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I-35W Bridge Collapse Investigation Continues

The National Transportation Safety Board (NTSB), Washington, D.C., recently issued a safety recommendation that addresses a design issue with the I-35W bridge that collapsed into the Mississippi River on August 1, 2007. The recommendation is made to the Federal Highway Administration (FHWA) and states: “For all non-load-path-redundant steel truss bridges within the National Bridge Inventory, require that bridge owners conduct load capacity calculations to verify that the stress levels on all structural elements, including gusset plates, remain within applicable design requirements, whenever planned modifications or operational changes may significantly increase stresses.”

“Although the board’s investigation is still ongoing and no determination of probable cause has been reached, interim findings in the investigation have revealed a safety issue that warrants attention,” said NTSB Chairman Mark V. Rosenker. “During the wreckage recovery, investigators discovered that gusset plates at eight different joint locations in the main center span were fractured. The board, with assistance from the FHWA, conducted a thorough review of the design of the bridge, with an emphasis on the design of the gusset plates. This review discovered that the original design process of the I-35W bridge led to a serious error in sizing some of the gusset plates in the main truss.”

Undersized gusset plates were found at 8 of the 112 nodes (joints) on the main trusses of the bridge. These 16 gusset plates (2 at each node) were roughly half the thickness required and too thin to provide the margin of safety expected in a properly designed bridge.

Also, according to the Minnesota Department of Transportation’s Web site, the new I-35W bridge is expected to be open by December 24 of this year. Among its features are as follows: structural enhancements, including the use of high-performance concrete and multiple levels of structural redundancy; a sensor and monitoring system built into the bridge; a 100-year life span; and ten lanes of traffic, five in each direction.

Liberty University to Offer Welding Engineering

The School of Engineering and Computational Sciences at Liberty University, Lynchburg, Va., launched in fall 2007, is aiming to add mechanical and welding engineering majors to the current degrees available. The likeliest launch for its new degree programs will be in the fall of 2010. Both will be four-year degrees when they begin.

“Welding will be enormously important in our curriculum. We have two of the top nuclear engineering firms in the world located in Lynchburg. Both Babcock & Wilcox and AREVA require highly skilled welding engineers in their processes and will provide tremendous opportunities for research and internships for our students,” said Dean Ron Sones. “Additionally, as Liberty launches a School of Aeronautics, students in the aircraft maintenance program will also require the development of welding skills. We also have a close relationship with NASA and would eventually hope to develop some research and training opportunities unique to their needs.”

Liberty already has some mechanical engineering expertise on campus. These scholars are helping to craft a curriculum that will pass the ABET accreditation test. The school’s hope is to attract a top scholar to develop the welding engineering program.

Liberty needs to raise about $15 to $20 million to build facilities with equipment and security systems. According to Sones, Chancellor Jerry Falwell Jr. has expressed a strong commitment to the engineering program and through his help, along with the support of local companies, the college hopes to raise the money within a year to begin construction. It will simultaneously pursue grant opportunities and corporate sponsorships.

Samuel Manu-Tech Acquires Tubular Products

Samuel Manu-Tech Inc., Toronto, Canada, has acquired Tubular Products Co., Birmingham, Ala. Tubular designs, engineers, manufactures, and supplies laser cut carbon steel tubing, fabricated tubular components, and welded subassemblies. These components are used in outdoor and power transmission equipment; all-terrain, automotive, and other vehicles; and reusable coil carriers.
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So Why Do We Need Standards, Anyway?

Standards are all around us, yet we are not even aware of most of them. Standards are documents that provide rules or guidelines that are produced by consensus and approved by a recognized body. Standards exist that control the food we eat, the electricity we use, and how our houses and factories are built, to name a few. Why do we need them? Here is an example: Let’s look at the toaster in your kitchen. You pull it off the shelf, plug it into an electrical outlet, and push down the lever. It heats and toasts the bread. What would happen if every manufacturer could install its own unique plug, or our houses all had different outlets, or the power company could provide us with different power voltages to our houses? It would be a nightmare. We would never be able to enjoy the conveniences of modern day living. But by incorporating standards, all these items must be produced in a certain way for use in the United States so they will work properly. If you took your toaster to Europe, however, it probably wouldn’t work because of the differences in the standards there.

