catalog, Bulletin E1.10, features a new look and removable Welding Gear catalog that details the company’s new Red Line™ welding apparel product line. An online Fast-Flip eBook version is accessible from the Web site. Products include a wide selection of power sources, welding consumables, accessories, automated solutions, and fume-control systems. Updates are detailed for the VRTEX™ 360 virtual arc welding training system, Viking™ welding helmets, Flextec™ 450 power source, Python® guns, a wide range of consumables, and numerous other products and accessories. Visit the Web site to view the catalog or call for a hard copy.

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A 16-page, full-color, well-illustrated brochure details the company’s new line of IPLEX LX and LT industrial videoscopes. The units are small, about 6 lb, with a 1.7-lb handset using TrueFeel™ precise scope tip articulation, quick-access menu buttons, and intuitive icon-based menu commands. Shown are examples of typical images obtained viewing a heat exchanger, gas turbine blade, wind turbine gear box at various gain settings, etc. Detailed are the image-storing features including high-quality JPEG still images and MPEG-4 movies that record into a removable USB flash drive.

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Do You Have Some News to Tell Us?

If you have a news item that might interest the readers of the Welding Journal, send it to the following address:

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Attn: Mary Ruth Johnsen
550 NW LeJeune Rd.
Miami, FL 33126.

Items can also be sent via FAX to (305) 443-7404 or by e-mail to mjohnsen@aws.org.
Noble Gas Solutions, Albany, N.Y., formerly AWESCO, has named Wayne Geraci safety and compliance manager, and Matt White regional manager for the Hudson Valley area. Before joining the company, Geraci worked 24 years at Vertis Communications where he served as corporate training manager and environmental health and safety manager. White previously worked as a facility group operations leader at Target and earlier as a communications/electronics officer in the U.S. Army, Airborne Division.

United Spiral Pipe Names President

Patrick J. Mullarkey has been named president of United Spiral Pipe, Pittsburg, Calif., a joint venture between United States Steel Corp., POSCO, and SeAH Steel Corp. Mullarkey began his career in the industry at Inland Steel in East Chicago, Ind., where he worked for 13 years before joining Raytheon Engineers & Constructors as a lead engineer for the blast furnace reline division where he worked for six years until joining United States Steel in 2000 to serve in the welded spiral pipe operation in the Slovak Republic.

Moser Inducted into Industry Week Hall of Fame

Harry Moser, founder of The Reshoring Initiative, Kildeer, Ill., has been inducted into the Industry Week Manufacturing Hall of Fame. Individuals are selected for this honor based upon their overall contributions to American manufacturing. In the industry for 40 years, Moser spent 22 years as president of Charmilles Technologies Corp., now GF Agie Charmilles, where he served as chairman emeritus. He retired from that position last month and now works full time at Reshoring Initiative. The Reshoring Initiative is supported by GF Agie Charmilles, the Association for Manufacturing Excellence, The National Tooling & Machine Tool Society, and the Swiss Machine Tool Society.

ASQ Global Names Managing Director

John T. Fowler has been named managing director of ASQ Global based at the society’s world headquarters in Milwaukee, Wis. Fowler has more than 30 years of experience in the pharmaceutical industry, including executive roles in sales and marketing. Most recently, he served as chief global services officer for the United States Pharmacopeial Convention.

Steel Market Development Institute Names Director

The Steel Market Development Institute (SMDI), Washington, D.C., a business unit of the American Iron and Steel Institute (AISI), has promoted Deanna S. Lorincz to senior director, SMDI communications. Lorincz joined AISI in 2001 as assistant manager of automotive market communications and later was promoted to director of automotive communications.

Northwire Appoints Regional Sales Managers

Northwire Technical Cable, Osceola, Wis., has hired Greg Reese as eastern regional sales manager and Howard Fish as western regional sales manager. Reese has more than 16 years of experience as a product manager, sales manager, and design engineer for cable assembly and electrical connection systems. His region includes 17 states in the eastern third of the country. Fish, with 30 years of marketing experience, will manage sales in 12 western states and Hawaii.

Koike Aronson Announces Employee Changes

Koike Aronson, Arcade, N.Y., has named Kenny Yokono a positioner sales engineer, and Shigeru Ohki as an electrical engineer. Matt Beardsley, formerly the quality manager, has been promoted to waterjet specialist. Yokono joined the company a year ago as a sales engineer in the Positioner Dept. to learn the quoting process before returning to Koike Sanso Kogyo Co., Ltd., (KSK) in Japan to make sales. Ohki has worked for KSK for the past 21 years as an electrical engineer. He is at the New York facility to learn its technology and structure in order to globalize technology throughout all of the Koike Groups.

ICALEO® Honors Two

Two Nobel prize winners were honored by the Laser Institute of America (LIA), based in Orlando, Fla., at the institute’s International Congress on Applications of Lasers and Electro-Optics (ICALEO®) held last September in Anaheim, Calif. U.S. Secretary of Energy Steven Chu received the 2010 Arthur L. Schawlow Award for his development of methods to cool and trap atoms with laser light and work as director of the Dept. of Energy Lawrence Berkeley National Lab and professor of physics and molecular and cell bi-
ology at the University of California, Berkeley. He received a silver medal, a special citation, and became a Fellow and Lifetime Member of LIA. Laser pioneer Charles Hard Townes was presented LIA's first Lifetime Achievement Award for his research work at Columbia University and Bell Telephone Laboratories that culminated in the seminal text, Microwave Spectroscopy, and the paper, Infrared and Optical Masers. His award includes a citation, cash prize, and elevation to the status of Fellow and Life Member of the institute.

**Director Named for Image of Welding Committee**

The American Welding Society and Welding Equipment Manufacturers Committee (WEMCO) have named Phillip Wittke chair of the Image of Welding Committee and to serve as a member of the WEMCO executive board. Wittke is with The Lincoln Electric Co. as director of marketing. He has more than 24 years of experience in the welding industry in Hong Kong, Taiwan, Australia, Indonesia, and Thailand.

**Eriez® Names Director**

Eriez®, Erie, Pa., a supplier of technology for magnetic, vibratory, and inspection applications, has promoted Dan Zimmerman to the new position of director of business development. Prior to this assignment, Zimmerman served as manager-sales/service support as well as market manager-metalworking.

**Obituary**

**Walter P. Simmons**

Walter P. Simmons, 76, died Nov. 28 in St. Clair, Mich. He started his career working for Welding Sales & Engineering Co. in Detroit, Mich. His father added another division to this company called Tuffaloy Products. The entire operation was later sold to Air Reduction Corp. in New York. He was an AWS member for 32 years, affiliated with the Detroit Section. After his father retired, Simmons continued to operate Tuffaloy. In 1963, he negotiated to purchase Tuffaloy from Air Reduction. Simmons was a key figure in the resistance welding industry. He served as 1967-1968 president of the Resistance Welding Manufacturers Association (now called the Resistance Welding Manufacturers Alliance). He received the prestigious Elihu Thompson Resistance Welding Award in 1999. Simmons is survived by his wife, Carroll, a daughter, and two sons.

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**CAN WE TALK?**

The *Welding Journal* staff encourages an exchange of ideas with you, our readers. If you’d like to ask a question, share an idea or voice an opinion, you can call, write, e-mail or fax. Staff e-mail addresses are listed below, along with a guide to help you interact with the right person.

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## POSTER ABSTRACT SUBMITTAL
### Annual FABTECH International & AWS Welding Show
Chicago, IL – November 13-16, 2011

**Submission Deadline: April 22, 2011**

*(Complete a separate submittal for each poster.)*

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- Only those abstracts submitted on this form will be considered. Follow the guidelines and word limits indicated.

  Complete this form using MSWord. Submit electronically via email to mventura@aws.org or print and mail.

- Any technical topic relevant to the welding industry is acceptable (e.g. welding processes & controls, welding procedures, welding design, structural integrity related to welding, weld inspection, welding metallurgy, etc.).

- Submittals that are incomplete and that do not satisfy these basic guidelines will not be considered for competition.

- Poster accepted for competition will be judged based on technical content, clarity of communication, novelty/relevance of the subject & ideas conveyed and overall aesthetic impression.

**Criteria by category as follows:**

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<td>(800) 443-9353</td>
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<td>.49</td>
<td><a href="http://www.sciaky.com">www.sciaky.com</a></td>
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<td>Select Arc, Inc.</td>
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<td><a href="http://www.select-arc.com">www.select-arc.com</a></td>
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<td>Uniweld Products, Inc.</td>
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<td><a href="http://www.uniweld.com">www.uniweld.com</a></td>
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<td>Weld Hugger, LLC</td>
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<td><a href="http://www.weldhugger.com">www.weldhugger.com</a></td>
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<td>Weldmex/FABTECH Mexico</td>
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Retro Systems, Hypertherm, Motoman, and Miller Electric, the facility is located in Grand Rapids, Mich. It adjoins Airgas’s 28th St. retail store, features updated automation equipment, is designed with demonstrations in mind, and accommodates different groups, making it useful for one-on-one discussions with production engineers and technology education sessions with students.

“We developed this automation center based on our belief that the long-term health of American industrial production is going to require increased levels of automation,” said David Clubb, an Airgas automation specialist.

The center will also be used for educational events with increasing frequency. The center is open by appointment as well.

Industry Notes

• The Office of Naval Research awarded Concurrent Technologies Corp. a competitively bid contract to maintain operation of the Navy Metalworking Center for the next five years. The Indefinite Delivery Indefinite Quantity contract has a two-year base period, three option years, and a ceiling of $99 million.

• The Fisher-Barton Group of Companies will construct an 1800-sq-ft, multimillion dollar addition to the materials lab in Watertown, Wis., featuring chemical analysis equipment.

• Lincoln Electric Holdings, Inc., Cleveland, Ohio, signed an agreement to acquire Mezhgostezet-Mtsehsk OAO, a welding wire manufacturer in Russia’s Orel region, and it also partnered with IPG Photonics Corp. to explore global opportunities in the high-power laser welding and cutting market.

• Grainger expanded its Tools for Tomorrow® scholarship program. In the 2010–2011 academic year, it will offer 75 community colleges across the United States two $2000 scholarships to award to community college students in industrial trades programs such as welding. For more details, go to www.grainger.com.

• E&E Manufacturing, Plymouth, Mich., is now accredited by the American Association for Laboratory Accreditation. This covers ferrous and nonferrous metals, is to ISO/IEC 17025:2005 standards, and allows the company to perform many tests.

• AWESCO, Albany, N.Y., a gas and welding equipment distributor, recently launched its new name, Noble Gas Solutions.

• El Paso Community College and The University of Texas at El Paso joined forces to help create future engineers. An articulation agreement recognizes enhancing educational opportunities for their students in the movement with both campuses.

• Camfill Farr Air Pollution Control opened a sales and service office in Gurabo, Puerto Rico, for users in the Caribbean.

• The Steel Market Development Institute is celebrating the use of high-strength steel in the structure for Chevy Volt’s plug-in electric vehicle, which is also Motor Trend’s Car of the Year.

• New Orleans-based Axon Calc, LLC, has been launched to create Web and mobile calculator applications for the engineering industry. For more information, visit AxonCalc.com.

• More than 40 industrial gas distributors attended the 15th annual meeting of the Airco Distributor Association in Miami, Fla. At the event, 21 vendors participated in various sessions.

• Insteel Wire Products Co., the wholly owned subsidiary of Insteel Industries, Inc., purchased certain assets of Ivy Steel & Wire, Inc., for a purchase price of approximately $51.1 million.

• National Metals, DeForest, Wis., is capable of processing complex parts from virtually any material with its new 60,000 lb/in² Jet Edge Mid Rail Gantry water jet cutting system.

• The 2010 Distributor of the Year honor for TRUMPF’s TruMark sales went to Gosiger Dayton, an Ohio-based company that represents the laser marking products.

• Northwire Technical Cable, Osceola, Wis., teamed with Patriot Technical Sales, Auburn, Mass., where its mil-spec, technical and retractile cables, and assemblies will be represented.

• The Custom Carbide Tools blog at www.customcarbidetools.com offers help to manufacturers seeking to reduce project costs in the aerospace, automotive, and marine industries. *

COMING EVENTS

— continued from page 56

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All papers published in the Welding Journal's Welding Research Supplement undergo Peer Review before publication for: 1) originality of the contribution; 2) technical value to the welding community; 3) prior publication of the material being reviewed; 4) proper credit to others working in the same area; and 5) justification of the conclusions, based on the work performed. The following individuals serve on the AWS Peer Review Panel and are experts in specific technical areas. All are volunteers in the program.

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Investigation on Welding Mechanism and Interlayer Selection of Magnesium/Steel Lap Joints

The addition of interlayers into lap joints was found to be beneficial to the improvement of joint shear strength

BY X.-D. QI, AND L.-M. LIU

ABSTRACT

Mg-Al-Zn alloys and Q235 mild steel were successfully joined in a lap joint with a hybrid laser-GTAW process. Fracture locations, joint strength, and fracture surfaces were observed. The results showed that the fracture locations of direct joints usually occurred at the Mg alloy/steel interface, while that of interlayer-added joints occurred across the fusion zone. The joint shear strength of a direct joint was much lower than that of interlayer-added ones, and the strength of Sn-added joint was actually the tensile strength. With the addition of interlayers, the type of joint rupture changed from cleavage to quasi-cleavage, indicating that the joint plasticity was improved, and the wettability of the melt on steel was also enhanced. The conclusions were that the wettability contributed to a compact metallurgical bonding between the weld metal fusion zone and steel, and thus to the improvement of joint shear strength. The interlayer selection should follow the principle of elevating its wettability on steel and avoid massive production of brittle intermetallics in the joint. The content of the interlayer is also discussed.

Introduction

Magnesium alloys, with their unique properties such as lower density, electromagnetic shielding, and damping capabilities (Ref. 1), have great potential for industrial applications. At present, steel is still one of the dominant materials in industry. Joining the two types of materials would achieve weight reduction and energy savings in the aerospace, aircraft, and automotive fields. Since the physical and chemical differences between the two materials such as melting temperature, electrical potential, and crystal structure are huge, and there is no interaction according to the Mg-Fe binary diagram, it is difficult to join them together. When gas tungsten arc welding (GTAW) with a greater heat input was applied to weld the two materials in any joint configuration, two cases occurred. One was that Mg alloys melted but the steel did not, and the other was that the steel melted while big holes formed in the Mg alloys. In both cases a joint could not be obtained. It is impossible for the two materials to be melted at the same time because the melting temperature of steel is as high as 1500°C and the boiling temperature of magnesium is as low as 1090°C, while the melting temperature of the magnesium is rather low up to 650°C. When the pulsed Nd:YAG laser beam welding process was used, the two materials could be joined together, although the weld appearance was rather poor and the joint strength did not reach practical use. Moreover, due to 3–10% electro-optical transformation efficiency and 8–20% absorptivity for Nd:YAG laser (Ref. 1) of Mg alloys at room temperature, a large amount of electricity would be consumed by laser, which conflicts with the present appeal of energy saving. However, the molten Mg alloys can absorb nearly 100% of the laser (Ref. 1), thus GTAW can be used to melt Mg alloys, while the laser could be employed to create deeper penetration (Ref. 2) into the steel. In view of the complexity of the assembly of the workpiece and relevant studies of our team (Ref. 3), a lap joint configuration was adopted. In the present study, an orderly combination of laser and GTAW in a hybrid welding process was investigated as an alternative choice (Refs. 4, 5) for joining Mg alloy to mild steel in a lap joint. A lower GTAW current can melt the Mg alloy fully without excessive consumption of laser energy, and the laser creates sufficient penetration, so the advantages of both processes are utilized to their maximum. Consequently, using the two processes together is possible, and the aim of saving energy can be achieved.

Watanabe (Ref. 6) reported that the joint strength was improved with the insertion of metal by resistance spot welding; nevertheless, excessive inserted metal could decrease the strength of the joint. D. Pierre (Refs. 7, 8) examined the chemical reaction between mild steel and liquid Mg-Si and Mg-Mn alloys. It showed that only the intermetallics and solid solutions of Fe-Si and Fe-Mn were detected at the Mg alloy/steel interface without interdiffusion between Fe and Mg elements, which indicates a Mg alloy/steel joint with higher strength may be realized with the addition of alloying elements. Our previous works (Refs. 9, 10) studied that the bonding mode of Ni- or Cu-added joints was “semimetallurgical.” What is more important is the joint shear strength was improved significantly with the addition of alloying elements into the lap joint. Generally, wetting in metal to metal is a vital factor in soldering and brazing (Refs. 11, 12), and it usually depends on the contact angle. The adhesion of molten metal on a solid one also depends on the contact angle, suggesting that the adhesion is closely related to the wettability. According to our previous works (Refs. 9, 10, 13), with the ad-

KEYWORDS

Mg Alloy
Steel
Wetting
Hybrid Welding
Laser-GTAW
dition of alloying elements, no gaps were found that could deteriorate the joint shear strength between the fusion zone and steel in the weld pool. Therefore, the aim of this study was to use the wettability of AZ31B Mg alloy on mild steel, with and without the addition of interlayer elements, to interpret the above phenomenon of gap disappearance, and to reveal the joint-bonding mechanism and to explore the principle for joint interlayer selection.

Experimental Procedure

Materials

The materials used were 2-mm-thick plates of AZ31B and AZ61 Mg alloy and 1.2-mm-thick sheet of Q235 steel, which is equivalent to Cr.D steel of AST-USA or E235B of 630-ISO. Their composition is shown in Table 1. They were all in dimensions of 60 × 80 mm. Interlayer materials were Ni, Cu, and Sn with purity of 99.9 wt-%, and Cu-Zn alloys that were H80 and H62. Their composition is shown in Table 2. All the interlayers were 0.1 mm thick and cut into 5–8 × 70 mm. Before welding, the base and interlayer materials were all rinsed and ground.

Welding Process

A lap joint of Mg alloy on steel plate was adopted with the overlapping width of 10–15 mm. The interlayer was set between the two materials as shown in Fig. 1A. The hybrid heating source is also shown in Fig. 1A. The axis of the Nd:YAG pulsed laser equipped with a GTAW torch was perpendicular to the plate of Mg alloy. The acute angle between the two axes was 40 deg as shown in Fig. 1A. The joint would not be formed without the penetration depth into the steel created by the laser, which is seen in the joint cross section shown in Fig. 2. Thus, it can be said that the laser has a leading role during welding. The welding parameters for optimum shear strength of all the interlayer-added and direct joints are shown in Table 3.

Tensile Shear Test

After welding, the weldment was cut into 10-mm-wide specimens. A sketch of it is shown in Fig. 1B. The tensile shear test was carried out with a travel speed of 2 mm/min at room temperature. The shear strength was calculated according to the following equation:

\[ \sigma_{\text{shear}} = \frac{F}{S_{\text{eff}}} \]

where \( F \) and \( \sigma_{\text{shear}} \) are the load and the ultimate tensile shear strength (UTSS), respectively; \( S_{\text{eff}} \) at the joint interface between the interlayer and steel is an initial rectangular bonding area with the width of

### Table 1 — Chemical Compositions of Base Materials (wt-%)

<table>
<thead>
<tr>
<th></th>
<th>Mg</th>
<th>Al</th>
<th>Zn</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>C</th>
<th>Fe</th>
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</thead>
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<tr>
<td>AZ31B</td>
<td>Bal.</td>
<td>2.5–3.5</td>
<td>0.6–1.4</td>
<td>0.2–1.0</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.0025</td>
</tr>
<tr>
<td>AZ61</td>
<td>Bal.</td>
<td>5.5–7.5</td>
<td>0.5–1.5</td>
<td>0.15–0.4</td>
<td>≤0.018</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>≤0.01</td>
</tr>
<tr>
<td>Q235 mild steel</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.30–0.65</td>
<td>0.12–0.30</td>
<td>≤0.045</td>
<td>0.050</td>
<td>0.14–0.22</td>
<td>Bal.</td>
</tr>
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Experimental Simulation

As wetting the steel with a Mg alloy is also a vital process during welding, the AZ31B Mg alloy, with and without interlayers, was used to examine whether the wettability of the melt was improved. In

Microstructure Observation

Ruptured specimens after the tensile shear test were reassembled to identify the fracture location, and the transverse sections, which were etched by Nital's reagent (volume 4% HNO₃ ethanol), were observed by scanning electron microscope (SEM) and optical microscopy. The fracture surfaces were also observed by SEM.

Table 2 — Chemical Compositions of Cu-Zn Alloys (wt-%)

<table>
<thead>
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<th></th>
<th>Cu</th>
<th>Zn</th>
<th>Fe</th>
<th>Pb</th>
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<td>H80</td>
<td>81</td>
<td>18.87</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>H62</td>
<td>61.5</td>
<td>38.32</td>
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<td>0.03</td>
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Table 3 — Welding Parameters in the Experiment

<table>
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<th>Value</th>
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<td>Laser Power, W</td>
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<td>Laser Focal Spot, mm</td>
<td>0.6–0.8</td>
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<td>Defocus, mm</td>
<td>–2.5</td>
</tr>
<tr>
<td>Pulse Frequency, Hz</td>
<td>33</td>
</tr>
<tr>
<td>Welding Speed, mm/min</td>
<td>750</td>
</tr>
<tr>
<td>Argon Flow Rate, L/min</td>
<td>5 for laser, 15 for GTAW</td>
</tr>
<tr>
<td>GTAW Current, A</td>
<td>75</td>
</tr>
<tr>
<td>Arc Length, mm</td>
<td>0.8–1</td>
</tr>
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</table>
addition, the wettability of AZ61 Mg alloy was examined.

Alloy Preparation

A typical transverse section of an interlayer-added joint is shown in Fig. 2. The depletion of the interlayer, which interacted with molten Mg alloy in the fusion zone (FZ), could be estimated from the size of area shown in Fig. 2, and each interlayer depleted accounts for 10~18 wt-% of the FZ, therefore the Mg alloy in the wetting experiment can be alloyed by those interlayer elements. Then the Mg alloys AZ31B-Ni, AZ31B-Cu, AZ31B-Sn, AZ31B-H80, and AZ31B-H62 were all prepared in the same amount of 1.5 g, which was estimated according to the melted content statically by laser-GTAW in 1 s.

Wetting Procedure

The sessile drop experiment (Ref. 14) was employed to study wettability. During the experiment, a high-purity argon gas atmosphere was maintained inside a furnace. The sample placed in the furnace was a steel plate with 1.5 g of Mg alloy on it. The furnace was heated up to 10~20°C higher than the liquidus temperature, which was determined on the basis of interlayer element-Mg binary phase diagrams. The furnace would hold at that temperature for 30 min to achieve equilibrium state, which was to keep the contact angle of the melt constant. Thereafter, a few protective agents that could not interact with but only wrap the melt were added to the sample, and thus it could be taken out of the furnace and swiftly cooled to room temperature to imitate the cooling process of welding. Finally, the contact angles were recorded and measured by a camera system. The contact angles were average values of at least three samples.

It is well known that the arc and laser of a hybrid heating source could generate extremely high temperatures up to 3000~4000°C in several microseconds (10^-6 s), which means that the melt in the weld pool could be heated to a rather high temperature. Thus, the melt could well wet on steel at that high temperature because the wettability can be enhanced with the increase of temperature (Refs. 15, 16). While the heating rate of the furnace could not reach that high, insulation for a long time would be an alternative method to keep contact angles of the melt constant (Refs. 10, 17).

Results

Figure 3 shows the morphology of a weld joint. It can be seen that some little bulges (pointed out by the arrows) are presented at the surface of the joint, and the ripples of the joint are generally regular except at the right end. When the hybrid welding moves to the end where the surfaces of the workpiece and working platform are not at the same level, the change of arc length leads to variation of arc voltage immediately, and then to the change of heat input, causing a bad appearance at the end of the joint.

Figure 4 shows the fracture locations of the joints with different Mg alloys. The dotted line in Fig. 4A presents a typical fracture path between AZ31B Mg alloy and Q235 steel. Most of the FZ is detached from the steel, and the residual part inside the molten pool bonded well with the steel. The bonding in Fig. 4B is better than that shown in Fig. 4A, indicating that the bonding between the two materials is more compact. As the load direction is parallel to the joint interface during shear test, and the crack initiation usually occurs at oval regions, the FZ would be subjected to shear force, and thus, the position where the poor metallurgical bonding between the Mg alloy and steel was located would fracture first. Some particles can also be seen in the FZ of both images, suggesting that spatter occurred in the welding process.

The fracture locations of the joints with various interlayers are presented in Fig. 5. From Fig. 5A, B, and D, it can be seen that
Fig. 8 — Schematic view of the welding process.

The joint, which is actually the tensile strength, of base metal AZ31B Mg alloy, which is with direct joint, the shear strength of Ni, 5C was formed. In view of nonuniform process. Thus, the pattern shown in Fig. 5C was formed. In view of nonuniform compositions adjacent to the melting line in the FZ, the fracture is prone to occur in the square region shown in Fig. 5C. However, the residual part embedded into the steel combines with the steel closely, and the same cases of the cracked joints could also be seen in Fig. 5A, B, and D. It is interesting and noticeable that they are bonded well with steel, which is discussed later.

The joint shear strength with different interlayers is shown in Fig. 6. Comparing with direct joint, the shear strength of Ni, Cu, and Cu-Zn alloy-added joints increases significantly or even surpasses that of base metal AZ31B Mg alloy, which is 160 MPa, denoted by the dash dot line. However, the strength of the Sn-added joint, which is actually the tensile strength, shows comparatively lower value. As mentioned above, the Sn interlayer could not maintain its original state, which led to inhomogeneous compositions in the FZ and deteriorated joint properties. From the role that the laser-GTAW hybrid welding technique and interlayers play, Fig. 6 can tell us that the technique could be utilized to join Mg alloy and steel, and with the addition of suitable interlayers, the joint shear strength could reach a significantly high value. Accordingly, the hybrid welding technique is a major premise for joining the two materials, and is a determining factor during welding, while in order to obtain a joint with higher shear strength, the addition of an interlayer is a must. Consequently, without the laser-GTAW hybrid welding technique, a joint could not be realized; and without suitable interlayers, the joint shear strength could not reach a high value.

Figure 7 shows fractographs of the joints after tensile shear test. Figure 7A presents some massive steps and large cleavage planes with flat surfaces, indicating that the direct joint exhibits brittle fracture features. With the addition of Ni and Cu interlayers, more and more tearing arises and little cleavage flat planes are shown in Fig. 7B and C, suggesting that the joint fracture presents both ductile and brittle features, which is so-called quasi-cleavage fracture. It implies that Ni- and Cu-added joints possess certain plasticity that may also be one of the reasons that the shear strength of both joints is higher than that of the direct joint. In Fig. 7D, an obvious boundary along the dashed line can be seen. The fracture surface upon the line is rougher than that below the line. As the fracture surface was obtained from the square regions in Fig. 5C, the part above the line is the fracture surface adhering to the upper part of the FZ, and the other beneath the line is the fracture of remelted Sn, showing that the upper fracture is more ductile than the lower one, and also testifying that the nonuniform composition in the FZ is adverse for joint performance. The case of fracture surface in Fig. 7C is almost the same to that of Fig. 7B and C; however, the fracture surface of H62-added joint in Fig. 7F is a little different from that of Fig. 7E, because there are much finer cleavage planes on the surface, suggesting that the fracture of the joint is inclined to fragile rupture, but is still more ductile than that shown in Fig. 7A.

Discussion

Solidifying Process

In the laser-GTAW hybrid welding process of lap joining AZ31B Mg alloy to Q235 mild steel, the Mg alloy was the first to melt when the hybrid heating source was applied. Once the steel was melted, the Mg element was drastically gasified as shown in Fig. 8. As the melting temperature of Q235 steel is as high as 1500°C, which is much higher than the 1090°C boiling temperature of Mg, the gasification of Mg inevitably occurs. With the welding process moving on, the rest of the molten Mg alloy would flow back to fill the space and weld pool created in the steel. Transverse sections are shown in Figs. 4 and 5. When the interlayer was added into the joint, the interaction between the Mg alloy and the interlayer, and that between the interlayer and the steel, should be considered. However, it is noticeable that before the Mg alloy was melted, the Sn interlayer must have been in a liquid state due to its rather low melting temperature of 232°C. There-
fore, an irregular shape after solidification is shown in Fig. 5C. As for the Cu-Zn interlayer, from H80 to H62, the content of Zn element increased from 20 to 38 wt-% inside the interlayer, while the boiling temperature of Zn, which is 906°C, is also lower than the melting temperature of steel, thus spatter appears more drastically than that of other joints during welding.

**Wetting Behavior in the Welding Process**

As the hybrid heating source moved along, the solidification process took place. However, the molten steel had to be solidified prior to the molten Mg alloy so that the melt of the Mg alloy could nucleate on the sites provided by the solidified steel. A key factor that determines whether a melt could nucleate well on a site is the wetting behavior of liquid on solid. The wettability can be estimated by the contact angle (Ref. 17). The smaller the contact angle is, the better the wettabili-

$$\theta = \sin^{-1}(1 + \cos \theta)$$

(1)

where \(\theta\) is the contact angle and \(\theta_{lv}\) is interfacial energy of liquid/vapor. Based on the reports of Ksiazek (Ref. 17) and Shen (Ref. 20), the relationship between the interfacial energy of the melt and temperature could be expressed simply as follows:

$$\theta_{lv} = C_0 - C_1 (T - C_2)$$

(2)

where \(C_0, C_1, \) and \(C_2\) are constant, and \(T\) is temperature of the experiment. It can be seen that the interfacial energy \(\theta_{lv}\) decreases with increase of temperature in liquid state, which is beneficial to the improvement of wettability in terms of Young’s equation (Ref. 21). However, a differential equation on temperature to Equation 1 is shown below

$$W_a(T) = C_3 + C_3 \cos \theta - \sin \theta(T)\theta_{lv}$$

(3)

where \(C_3\) is still constant. During welding, the variation of temperature is rather swift, which means that the temperature in the weld could reach extremely high or low values in a short time, and the wetting behavior would keep on until the melt solidified completely. The contact angle can become rather small or even invariable with increasing temperature (Refs. 21–23), while \(\sin \theta\) and \(\theta_{lv}\) in Equation 3 would be small enough, thus the third term on the right of Equation 3 can be eliminated. Therefore, in the welding process, it could be seen that the variation of \(W_a\) to temperature could only be associated with contact angle, and the effect of \(\theta_{lv}\) can be almost neglected, indicating that \(\theta_{lv}\) could be seen as a constant during the wetting experiment. The increment of \(W_a\) could improve the interfacial shear strength (Ref. 21) and thus the bonding between two materials. The contact angle \(\theta_0\) of molten AZ31B Mg alloy on Q235 steel is 143 deg as shown in Fig. 9A, while \(\theta_1\) in Fig. 9B is 114 deg, indicating that the wettability of molten Mg alloy on steel is improved with the addition of alloying element Al, and that Al could be used as a sort of active element (Ref. 24) that contributes to the improvement of wettability of molten Mg alloy on steel. Compared with the lap joints shown in Fig. 4, molten AZ61 Mg alloy is easier to nucleate on the site of the steel, and thus the bonding between them is more compact, which could also be seen from the maximum shear strength comparison that is 101 MPa for AZ31B joint and 125 MPa for AZ61 joint (Ref. 25).

The fracture location shown in Fig. 5 indicates that although the bonding between the FZ and steel is mechanical according to our previous works (Refs. 9, 10), they are all bonded compactly with each other in the tensile shear test. Due to the formation of the fracture mode. Consequently, the phenomenon of the fracture location in Fig. 5 can be comprehended easily. Meanwhile, with the addition of interlayers, the wettability of molten metal in the weld was improved substantially, as the gaps disappeared between the FZ and steel (Refs. 9, 10), and thus the bonding between the FZ and steel was enhanced greatly. Accordingly, the wettability of AM was advanced is mainly attributed to the wetting on steel by those elements se-

**Shear Strength Improvement**

The penetration depth into the steel was an important factor for strength improvement. Obviously, if there was no penetration depth into the steel, there would be no lap joint strength. The effect of penetration depth on the joint shear strength was investigated by other reports (Ref. 25) and Shan (Ref. 26), and the results showed that the strength would be elevated with the increase of penetration depth. The optimum shear strength of the direct joint in Refs. 25 and 26 is not more than 125 and 123 MPa, respectively, indicating that deeper penetration could not increase the shear strength further. Moreover, gaps could be found between the FZ and steel (Refs. 10, 13) in direct joints, which may be one of the reasons that the joint shear strength degraded. The fracture location shown in Fig. 4A also verifies the effect of the gaps, suggesting that the bonding between the Mg alloy and steel is really poor. However, with the addition of interlayers, the wettability of molten metal in the weld was improved substantially, as the gaps disappeared between the FZ and steel (Refs. 9, 10), and thus the bonding between the FZ and steel was enhanced greatly. Consequently, the phenomenon of the fracture location in Fig. 5 can be comprehended easily. Meanwhile, with the addition of interlayers, a lot of intermetallics, which play a vital role in the joint strengthening effect (Refs. 10, 25), were generated in the FZ, and the bonding mode changed from complete mechanical to “semitemetalurgical” (Refs. 9, 10, 25). Accordingly, the joint shear strength improved significantly as shown in Fig. 6. Besides, from the joint fracture surface of Fig. 7, it can be inferred that the joint also gained certain plasticity with the interlayer addition due to the transformation of the fracture mode.

**Interlayer Selection**

Actually, the reason that the wettability of AM was advanced is mainly attributed to the wetting on steel by those elements se-
lected. As the wettability of Cu, Ni, Sn, or Zn on steel is good (Refs. 15, 27, 28), the AM in the weld pool could well wet on steel after the addition of these elements. Theoretically, the more these elements were added into the AZ31B Mg alloy, the more the wettability of the AM on steel was improved. However, in the present experiment, taking the Cu-added joint as an example, when the content of Cu was up to more than 30 wt.-% of the FZ, the weld appearance was good without penetration depth into the steel or rather bad with big holes, both of which would cause the joint shear strength to decrease drastically. In the present experiment, approximately 30 wt.-% of Cu corresponds to a 0.3-mm-thick Cu interlayer, which if added into the joint can lead to weld failure. The optimized parameters used in the experiment were set for joining 2-mm-thick Mg alloy to 1.2-mm-thick steel in a lap joint. Increasing either laser energy or GTAW current could degrade the joint bonding. Hence, the amount of Cu interlayer should be confined within but excluding 30 wt.-%. Although molten Al could wet well on steel (Ref. 29), the selection of it may not be suitable for the joint. Massive brittle phases Mg7Al12 and Mg2Al3 (Refs. 30, 31) could be produced during welding, which would embrittle the joint and deteriorate the strength. Therefore, joint embrittlement should be avoided with interlayer selection.

Conclusions

With the addition of interlayers, the wettability of AZ31B Mg alloy on steel was significantly improved. Some conclusions are as follows:

1) The bonding of interlayer-added joints is more compact between the fusion zone and steel than that of direct joints.
2) Better wettability and deeper penetration in the weld contribute to greater shear strength in a lap joint. With the lack of either, the joint strength could not achieve higher value.

The principle of interlayer selection for a lap joint between Mg alloy and steel is as follows: First, the wettability of alloying elements on steel should be good, indicating that the contact angle ought to be as small as possible; second, the amount of the interlayer used during welding depends on the thickness of base materials. In terms of 2-mm-thick Mg alloy and 1.2-mm-thick Q235 steel, the best content of Cu, Ni, and Cu-Zn alloy is in the range of 10–18 wt.-% or 0.1-mm-thick interlayer; third, massive production of brittle intermetallics should be avoided with the addition of selected interlayer.

Acknowledgments

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References

Laser Welding of High-Strength Galvanized Steels in a Gap-Free Lap Joint Configuration under Different Shielding Conditions

By designing the specific shielding conditions, completely defect-free lap joints of the galvanized steels in a lap joint configuration are achieved by a single laser beam without pre- and postweld processing

BY S. YANG, B. CARLSON, AND R. KOVACEVIC

Introduction

In order to reduce fuel consumption, enhance passenger safety, and improve corrosion resistance, different grades of high-strength galvanized steels are increasingly used in the automotive industry. In the past, the high-strength galvanized steels used in the automotive industry were commonly joined with resistance spot welding. Considering the high speed, low heat input, deep penetration, and high flexibility of laser beam welding, the automotive industry has shown significant interest in applying high-powered lasers to joining galvanized steels. However, it is difficult to achieve a high-quality weld of galvanized steels in a lap joint configuration with using a single laser beam because of the presence of highly pressurized zinc vapor. The boiling point of zinc is 906°C, which is lower than the melting point of steels (over 1500°C). During laser welding of galvanized steels in a gap-free lap joint configuration, the highly pressurized zinc vapor is easily developed at the interface of the two metal sheets. The highly pressurized zinc vapor expels the liquid metal out of the molten pool and produces weld defects such as spatter and porosity during the laser welding process. These defects significantly degrade the mechanical properties of the weld joints.

In the past several decades, many efforts have been made to suppress the effect of the highly pressurized zinc vapor on the weld quality. The American Welding Society requires complete removal of the zinc coating layer at the interface of two metal sheets along the weld interface prior to laser welding (Refs. 1, 2). Currently, setting a small gap between the two metal sheets is a common way for industries to join the galvanized steels in a lap joint configuration (Ref. 3). Mazumder et al. (Refs. 4–6) developed a technique of alloying the zinc with the copper before the steel is melted. The melting point of the copper-zinc compound is 1083°C (between the melting temperature of steel and the boiling temperature of zinc). However, the solubility of copper into the steel could lead to additional problems such as hot cracking and corrosion (Ref. 7). Redesigning the lap joint to allow the zinc vapor to be evacuated, prior to the molten pool reaching the interface of two metal sheets, has been explored in order to mitigate the effect of the zinc vapor (Refs. 8–11). In addition, Pennington et al. (Refs. 12, 13) proposed to deposit a nickel coating along the weld interface after stripping off the zinc coating at the interface of two metal sheets. The nickel has a melting point of 1453°C, which is higher than the boiling point of zinc. By replacing the zinc coating with a nickel coating in the weld area, the laser welding process becomes stable and accompanied by an associated corrosion protection. Unfortunately, this method will impose additional cost and reduce productivity. Pulsed laser (Ref. 14), dual laser beam or two lasers (Refs. 15–20), and hybrid laser welding...
(Refs. 21–24) were also used to weld galvanized steels in a gap-free lap joint configuration. Guanini et al. (Ref. 18) modified the dual beam to join the galvanized steel sheets in a gap-free lap joint configuration where the first beam cut a slot to provide an exit path for the zinc vapor and the second beam was applied to join the metal sheets. However, experimental results demonstrated that spatter and porosity were still present in the lap joints. The laser-arc hybrid welding technique was also used by Kim et al. (Ref. 24) to join SGCD1 galvanized low-strength steel with a 1.0-mm thickness in a gap-free lap joint configuration. It was revealed that the formation of porosity was the main concern when using hybrid laser-arc welding of galvanized steels. In addition, they showed that process instability was the main cause of the generation of spatter and porosity in the welds. Spatter significantly damaged the torch electrode and the porosity lowers the mechanical properties of the welds. Additionally, Gu et al. (Ref. 25) also introduced the arc into the laser welding process where two heat sources share the common molten pool. They claimed that the arc enlarges the molten pool providing more space for the zinc vapor to escape. However, spatter and porosity were still observed in the welds. Recently, a method was proposed and patented by Li et al. (Refs. 26, 27) in which a thin aluminum foil layer was placed along the weld interface to form an Al-Zn alloy during the laser welding process. They claimed that the level of the zinc vapor pressure was decreased through the formation of the Al-Zn alloy. In order to achieve high-quality lap joints, the two metal sheets should be tightly clamped. Li et al. (Ref. 27) claimed that if a gap existed at the interface of two metal sheets, weld defects would be produced in the welds. Furthermore, the weld became brittle due to the dissolution of aluminum-steel alloy into the weld. Recently, Yang and Kovačević (Ref. 28) proposed a new welding procedure, which is a combination of a fiber laser with a gas tungsten arc welding (GTAW) torch used to preheat the top surface of the galvanized metal sheets. The GTAW preheating process burns the zinc coating at the top surface of the metal sheet, which helps in generating a thin film of the metal oxides (Ref. 28). The heated surface with the thin film of metal oxides will drastically improve the absorption of laser beam energy into the welded material. Furthermore, the zinc coating at the interface of the two metal sheets is transformed into zinc oxides, which has a higher melting point (above 1900°C) than that of steel (over 1500°C) resulting in less vapor generation and a more stable welding process. A completely defect-free, high-strength lap joint was achieved. However, this process requires a specific offset between the laser beam and GTAW torch that could hinder the application of this welding procedure in a highly automated welding application. The automotive industry continues to search for a new laser welding procedure to weld high-strength galvanized steels in a gap-free lap joint configuration with a single laser beam without the pre- and/or postweld processing requirements. Until now, there is no reference in the open literature on using a single laser beam to successfully join galvanized steels in a gap-free lap joint configuration without the pre- and/or post-processing requirements. Therefore, it is important to develop an efficient and robust laser welding technique to satisfy the demand from the automotive industry. The main objective of this work was to respond to this demand and develop a cost-effective and easy-to-automate laser welding technique.

In this study, the laser welding process was conducted to join galvanized DP980 steel sheets in a gap-free lap joint config-
Table 1 — Laser Welding Parameters

<table>
<thead>
<tr>
<th>No.</th>
<th>Coaxial Shielding Gas</th>
<th>Side Shielding Gas</th>
<th>Back Shielding Gas</th>
<th>Laser Power (W)</th>
<th>Welding Speed (mm/s)</th>
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<tr>
<td></td>
<td>Type</td>
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<td>Type</td>
<td>Flow rate (ftVh)</td>
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<td>30</td>
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<td>Ar</td>
<td>30</td>
<td>3600</td>
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<tr>
<td>3</td>
<td>Ar</td>
<td>30</td>
<td>Ar</td>
<td>30</td>
<td>3600</td>
</tr>
<tr>
<td>4</td>
<td>He</td>
<td>30</td>
<td>Ar</td>
<td>30</td>
<td>3600</td>
</tr>
<tr>
<td>5</td>
<td>75% Ar+25% CO₂</td>
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<td>Ar</td>
<td>30</td>
<td>3600</td>
</tr>
<tr>
<td>6</td>
<td>98% Ar+2% O₂</td>
<td>30</td>
<td>Ar</td>
<td>30</td>
<td>3600</td>
</tr>
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<td>Ar</td>
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</tr>
</tbody>
</table>

Fig. 3 — Unstable zinc vapor and laser-induced plume: A — Taken with color CCD camera at 30ft/s; B and C taken with high-speed camera at 4000ft/s assisted with a green laser.

Fig. 4 — Effect of side shielding gas on the stability of the welding process and keyhole: A — Top view of the lap joint obtained in Experiment 3; B — bottom view of the lap joint obtained in Experiment 3; C — top view of the lap joint obtained in Experiment 4; D — bottom view of the lap joint obtained in Experiment 4.

Zinc vapor direction

As shielding gas has a significant effect on the stability of the welding process and the weld quality (Refs. 29–31), the gases, including pure argon, helium, and carbon dioxide as well as oxygen, were combined in different ways to study the influence of the shielding conditions on the weld quality and the keyhole stability. An optimal shielding condition was proposed for the welding of galvanized steels in a gap-free lap joint configuration. The mechanism of stabilizing the laser welding process was studied. In addition, a high-speed CCD camera with the frame rate of 4000 ft/s was used for on-line monitoring of the dynamic behavior of the molten pool and the laser-induced plasma. Energy-dispersive X-ray spectroscopy (EDS) tests were carried out to determine the chemical composition at the top surface as well as along the fusion zone of the welds. Microhardness and tensile shear tests were carried out to evaluate mechanical properties of the welds.

Experimental Setup

The material used in this study was galvanized DP 980 steel sheet. The zinc coating was hot dipped at the level of 60 gm/m² per side. Specimens with the dimensions of 200 × 85 × 1.2 mm and 200 × 85 × 1.5 mm were cut using an abrasive water jet. The 1.2-mm-thick metal sheet was selected as the top sheet and the 1.5-mm-thick metal sheet as the bottom sheet. The two metal sheets were then tightly clamped together during the laser welding process and a zero
A high-speed CCD camera with 4000 fps and a color CCD camera with 30 fps was applied to monitor the laser welding process. In addition, a CCD color video camera was used to monitor the laser-induced plasma and plume. The chemical compositions of base metal and weld zone were analyzed by EDS. A green laser with a centre wavelength of 532 nm and a maximum output power of 6 W was selected as the illumination source to suppress the laser-induced plume in order to obtain clear images of the molten pool. Furthermore, the influence of the shielding conditions on the weld quality was evaluated using different combinations of the coaxial, side, and back shielding gases. The distance between the side shielding gas outlet (Fig. 1) and the laser spot was about 10–20 mm. In order to investigate the effect of the coaxial shielding gas on the welding quality, pure argon and helium, and the mixtures of argon and 25% and 10% CO2 as well as the mixture of argon and 2% O2 were used as the coaxial shielding gas in different welding experiments while maintaining all other welding parameters constant. Similarly, two kinds of gases, pure argon and pure helium, were selected as the side shielding gas to study the effect of the side shielding gas on weld quality in a sequence of experiments on the condition that all other welding parameters were kept constant. Table 1 presents the combinations of different gases and the laser welding parameters used in this study. The experimental setup is shown in Fig. 1. In addition, the lap joint coupons were sectioned, ground, polished, and etched for hardness measurement and examination under the optical microscope.

Results and Discussion

Investigation on the Effect of Different Shielding Conditions on Weld Quality

To study the effect of different coaxial shielding gases on the welding quality, pure argon and pure helium were used as the coaxial shielding gas in Experiments 1 and 2, respectively. In addition, the pure argon gas was used as the back shielding gas in Experiments 1 and 2. No side shielding gas was incorporated into these two experiments. Figure 2 shows the top and bottom views of the laser-welded lap joints obtained in Experiments 1 and 2. As shown in Fig. 2A, a large amount of spatter and porosity were produced in the laser-welded lap joints in Experiment 1. The spatter scattered along the laser-beam-delivered path will absorb and block a portion of the laser beam energy. However, when the coaxially delivered shielding gas was switched from pure argon to pure helium and the back shielding gas was maintained as pure argon (in Experiment 2), the laser welding process became very stable and no liquid metal was ejected from the molten pool. A sound weld with complete penetration was achieved with helium, as shown in Fig. 2C and D. The large difference in the weld quality between the shielding conditions specified by Experiments 1 and 2 was a result of the different ionization potentials of argon and helium. Helium has a higher ionization potential and better thermal conductivity than that of argon (Ref. 32). When helium was used as the coaxial shielding gas, the size of the produced plasma was small and stable (Ref. 32), and the laser beam energy could be better coupled into the welded material resulting in the formation of a stable keyhole. The presence of a stable keyhole will provide the channel to consistently vent out the highly pressurized zinc vapor. However, when the coaxially delivered shielding gas was argon and no side shielding gas was utilized, a large volume of the laser-induced plasma was directly formed on top of the molten pool, as shown in Fig. 3. As shown in Fig. 3, the laser-induced plasma is very unstable and dynamically fluctuated over time when argon was used as the shielding gas (Ref. 28). The unstable laser-induced plasma not only significantly influences the coupling efficiency of laser beam energy into the welded material but also changes the direction and size of the keyhole (Ref. 34). Under this welding condition, the keyhole tends to collapse and the highly pressurized zinc vapor will be trapped into the molten material. As shown in Fig. 2B, only partial weld penetration was achieved in the lap joints obtained when argon was used as the shielding gas because the laser-induced plasma and the produced spatter absorbed, scattered, and blocked the laser beam energy. This fact suggests that it was
Fig. 8 — Lap joint obtained in Experiment 7: A — Top view; B — bottom view.

Fig. 9 — X-ray transmission images of keyhole and transverse sections for increased weld penetration by adding oxygen into the shielding gas (fiber laser power: 7 kW; welding speed: 1 m/min) (Ref. 43).

Fig. 10 — Lap joints obtained with different flow rates in Experiments 8-10: A — Top view of lap joints with a side flow rate of 20 ft³/h; B — bottom view of lap joints with a side flow rate of 20 ft³/h; C — top view of lap joints with a side flow rate of 30 ft³/h; D — bottom view of lap joints with a side flow rate of 30 ft³/h; E — top view of lap joints with a side flow rate of 40 ft³/h; F — bottom view of lap joints with a side flow rate of 40 ft³/h (laser power: 3600 W; welding speed: 40 mm/s).

Critical to control the formation and stability of the laser-induced plasma in order to produce the stable keyhole for the laser welding process of galvanized steels in a gap-free lap joint configuration, thus achieving sound lap joints. The back side shielding gas can cool the weld to some extent to decrease the pressure level of zinc vapor because the zinc vapor pressure level is directly related to the temperature (Ref. 32). In general, when large amounts of spatter are produced, only partial penetration can be achieved.

As mentioned previously, the unstable plasma is one of the reasons for the collapse of the keyhole (Refs. 28, 34). Furthermore, the negative effects related to the unstable laser-induced plasma can be eliminated by applying a shielding gas with an approximate flow rate (Ref. 32, 34). In order to suppress the laser-induced plasma and achieve the stable keyhole, pure argon and pure helium were selected as the side shielding gases in Experiments 3 and 4, respectively. Figure 4 shows the experimental results. Neither spatter nor porosity were present in the laser welded lap joints and completely penetrated lap joints were achieved with both of these laser welding processes. This fact indicates that the laser welding process of galvanized steels was stabilized by the introduction of the side shielding gas. During the laser welding process, the side shielding gas will blow away the laser-induced plasma and plume. Furthermore, the use of side shielding gas stabilized the turbulent molten pool caused by the highly pressurized zinc vapor resulting in the flat surface of the welds (Refs. 30, 34), which will be shown in the following section by the high-speed camera. Compared with Experiment 1, the absorption efficiency of the laser beam energy was increased and the laser beam was relatively uniform enabling it to be coupled into the welded material and generate a stable keyhole. Similar to Experiment 2, the stable keyhole mitigates the highly pressurized zinc vapor.

Marangoni convection driven by the surface tension gradients is one of the main factors to influence the keyhole shape and its dynamics (Ref. 35). It has been revealed that the addition of active gases such as O₂ and CO₂ into the argon shielding gas can change the Marangoni convection from outward to inward, as shown in Fig. 5 (Ref. 36). In addition, the surface tension of a molten pool can be lowered (Ref. 37). The outward and inward Marangoni convection are shown in Fig. 5. When active gases such as O₂ or CO₂ are introduced into the shielding gas, it is possible to deepen and enlarge the keyhole, compared with the case using pure inert gas as the shielding gas (Ref. 37). In order to investigate whether adding the active gases O₂ or CO₂ into the inert gas could facilitate formation
of the keyhole and enhance its stability for laser welding of galvanized steels in a gap-free lap joint configuration. The mixture of argon + CO₂ and argon + O₂ was further tested in Experiments 5–7. The high CO₂ or O₂ content in the shielding gas may decrease the mechanical properties of welds (Ref. 30). When welding steel, the percentage of O₂ and CO₂ in the inert shielding gas is recommended to be no more than 25% in order to maintain the same properties in the weld as the base material (Ref. 38). In addition, the mixture of 98% argon and 2% O₂ is commonly used in industry for welding steel. Therefore, the mixtures of 75% Ar + 25% CO₂ and 98% Ar + 2% O₂ were used in the experiments. Figure 6 shows the experimental results. As shown in Fig. 7, high-quality welds with complete penetration were achieved. Figure 7 shows the cross-sectional view of the lap joints obtained in Experiment 5. As shown in Fig. 7, no porosity is present in the lap joints.

By direct observation of the laser welding process, it was found that the welding process in Experiment 5 with the mixture of 75% Ar + 25% CO₂ was the most stable among all the gas mixtures tested. In addition, the laser welding processes in Experiments 4 and 6 exhibited a more stable process than that of Experiment 3. When using pure argon as the coaxial shielding gas in Experiment 3, the welding process was slightly unstable and a small amount of spatter was observed during the laser welding process. More severely, some porosity was produced in the welds, suggesting that when the coaxially delivered shielding gas contains either CO₂ or O₂ or is pure helium, the laser welding process obtains the greatest degree of stability. Therefore, it is recommended to introduce CO₂ or O₂ gas into the shielding gases or use pure helium or the mixture of He and Ar instead of pure argon to stabilize the laser welding process for galvanized steels. Trials were also carried out to join the galvanized steels in a gap-free lap joint configuration with 90% Ar + 10% CO₂. Figure 8 shows the experiment results. As shown in Fig. 8, complete penetration was achieved and the weld bead was continuous without the presence of spatter or porosity. Further studies will be performed to explore the process window for different gas ratios in different shielding conditions.

**Mechanism for Enhanced Stability of the Laser Welding Process by the Introduction of Active Gases**

As discussed in the previous section, the introduction of an active gas (O₂ or CO₂) into the shielding gas can suppress the highly pressurized zinc vapor and stabilize the laser welding process. During laser welding of galvanized steels, the active gases play these possible roles as follows:

1. During the laser welding process, dissociation and ionization processes take place in the gases (Ref. 39). The chemical reaction between Zn vapor and the active
Fig. 14 — The images of the molten pool successively obtained in the stable laser welding process (laser power: 3600 W; welding speed: 40 mm/s; the coaxial 90% Ar +10% CO2 shielding gas: 30 ft³/h; the back and side pure argon shielding gas: 30 ft³/h).

Fig. 15 — EDS analysis of the top surface of weld: A — EDS result in the measured spot; B — SEM image of the top surface of weld. Welds obtained by the following welding parameters: Laser power: 3600 W; welding speed, 40 mm/s; the coaxial shielding gas, 30 ft³/h of the mixture of 75% Ar + 25% CO2; back and side shielding gas, 30 ft³/h of pure argon.

Influence of the Side Shielding Gas Flow Rate on Weld Quality

In order to study the influence of the gases O2 and CO2 will form ZnO according to 2Zn + O2 → ZnO and CO2 → C + O2 → Zn+ O → ZnO. This chemical reaction could help stabilize the welding process.

2. A thin film of metal oxides (mainly iron oxides) could form in the front of the molten pool. The formation of metal oxides as well as heated surface material increased the coupling efficiency of laser beam energy into the welded material (Refs. 40, 41). Under this condition, the keyhole was readily formed, which provided the channel for the highly pressurized zinc vapor to be vented out. When the surface tension had an outward pattern, weld penetration was shallow (Ref. 42). Inversely, deep weld penetration can be obtained when the surface tension has an inward pattern. By introduction of active shielding gases such as O2 and CO2, the surface tension changed from an outward pattern to an inward pattern (Ref. 43). Consequently, the keyhole was enlarged and deepened (Ref. 43), as shown in Fig. 9.

3. The viscosity of molten metal was decreased through introduction of active shielding gases such as O2 and CO2 in comparison with the laser welding experiments where pure argon was used as the shielding gas (Ref. 44). Therefore, the shear force exerted on the keyhole wall by the highly pressurized zinc vapor could be reduced. Thus, the potential for formation of spatter and porosity was subsequently reduced.

During the laser welding process, carbon dioxide can be dissociated into CO+½O2 or C+O2, depending upon the dissociation potential. If the dissociation potential is high enough, the CO is further transformed into C + ½O2. The large amount of carbon dissolving into the weld metal reduces the corrosion resistance of the low-carbon grades of steels (Ref. 45). Furthermore, the strength of the welds may be decreased by reducing the amount of deoxidizing alloying elements such as manganese and silicon, which react with oxygen in the shielding gas (Ref. 45). In like manner, the addition of oxygen into the shielding gas may pose a risk for the reduction of the weld strength. Therefore, the issue on control of the percentage of CO2 or O2 in the shielding gas may be of concern when using the mixtures of Ar + CO2 or Ar + O2 in the shielding gas for laser welding of galvanized steels. On the other hand, since the laser welding process was carried out at the high welding speed, the cooling rate was fast. As a result, the interaction time between the carbon or oxygen and the deoxidizable alloys was extremely short such that the issues mentioned previously may not be of concern. Further studies are planned to explore these phenomena.

Influence of the Side Shielding Gas Flow Rate on Weld Quality

In order to study the influence of the
side shielding gas flow rate on the weld quality, laser welding experiments were carried out with shielding conditions as follows: no coaxial shielding gas, a constant 30 ft³/h pure argon back shielding gas flow rate, pure argon side shielding gas flow rate varying from 20 to 40 ft³/h. Figure 8 shows the experimental results on the weld quality. As shown in Fig. 8, no spatters or porosity were generated in the welds and complete penetration was achieved in the welds when the flow rate of the side shielding gas was 20 and 30 ft³/h. When the flow rate of the side shielding gas was increased to 40 ft³/h, the welding process became dramatically unstable and some spatter and porosity were produced in the welds, as shown in Fig. 10E. In addition, only partial penetration was achieved in the welds. This phenomenon can be explained by the fact that when the flow rate of the side shielding gas was increased to a sufficiently high level, the argon gas enabled the formation of more plasma when the laser beam penetrated through the argon gas than what laser-induced plasma was blown off for the given laser power and welding speed. It is worth mentioning that the argon side shielding gas can be replaced by another shielding gas such as helium to suppress the laser-induced plasma with the optimal flow rate to achieve a sound lap joint.

Influence of Welding Speed on Weld Quality

In order to study the influence of the welding speed on weld quality, three trial tests were conducted where the welding speed was varied from 30 to 60 mm/s in increments of 10 mm/s and all other welding parameters were identical to those in Experiment 4. Experimental results demonstrated that for a given laser power of 3600 W, a sound weld could be achieved at welding speeds of 30, 40, and 50 mm/s. However, the laser welding process tended to become unstable, producing spatter and porosity in the welds at the welding speed of 60 mm/s, as shown in Fig. 11. The instability of the laser welding process at 60 mm/s welding speed can be explained by the fact that when the welding speed was increased, the keyhole became unstable and tended to collapse (Ref. 46). Keyhole formation required that the laser beam energy density was beyond some threshold value (Ref. 47), as shown in Fig. 12. The energy density can be described by the following equation:

$$E_d = d \times \left( \frac{P_d}{V} \right)$$

(1)

where d is the focused spot size, $P_d$ is the laser power at the focus point, and V is the welding speed. When the speed was increased, the energy density was decreased and the keyhole tended to collapse. The collapsed keyhole failed to vent out the highly pressurized zinc vapor, which led to...
a large amount of spatter and porosity in the welds. The spatter flying in the laser beam path absorbed and reflected the laser beam energy. In addition, the multi-reflection will not occur in the collapsed keyhole. So, when the keyhole is collapsed, a relatively lower level of laser beam energy is absorbed by the welded material, resulting in partial penetration. Therefore, it is important to control welding speed for obtaining a stable keyhole. In addition, when welding speed was relatively lower, for the given laser power and shielding gas flow rate, it was more possible to achieve complete penetration. When complete penetration was achieved, a portion of the highly pressurized zinc vapor can escape from the bottom of specimens producing a more stable laser welding process.

Direct Observation of Dynamic Behaviors of the Molten Pool with the Machine Vision System

To study the behaviors of the molten pool and the keyhole dynamic, a high-speed (4000 fps) CCD camera was applied to monitor the laser welding process in real time. Figures 13 and 14 show the molten pool and the keyhole obtained during the unstable and stable laser welding processes. During the unstable laser welding process, the keyhole has difficulty forming, as shown in Fig. 13. In addition, the molten metal flow in the rear part of the molten pool dramatically fluctuates over time. When the welding process was unstable, the highly pressurized zinc vapor developed at the interface of two metal sheets ejects the liquid metal out of the rear portion of the molten pool. This explosive liquid metal condensed in the air and became spatter that was deposited on the weld surface or weld zone in random directions. A large amount of spatter not only damaged the optical lens but also produced poor quality lap joints and poor surface appearance. The presence of the spatter and porosity in the welds dramatically reduced the strength of the lap joints. In contrast, a stable keyhole was consistently formed and kept open during the entire laser welding process, which mitigates the highly pressurized zinc vapor, thus producing a stable laser welding process. As shown in Fig. 14, the keyhole appears as a black spot located in front of the molten pool. Due to the mitigation of zinc vapor through the stable open keyhole, the molten pool was stable and no liquid metal was rejected from it. Consequently, sound lap joints were achieved in the stable laser welding process. Furthermore, the coupling efficiency of laser beam energy into the welded material was enhanced by multi-reflection into the keyhole. Therefore, deep weld penetration is attained.

Energy-Dispersive X-Ray Spectroscopy (EDS) Analysis

In order to analyze the chemical elements of the weld and ensure that the use of high levels of CO₂ would not cause the loss of the alloying elements in the weld, energy-dispersive X-ray spectroscopy (EDS) experiments were carried out at different locations on the top surface and along the cross-sectional zone of the welds. Figures 15 and 16 present typical EDS analysis results at the measured points on the top surface and along the cross section of the weld. Figure 17 shows the EDS analysis results at the cross section of the base material. As shown in Fig. 15, the O, Fe, Mn, and Zn elements are presented in the EDS analysis results detected on the top surface of the weld. It is conjectured that the zinc oxide, iron oxides, and manganese oxide are probably produced on the top surface of the welds due to the dissociation of CO₂ into the formations of CO + O₂ or C + O₂. The oxides of ZnO, MnO, and FeO are produced according to the following reactions: Zn + ½O₂ → ZnO; Fe + ½O₂ → FeO; and Mn + ½O₂ → MnO. Furthermore, for all of the measured points in the cross section of the weld, the presence of Fe and Mn elements without the O element was identified from the peaks present in the EDS analysis results. Based on the absence of the oxygen element in the weld, the conclusion may be made that no oxygen contamination has occurred in the weld during the laser welding process with the introduction of oxygen and carbon dioxide. Based on the weight percentages of various elements in Figs. 16 and 17, the amount of the essential alloying element of Mn in the weld is not degraded during the laser welding process even if a high percentage of CO₂ is used in the coaxial shielding gas. This fact indicates that the issue of the loss of oxidizing alloy elements such as manganese may not be of concern for the high-speed laser welding process with the addition of carbon dioxide or oxygen into the coaxial shielding gas. However, further study is still required for the resistance test. Since the iron oxides can influence the metallurgical properties of welds (Ref. 39), the percentage of oxygen or carbon dioxide in the shielding gas mixture should be controlled in order to maintain the same chemical composition and mechanical properties of the welds as the base material.

Mechanical Tests

Vickers hardness measurements were conducted on a cross section of the weld along a line 0.25 mm under the top surface using a load of 200 g and a 10-s dwell time. Figure 18 shows the measured line and the hardness profiles across the weld zone and the heat-affected zone (HAZ) as well as the base material. The microhardness values are a function of the distance from the weld center. In the fusion zone, the weld has a higher hardness value than that of the base material due to the fast cooling. The hardness then decreases toward the fusion boundary. Because of the effect of softening, the HAZ is characterized by the lowest hardness value, lower than that in both the weld zone and the base material. Tensile shear tests were performed to determine the strength of the welds. The sample geometry is shown in Fig. 19. The tensile shear strength is determined by the average value of two series of values taken on the same specimen welded under a specific set of welding parameters. The weld width at the interface measured from the weld cross section, which was changed by different welding conditions, was used to calculate the tensile strength. Figure 20 shows the weld fracture location after the tensile shear test. As shown in Fig. 20, both of the test specimens are broken under the shear force at the fusion zone, for a coaxial shielding gas mixture of 90% Ar + 10% CO₂. However, when the coaxial shielding...
gas is switched to the mixture of 75% Ar + 25% CO₂ and the other welding parameters are kept the same as in the case of using the 90% Ar + 10% CO₂, the fracture of test samples happens in the HAZ, as illustrated in Fig. 20B. Figure 21 summarizes the tensile test results. The average shear strength for the welds obtained with the welding parameters in Fig. 20A is 860 MPa and the average tensile strength for the welds obtained with the welding parameters in Fig. 20B is 800 MPa. The strength of the base material is 980 MPa. Comparison of the strength of the welds with that of the base materials reveals that the strength is slightly reduced when using the mixtures of 75% Ar + 25% CO₂ and 90% Ar + 10% CO₂ as the shielding gases.

Laser Welding of Galvanized Steels in a Gap-Free Lap Joint Configuration with a Single Side Shielding Gas

In order to study the influence of a single side shielding gas on the weld quality, a further trial test was conducted where the welding speed was 30 mm/s, laser power was 3600 W, the side shielding gas flow rate was 30 ft/³/h, and no back and coaxial shielding gases were used. As shown in Fig. 22, a sound lap joint with complete penetration was also achieved. No spatter and porosity were produced on the welds. Therefore, it is also possible to just use a single side shielding gas for laser welding of galvanized steels in a gap-free configuration to obtain sound lap joints. Further studies on the influences of side shielding gas composition, size/shape of the side shielding gas nozzle, distance of the side shielding gas nozzle from the keyhole, and the angle of the nozzle with respect to the plane of the top sheet on the weld quality are needed to be completed for a given welding speed and laser power. In this paper, we will not discuss these issues.

Conclusions

The following conclusions can be drawn from this work:

1. With the specific shielding conditions, a completely defect-free lap joint of galvanized steels in a gap-free configuration can be achieved by a single laser beam without pre- and postweld processing. The proposed laser welding procedure, which is robust, can be conducted at high speed to obtain completely penetrated, high-strength lap joints.

2. The introduction of the side shielding gas can not only suppress the laser-induced plasma and plume but also stabilize the turbulent molten pool caused by the highly pressurized zinc vapor resulting in a stable keyhole, which allows the highly pressurized zinc vapor to be vented out. With the formation of the keyhole, the absorption efficiency of laser beam is increased, and it is better coupled to the materials to be welded. It is not necessary to use the bottom shielding gas during the laser welding process.

3. The keyhole could be stabilized, enlarged, and deepened by the addition of active gases (O₂ and CO₂) during the laser welding process. Compared with the case of using pure argon, deeper penetration could be achieved when adding the active gas (O₂ and CO₂) into the shielding gas.

4. Lower travel speeds that result in complete penetration produced sound welds whereas the partial penetration weld made at the fastest travel speed was defective.

5. Alloying elements such as Mn are not reduced by the introduction of the active gas (O₂ and CO₂) into the coaxial shielding gas.

6. The fracture location of the welds varies from the fusion zone to the heat-affected zone (HAZ) during the tensile tests with an increase in the percentage of CO₂ in the mixture of argon + CO₂. In addition, the HAZ is softened during the laser welding process. Furthermore, EDS analysis results do not detect a loss of Mn in the weld during the laser welding process.

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References


The Effect of Helium on Welding Irradiated Materials

A nuclear reactor's inner components are exposed to neutron fluxes, resulting in the transmutation of minor elements that generate helium in the material's matrix, but weld cracking can be suppressed by using a few techniques

BY S. LI, M. L. GROSSBECK, Z. ZHANG, W. SHEN, AND B. A. CHIN

ABSTRACT

Energetic neutron irradiation and associated transmutation reactions are known to cause significant damage to materials. The resultant deterioration in the mechanical properties and corrosion resistance plays a decisive role in the life expectancy of nuclear reactor components. With the first generation of nuclear power plants reaching their life expectancy, the repair and replacement of degraded reactor components will be required. Hence, joining using conventional welding techniques will be needed. However, during welding of irradiated materials, a major difficulty must be overcome. Helium generated in the material from transmutation reactions is almost insoluble in a solid matrix. Under the high temperatures and high thermal stresses generated during welding, helium bubbles will grow and coalesce along the grain boundaries. This will cause intergranular cracking and fracture of the components during welding repair. This article reviews the investigations that have occurred involving welding postirradiated materials over the last 25 years. The effect of helium on the weldability and postweld properties of the irradiated structural materials, such as stainless steels, is summarized. Theories that have been developed to describe the helium-induced cracking are discussed along with possible techniques to suppress cracking and improve the weldability of irradiated materials.

Introduction

At the present time, there are 104 operating nuclear reactors in the United States with an average age of more than 30 years (Ref. 1). The Atomic Energy Act provides for the Nuclear Regulatory Commission (NRC) to issue licenses for 40 years of operation with provisions for renewal for an additional 20 years. License extensions have been applied for 72 reactors with 51 already granted (Ref. 2). Analysis of materials degradation is already in progress for anticipated operation of 80 years (Ref. 3). Exposure to energetic neutron irradiation produces significant damage in the microstructure of metallic materials (Ref. 4). This damage will result in a corresponding deterioration in mechanical properties of inner structural components of a nuclear reactor, limiting the useful life of these components (Ref. 5). For 60- and 80-year lifetimes, component failures due to cracking are a major consideration, especially in the light of cracking core internal components and control rod nozzles in plants after less than half this time (Ref. 6). Therefore, it is to be expected that the repair and replacement of degraded reactor components will be necessary. Such repair procedures are likely to require the use of a joining process such as fusion welding. As discussed further in this article, the production of helium by neutron interactions in structural alloys presents a major obstacle to repair welding. Even at the inner wall of the pressure vessel at the midplane location, helium concentrations exceed permissible levels for normal arc welding in structural alloys after 40 years. At the top of the pressure vessel in pressurized water reactors (PWRs), the neutron flux is approximately a factor of 10 lower, permitting repair welds of structures such as control rod nozzles at a lifetime of 40 years, but the issue becomes more uncertain for an 80-year lifetime. Repair welds have been made in a vessel head with minimal exposure, but considering the severity of the problem and projected lifetime of modern reactor plants, most reactor operators have chosen vessel head replacement. This article addresses the potential and limitations of repair welding for neutron-irradiated materials.

Helium in postirradiated material is primarily generated by \( (n, \alpha) \) reactions of thermal neutrons and alloy constituents, principally with boron and nickel:

\[
\begin{align*}
^{10}\text{B} + n &\rightarrow ^{7}\text{Li} + ^{4}\text{He} \\
^{58}\text{Ni} + n &\rightarrow ^{59}\text{Ni} + \gamma \\
^{59}\text{Ni} + n &\rightarrow ^{56}\text{Fe} + ^{4}\text{He}
\end{align*}
\]

Because helium is essentially insoluble in metal, the entrapped helium tends to precipitate as clusters and nanometer-scale bubbles even at relatively low temperatures (Refs. 7, 8). Preferred nucleation sites for helium bubbles are point defects, dislocations, and grain boundaries (GBs). At elevated temperatures, helium bubbles grow rapidly under the influence of both temperature and stress. The growth of GB helium bubbles will result in the weakening of the GB and intergranular fracture, leading to severe embrittlement in the materials (Refs. 9, 10). The degradation in mechanical properties, such as tensile strength, fatigue, and creep, due to the presence of entrapped helium in irradiated metal, has been studied by many re-

KEYWORDS

Nuclear Reactor
Helium
Irradiated
Heat-Affected Zone (HAZ)
Weld Cracking
Gas Metal Arc (GMA) Weld
Yttrium Aluminum Garnet (YAG) Laser Welding

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to repair corrosion cracks on a Type 304 stainless steel nuclear reactor vessel at the Savannah River Site failed in 1986 (Ref. 22). When the repair was performed, the helium contained in the steel wall was measured to be 3 atomic parts per million (appm). Patches were welded over the cracks on the wall using conventional GTA welding, and an examination after welding revealed extensive cracking in the HAZ of the patch welds. These HAZ cracks led to larger leaks in the reactor vessel and shutdown of the reactor (Ref. 22). Similar results were observed by Kanne et al. in welds of a sample from the Savannah River Reactor tank wall, which contained 30 appm helium after 12 years of reactor operation (Ref. 23). The HAZ cracking was intergranular and attributed to helium embrittlement.

Over the past 25 years, the effect of helium on the weldability and postweld properties of the irradiated structural materials, such as stainless steels, has been investigated. Theories have been developed to describe helium-induced cracking in irradiated metallic materials during welding, and several techniques have been applied to suppress cracking and improve the weldability of irradiated materials.

Helium-Doping Technique

Materials used in the studies of irradiated materials’ weldability can be divided into two types: neutron-irradiated materials and helium-doped materials. In order to reduce the radiological hazard and avoid the difficulty of hot cell operation, helium-bearing materials obtained using the “tritium trick” technique have been used to study the effect of helium on the weldability of irradiated materials (Ref. 24). In this technique, helium is introduced into the material by diffusing tritium into the test material and allowing the tritium to decay to helium. The test specimens are placed in a tritium gas pressurized vessel at an elevated temperature (300°C) for a specified time, 30 days for instance, to allow tritium to uniformly diffuse into the material. After tritium charging, the exposed materials are removed from the vessel, kept at low temperature to keep tritium from diffusing out of the material, and the tritium is allowed to decay with its 12.34-year half life. The dissolved tritium decays to form helium by the following reaction: \( ^3H \rightarrow \beta + ^4He \). When the desired helium concentration is obtained, the excessive tritium is removed by placing the material in a vacuum vessel at a high temperature, thus stopping the further generation of helium. By changing the tritium charging pressure and aging time (decay time), a wide range of helium concentrations can be obtained. Details of the helium-doping process can be found in several references (Refs. 25, 26). Although the microstructure of tritium charged and aged material does not completely represent the radiation damage in neutron irradiated materials, the “tritium trick” allows the effect of helium to be isolated from other lattice damage due to neutron irradiation.

Helium-bearing steels obtained by helium implantation have also been made and used in weldability investigations (Refs. 27, 28).

**Weldability of He-Containing Materials**

The weldability of stainless steels using conventional welding processes is strongly affected by the presence of helium. Lin et al. systematically studied the helium effect on the weldability of 316 stainless steel (Refs. 25, 29, 30). In their study, helium-doped steels with helium concentrations of 0.18, 2.5, 27, 105, and 256 appm were obtained by tritium charging and aging. Gas tungsten arc welding was used on the plates of helium-doped steels. The specimens were fully constrained during the welding process to simulate the structural restraint encountered in practical repair and maintenance. Metallographic examinations showed that specimens containing a very low helium concentration (0.18 appm) could be successfully welded with-

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**Table 1 — Comparison of Helium-Induced Weld Cracking Tendency among Various Alloys (Ref. 29)**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>He Concentration (atomic parts per million)</th>
<th>Crack Length (mm/mm)</th>
<th>Tendency for Weld Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA*316 SS</td>
<td>2.5</td>
<td>0.79</td>
<td>High</td>
</tr>
<tr>
<td>20%CW**316 SS</td>
<td>2.0</td>
<td>0.06</td>
<td>Low</td>
</tr>
<tr>
<td>SA* PCA</td>
<td>2.0</td>
<td>0.0017</td>
<td>Very Low</td>
</tr>
<tr>
<td>RSP***304 SS</td>
<td>7.0</td>
<td>0.0</td>
<td>None</td>
</tr>
<tr>
<td>HT-9</td>
<td>1.0</td>
<td>0.0009</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

*Solution Annealing (at 105°C for 1 h in an inert atmosphere).
**Cold Work.
***Rapidly Solidified Processing.
welded, helium-doped specimens failed at high temperature and stress during the welding process. Results of an annealing study on helium-containing steel provided support in evidence of the effect of stress on weld cracking. Intergranular HAZ cracking occurred along prior-austenite grain boundaries in ferritic austenitic Fe-16Cr-11Ni-3Mo-Ti austenitic steels containing very low helium concentrations, HAZ cracking occurred along prior-austenite grain boundaries in ferritic Sandvik HT-9 steel (12Cr-1MoV) doped with 1 appm He (Refs. 34, 36). Severe fusion and HAZ cracking were also reported by Lin and Braski in the vanadium alloy, V-15Cr-5Ti, with 25.6 appm helium introduced by tritium charging and decay (Ref. 35). The results revealed that the vanadium alloy is more susceptible to fusion zone cracking than helium-doped 316 stainless steel, which demonstrated fusion zone cracking only in welds containing very high helium (>105 appm). Fabritsiev et al. reported that welding caused a dramatic degradation in fatigue properties for neutron-irradiated Fe-16Cr-11Ni-3Mo-Ti austenitic steel (Ref. 38) and 316 stainless steel (Refs. 37, 41). Even at a helium concentration of 1 appm, the number of cycles to failure in low-cycle fatigue tests for the austenitic steels decreased by a factor of four to five following welding (Ref. 38).

In summary, helium entrapped in irradiated materials degrades their weldability by producing cracking in the HAZ and, with higher helium concentrations, in the fusion zone. The severity of the degradation has been found to be influenced not by single parameters, but rather by the interaction of multiple parameters. The weldability is primarily affected by the combination of helium concentration and welding conditions such as heat input, weld penetration, and weld constraint. Successful welding without the formation of weld defects can be obtained in stainless steels containing very low levels of helium, which indicates the existence of a helium threshold, below which crack-free welds can be made. Above the threshold, the extent of cracking increased with an increase in helium concentration. As the helium concentration was reduced, welding defects in irradiated materials varied from severe surface cracking, to subsurface cracking, and to helium bubble formation along GBs (Ref. 42). A linear relationship between the extent of weld cracking and helium concentration was observed (Ref. 43). Based on this relationship, Wang et al. estimated the threshold level for cracking in helium-doped 316 stainless steel during GTA welding to be approximately 1 appm (Refs. 43, 44). Cracking in the welds of the irradiated materials is due to the growth and coalescence of helium bubbles at GBs, and is controlled by the combination of high temperature and stress during the welding process. Conventional stringer bead GTA welding results in high heat input, deep penetration, and strong shrinkage stresses. These adverse factors combine to make irradiated materials more susceptible to weld cracking. By applying lower heat input and less restraint, sound GTA welding of neutron-irradiated steels containing helium up to 10 appm was accomplished (Refs. 42, 45–48).

Weld Cracking Tendency for Different He-Containing Alloys

Because of the complexity of helium embrittlement during welding, the tendency of weld cracking for different irradiated alloys is also affected by their microstructure, chemical composition, and fabrication history. Table 1 lists a comparison for several alloys that describes the GTA weld cracking tendency (Ref. 29). Annealed Type 316 stainless steel shows the worst susceptibility to helium-induced cracking, while rapidly solidified processed 304 stainless steel exhibits the best resistance. Techniques that inhibit the formation and growth of helium bubbles along GBs improve the weldability of helium-bearing alloys. Cold working was
found to alleviate the HAZ cracking in helium-bearing steel (Ref. 49). This tendency is attributed to the following two possible mechanisms: 1) a high dislocation density that traps helium atoms and vacancies or 2) recovery processes of cold-worked grains that reduce available vacancies for bubble growth. Precipitates in the alloys may act as trapping sites for helium, thereby inhibiting helium embrittlement. For example, Ti-modified austenitic stainless steel (PCA) exhibits much better resistance to GTA weld cracking than SA 316 stainless steel because the addition of Ti to the austenitic stainless steel leads to the formation of MC precipitation (Refs. 49, 50).

Tosten et al. reported that more extensive helium-induced weld cracking occurred in a high-carbon Type 304 stainless steel than in a special grade (ITER Grade) of 316LN (316LN-1G) stainless steel after plates of both steels were welded using low heat gas metal arc (GMA) overlay welding (Ref. 51). Both steels were tritium charged and aged to contain helium concentrations of 90 appm. The authors suggested two possible reasons for this behavior as follows: 1) 316LN is inherently more resistant to high-temperature creep than 304 stainless steel and therefore stress-induced cavity growth (intergranular cracking in HAZs) is suppressed in 316LN, or 2) carbides present at GBs in 304 steel may provide more nucleation sites for helium bubbles. Further investigation is needed to provide a better understanding of observed results.

The method of helium introduction may also affect the weldability of materials. Kanne et al. reported that irradiated steel is more susceptible to helium embrittlement during welding than tritium charged and aged steel (Ref. 52). Kanne et al. hypothesized that this was due to the difference in distribution of helium in irradiated and tritium charged and aged steel (Ref. 52). In the irradiated material, the distribution of helium from the transmutation reaction depends on the distribution of the transmutation element in the material. For example, the helium from boron transmutation is expected to be in the grain boundaries. On the other hand, for tritium charged and aged material, helium is expected to distribute uniformly in the steel due to the high solubility of the tritium in the stainless steel. Additionally, the presence of other transmutation products and matrix damage in the irradiated material may also play an important role in helium embrittlement susceptibility. However, Wang et al. found weld cracking in neutron-irradiated 316 stainless steel and PCA alloys was no greater than that in materials doped with He by tritium charging and aging (Ref. 53).

**Mechanism of Helium Embrittlement during the Welding Process**

To quantitatively understand the mechanism of helium embrittlement, Lin et al. (Ref. 25) and Wang et al. (Ref. 44) proposed a model for the growth kinetics of helium bubbles during the welding process. Kawano et al. later proposed different “simulation modes” to predict the weldability of irradiated stainless steel (Ref. 54). These modes have been found to agree with experimental observations. Based on these modes, evaluation of the helium bubbles can be divided into several stages, including helium bubble nucleation, coalescence, growth, and resultant cracking in the HAZ during welding.

**Helium Bubble Behavior in the Heat-Affected Zone**

**Nucleation of Helium Bubbles**

Even though it has been observed that nano-scale helium bubbles distribute throughout the matrix of annealed helium-containing materials, helium embrittlement during welding is considered to be attributed primarily to the growth of GB helium bubbles. Kawano et al. proposed that helium bubbles nucleate at GBs during the heat-up period of welding (Ref. 54). Assuming the bubbles homogeneously nucleate at the grain boundary, the density of the nucleated bubbles \(N_0\) is proportional to the helium concentration, \(C_{He}^{i}\)

\[
N_0 = A C_{He}^{i}
\]

(4)

where \(A\) is a constant. The adjustable parameter based on the experimental data. Postirradiation materials contain a high density of defects due to the neutron irradiation. Helium atoms in the grain interiors are trapped in these defects. It has been found that the formation of bubbles on GBs is accompanied by the development of a bubble-free zone adjacent to the boundaries in most cases (Ref. 55). Therefore, it is expected that only the helium atoms adjacent to GBs contribute to bubble nucleation. More studies and knowledge of the bubble morphology in helium-containing materials are needed to determine a reasonable value of \(A\). This determination is complicated by the fact that bubbles in the range of 6–18 nm have been observed in irradiated stainless steel (Ref. 56). Clearly, the bubbles observed in welded material result from growth and coalescence of the numerous nucleated bubbles.

**Bubble Coalescence**

At the elevated temperatures experienced during welding, helium bubbles along GBs migrate and coalesce, which results in a decrease in the bubble density (Refs. 57, 58). During this stage, the time rate of change of the bubble density \((N)\) is given by (Refs. 54, 59)

\[
\frac{dN}{dt} = \frac{2 \pi D_p R^2}{\ln(L/4R)}
\]

where \(L\) is the bubble spacing, \(D_p\) is the bubble diffusion coefficient, and \(r\) is the bubble radius.

**Bubble Growth**

The growth of helium bubbles at GBs in the HAZ during welding can be divided into three sequential time regimes (Ref. 25). Figure 2 shows a schematic of the helium bubble growth mechanism along GBs during welding (Ref. 25). Regime 1 is the heat-up period before melting occurs. In this regime, bubble nucleation along GBs occurs. The bubbles can grow by absorption of thermal vacancies during the heat-up period. However, compressive stresses

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*Fig. 3 — Schematic representation of the GMA cladding process (Ref. 65).*
generated by the thermal expansion of the material will retard the growth of the bubbles. It is reasonable to conclude that the growth of bubbles is minor in this regime.

Regime II is when the molten pool is present, during which the HAZ is in a stress-free state. In this regime, the bubbles grow primarily through the absorption of vacancies into helium bubbles. The driving force for growth is the helium gas overpressure in the bubble. Under high temperature, the gas pressure in the helium bubble exceeds the surface tension restraint. This overpressure prevents thermal emission of vacancies for the bubbles and results in a net vacancy flux to the bubbles. This process is particularly favored at the HAZ close to the molten pool, where the temperature is close to the melting point, thus there is a high vacancy concentration. The growth rate of the bubbles in this regime is given by (Ref. 25)

$$\frac{dr}{dt} = \frac{8\delta D_{gb} c_{\Omega}}{2r^2} \tag{5}$$

where $\delta$ is the grain boundary thickness, $\Omega$ is the atomic volume, $D_{gb}$ is the self-diffusion coefficient in the GB, and $c_{\Omega}$ is the equilibrium vacancy concentration. Equation 5 indicates that bubble growth during this regime is significantly affected by vacancy concentration. At low temperatures (below 1000°C in steels) with low vacancy concentration, no significant bubble growth is predicted (Ref. 25). Based on temperature profiles of the HAZ during the GTA welding process, the radius of the helium bubble at the end of regime II is 0.025 μm according to Equation 5 (Ref. 44).

Regime III occurs after the molten pool has begun to solidify. In this regime, strong tensile stress is generated in the material due to shrinkage during cooling. The helium bubble growth is still caused by the vacancy adsorption. However, the driving force for adsorption is the external stress. Under this condition, the growth rate of the helium bubbles is approximately given by (Ref. 25)

$$\frac{dr}{dt} = -\frac{2m\delta D_{gb} c_{\Omega}}{\alpha r \kappa T} \tag{6}$$

where $\alpha$ is the spacing between the center of the bubbles and $\Omega$ is the shrinkage stress normal to the GB. This model has the ability to predict the bubble sizes in different locations of the HAZ, which have experienced different thermal histories and residual stresses. Based on Equation 6, Lin et al. calculated the approximate bubble size after regime III in the HAZ for helium-charged Type 316 stainless steel. The results showed that the bubbles on grain boundaries located 1 to 3 grain diameters from the fusion zone should be 0.85 μm in diameter 1.0 s after resolidification of the molten pool (Refs. 25, 29). This result was consistent with the measured time between the passing of the weld torch and onset of cracking, and the observed size of dimples decorated on the grain boundaries on the fracture surface. The high consistency of the calculated result based on the model and the experimental data suggests that the contribution of bubble coalescence to the bubble growth is a secondary effect. Comparing the calculated radius of helium bubbles at the end of regime II to that at the end of regime III clearly suggests that the dramatic growth of the helium bubble is stress assisted.

**Cracking at the Grain Boundary**

The formation and growth of GB helium bubbles reduce the contact areas of the GB and weaken the GB (Refs. 25, 52–54). Cracking in the HAZ of irradiated materials is ductile fracture with helium bubbles at grain boundaries acting as cavities or voids. The cracking occurs when the tensile stress induced by weld shrinkage in the HAZ exceeds the fracture strain. The fracture strain ($\gamma_f$) can be calculated by (Ref. 54)

$$\gamma_f = \frac{(1-n)\ln(L/2r)}{\sinh \left[ \sqrt{3(1-n)/2} \right]} \tag{7}$$

where $n$ is the work-hardening rate, $L$ is the bubble spacing, and $r$ is the bubble radius.

In order to better understand the mechanism of weld cracking in irradiated materials and verify the proposed models, welding simulations were performed on 304 stainless steels containing helium both by tritium charging and decay (Ref. 60) and helium implantation (Refs. 61, 62). Applied through a simulator, the testing material was subjected to various thermal and stress cycles similar to the conditions the irradiated material would experience during an actual welding process. The helium bubble behavior (size and density) in the test material under different conditions was examined. A comparison between the theoretical model calculation and experimental results showed good agreement (Refs. 61, 62), which provides further evidence of the combined effects of high temperature and stress on weld cracking.

**Helium Bubble Behavior in the Fusion Zone**

In the fusion zone, brittle failure is caused by the precipitation of helium bubbles along the dendrite boundaries. During material resolidification, helium is rejected by the growing dendrites due to the low solubility of helium in the solid. Helium bubbles are trapped between dendrites after solidification, which results in formation of microcracks and weakening of the interdendritic region. The shrinkage stress during weld cooling causes propagation of these microcracks and brittle rupture.

**Techniques to Improve the Weldability of Irradiated Materials**

**Low-Heat Gas Metal Arc (GMA) Weld Cladding Technique**

Researchers at Westinghouse Savannah River Co. developed a low-heat gas metal arc (GMA) weld cladding technique to improve the weldability of helium-containing materials (Refs. 63–66). Figure 3 shows a schematic representation of the GMA cladding process (Ref. 65). To minimize the heat input, this technique employs a short-circuiting metal transfer mode and high-speed cross-joint mechanical oscillation to produce cladding of adequate width to cover the repair area. Compared with conventional GTA welding, this technique generates much less heat during welding. The penetration of weld metal cladding into the underlying base metal was only about 0.076 mm (Ref. 65). The low heat input and shallow weld penetration produced by this technique was intended to minimize the temperature and stress around the weld, thus minimizing helium embrittlement cracking.

Type 304 stainless steel containing helium from tritium decay was welded using the GMA cladding process, in which 308L welding wire was used as the filler metal (Ref. 65). Metallographic results showed that toe cracking, experienced on conventional stringer welds, was eliminated in the steel containing helium at concentrations up to 220 ppm (Ref. 65). Underneath intergranular cracking started appearing in the GMA welds with 17 ppm helium content and found to increase with higher helium concentrations. However, the amount of underbead intergranular cracking in GMA welds is much less compared with that in the GTA stringer welds.

Kanne et al. studied the mechanical properties of GMA cladding welds of 304 stainless steel plates that contained 3 to 220 ppm helium from tritium decay (Ref. 64). The tensile tests were performed to evaluate the strength and ductility of the HAZ, and the interface between the cladding and base steel. The axis of the tensile test was perpendicular to the clad surface. Bending tests were used to determine the effect of stress on existing helium cracks, and were performed on wafer specimens that were machined to contain both weld cladding and base metal. No sig-

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significant degradation in mechanical properties was found for welded specimens containing less than 30 appm helium. A sharp drop in area reduction was observed for test samples with helium concentrations above 35 appm. The specimens failed in a completely brittle fracture mode when the helium concentration was increased to 221.1 appm. The significant decrease in ductility and strength was attributed to the change in failure location from base metal to the underbead HAZ, where excessive helium bubble growth occurred.

Similar results were observed by Goods et al. when the GMA cladding was applied on Type 304 stainless steel containing 2.7 and 85 appm helium from tritium decay (Refs. 58, 66). In their process, cladding with a thickness of 1.5 mm was welded onto the helium-containing steel. The penetration into the base metal was about 0.1 to 0.2 mm. No toe cracking in the cladding was observed. Scanning electron microscope examination revealed that intergranular cracks occurred in the HAZ of all helium-containing samples. The orientation of the cracks were preferentially normal to the cladding fusion boundary, and the crack facets exhibited a dimpled structure, indicative of helium-induced weld cracking. However, the extent of weld cracking was significantly reduced compared to that of the conventional stringer bead welds.

Kanne et al. applied the GMA cladding technique to irradiated 304 stainless steel that contained 10 appm helium (Refs. 52, 55). The irradiated steel was obtained from reactor tank walls at the Savannah River Site. A specimen from a 15-cm disc was welded. The irradiation resulted in a helium concentration of 10.4 appm on the inside surface and 5.0 appm on the outside surface of the disc. A GMA cladding weld approximately 7.6 cm long and 2.6 cm wide was made on each side of the disc. Metallographic examination and dye penetration testing revealed that surface cracks were eliminated, and underbead cracking was minimal in the welds. On the other hand, the conventional GTA welding method resulted in deep surface cracks from base metal to the underbead HAZ.

Stress-Modified Welding Technique

Because internal tensile stresses significantly accelerate the growth of helium bubbles during the cooling of the weld, it was hypothesized by Lin and Chin that changing the stress state in the material during welding would suppress the growth of helium bubbles and hence stop cracking (Ref. 25). During weld solidification and cooling, the principal shrinkage-induced tensile stress is perpendicular to the welding direction. Wang et al. applied a controlled compressive stress perpendicular to the welding path to improve the weldability of irradiated steels (Refs. 44, 67-71). In their study, the stress-modified complete penetration GTA welding process was used to weld tritium charged and aged Type 316 stainless steel sheets containing helium concentrations of 10 and 256 appm. Experimental results showed that GB helium bubble growth was effectively retarded. The bubble growth was reoriented from along grain boundaries parallel to the weld path to along GBs perpendicular to the weld path. Wang et al. found that a compressive stress level at approximately 25% of the room temperature yield strength eliminated all fusion zone and HAZ cracking (Refs. 44, 67, 68). The mechanical properties were studied for the unwelded base steel and stress-modified welds containing 10 appm helium (Refs. 43, 44). In nearly all cases, the helium-bearing tensile test samples failed in the base metal region. The ultimate, yield strength, and elongation values of the stress-modified welds were found to be similar to the values of unwelded helium-containing base steel. Their conclusion was that sound welds may be produced in helium-containing material using the stress-modified welding technique. Other steels were also investigated. By applying a compressive stress of 55 MPa perpendicular to the weld direction, successful GTA welding was also achieved in neutron-irradiated 20%CW 316 stainless steel, 25%CW PCA, and HT-9 steel (Ref. 53).

It appears that this technique is the solution to the problem of repairing irradiated materials. However, application of a compressive stress to the actual components is difficult or impossible. Thus, the technique illustrates the nature of the problem and provides guidance for further research, but additional work is required nonetheless.

Yttrium Aluminum Garnet (YAG) Laser Welding Technique

Welding helium-containing/irradiated materials using a Nd:YAG laser beam has been investigated by several Japanese groups (Refs. 27, 72-77). The laser welding method was found to minimize the heat input and stress in the welds and greatly improve the weldability of irradiated materials. Kawano et al. conducted bead-on-plate YAG laser welding on 304 stainless steel containing 0.5, 5, and 50 appm helium (Ref. 27). The experimental material was obtained by helium ion implantation using a cyclotron. It was found that the value of heat input during welding strongly affected the weldability of the material. When laser welding with a heat input of 20 kJ/cm was performed, which is typical for conventional GTA welding, intergranular cracking was observed in the HAZ in the specimens containing 50 appm helium. On the other hand, helium bubble growth was negligible even in the specimens containing 50 appm helium after laser welding with 1 kJ/cm heat input, which is typical for laser welding.

It was found that YAG laser welding mitigated weld cracking in irradiated steels as compared with GTA and GMA weld cladding methods, even though equivalent heat input (1.5~2 kJ/cm) was used during GTA and GMA welding (Refs. 27, 73). The authors hypothesized that this is because the YAG laser generates much smaller weld beads (less than 0.5 mm), and thus, causes lower effective heat input and less stress in the material (Ref. 27).

Nishimura et al. successfully lap welded unirradiated 316L stainless steel plates (0.5 mm thick) to neutron-irradiated 304L stainless steel plates (8 mm thick) using a high-power YAG laser under conditions of both continuous wave (CW) and pulse modes (Ref. 72). Bead-on-plate welding was also performed on the irradiated 304L stainless steel. A lap weld was irradiated in a boiling water reactor (BWR) and contained 9 ppm helium. The heat input generated by the laser was 240–360 J/cm for the pulse mode and 420–540 J/cm for the CW mode. For lap welded specimens, no helium-induced cracking in the HAZ was observed in any welds. However, cracks in the weld metal appeared in irradiated steel for pulse laser welds. For bead-on-plate welding, HAZ intergranular cracks were only observed in specimens welded by the CW YAG laser with the highest heat inputs (480 and 540 J/cm). Tensile tests revealed that YAG laser welded specimens showed good mechanical properties. All specimens failed not in the irradiated 304L steel but in the unirradiated material (Ref. 72).

Welding irradiated 316LN-IG stainless steel plates and tubes, containing 3.3 appm helium, using a YAG laser has been reported by Yamada et al. (Refs. 74-76). YAG laser welding (heat input 1.2 kJ/cm) was carried out in a hot cell by remote operation and performed to weld the following three types of specimens: unirradiated/irradiated, irradiated/irradiated, and irradiated/irradiated. The tensile tests of the welded specimens showed that the material’s ductility was reduced by the welding for all three types of specimens. However, it was found that the ductility of an irradiated/irradiated specimen was similar to that of an irradiated material without welding. The reduction in the ductility caused by irradiation damage was much larger than
that by welding (Ref. 75). Laser welding did not worsen the ductility of the irradiated welds. Three-point bend tests were also performed on YAG laser welded irradiated 316LN-IG stainless steel specimens (Ref. 74). The results showed that the bend properties of irradiated/irradiated welds were almost the same as the bend properties of an unirradiated/irradiated weld. It is believed that helium embrittlement does not affect the bend properties of laser welded 316LN-IG stainless steel specimens containing 3.5 appm helium.

Conclusions

The exposure of a nuclear reactor's inner components to intense neutron fluxes results in transmutation of minor elements, and in some cases, major alloy components, that generate helium in the matrix of the material. This helium is nearly insoluble in the matrix and can lead to serious heat-affected zone cracking during weld repair. This article summarizes the effects of helium on the weldability of helium-bearing materials and their postweld mechanical properties. The mechanism of helium-induced weld cracking is discussed. Novel welding techniques, such as low-heat gas metal arc welding, stress-modified welding, and YAG laser welding, can be used to effectively suppress the weld cracking and yield mechanical properties similar to that of a base metal.

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