The welding industry uses many specifications in the design, testing, manufacture, and use of its products. The American Welding Society is involved in creating the majority of these welding standards. The term “standard” encompasses five AWS document formats: code, specification, recommended practice, guide, and method.

A relatively small group of AWS members spends thousands of hours every year creating and maintaining the many AWS welding-related standards. These standards cover every welding and allied joining process, filler metals, qualification and certification programs, and applications such as structural, automotive, and aerospace. AWS D1.1, **Structural Welding Code — Steel**, is used throughout the world in welding steel structures.

This group of highly experienced and knowledgeable persons working in their individual committees follow stringent rules established by the AWS Technical Activities Committee (TAC) to ensure the standards are technically correct and that consensus practices have been followed. The TAC, Standards Council, and the AWS board of directors then must approve the standards. If we want to receive American National Standards Institute (ANSI) accreditation, they are sent to ANSI for its approval as well. These standards must be maintained on a five-year minimum cycle.

Since these standards are based on years of successful experience in joint design, process parameter development, inspection methods, equipment control, and process verification methods, we know that sound joints and safe structures can be produced.

I mentioned earlier that the toaster might not work in Europe. The same is true for many of our filler metals and welding equipment. To this end, the AWS International Standards Activities Committee (ISAC) has been working with the international community for many years to establish common standards that can be used throughout the world. Great strides have been made in recent years in achieving common standards, or standards that are cohabitated with one or more national standards, giving the user a choice. This allows U.S. products to be used in European products and vice versa.

How can you participate in ISAC or any of the other committees? As AWS members, you are encouraged to submit an application to join one or more of the standards-developing committees. These committees are constantly looking for new members with other views and experiences to provide input in creating new standards or maintaining current ones. Belonging to a standards-writing committee requires a considerable commitment in both time and travel. However, it is a rewarding experience. You develop increased knowledge from your other committee members and contribute to the successful use of new processes and/or joining of new materials. Your fellow committee members will become valuable resources of vast information that you can tap when needed. Personally, being part of several AWS technical committees for more than 30 years has been among my most enjoyable and rewarding experiences. You, too, can share that experience by contacting the appropriate committee secretary or sending an e-mail to John Gayler at AWS at gayler@aws.org to request an application.

Now, go plug in that toaster. I bet it will work.

Matthew J. Lucas Jr.
Chair, AWS Technical Activities Committee
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*The new warranty applies to standard torches, regulators and flowmeters manufactured on or after January 1, 2008. All items manufactured before that date will still have a five-year warranty.

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Aker Announces Plans to Build CO₂ Capture Facility

Aker ASA, Oslo, Norway, recently announced plans to build a large carbon dioxide capture facility. The planned budget is about $158.6 million. The facility is expected to be operational as early as 2009, removing carbon dioxide from exhaust emissions.

In recent years, Aker has worked extensively on developing new CO₂ capture technology. In 2007 it established Aker Clean Carbon, a wholly owned subsidiary. According to the company, the primary purpose of the new facility will be to develop construction methods and effective execution models that will make “carbon sequestration so inexpensive that it becomes cheaper to clean emissions than to pollute.”

Industrial facilities and power-generation plants that burn fossil fuels release huge volumes of carbon dioxide. On a global basis, the 4000 largest plants in operation today are estimated to generate about 40% of the CO₂ releases into the atmosphere. In addition, and on average, a new coal-fired power plant is completed each week in China.

“We have come a long way. To advance further, we must prove that we are able to package technology in commercially attractive solutions,” said Leif-Arne Langøy, Aker ASA chairman and CEO.

The new plant will have the capacity to remove 100,000 metric tons of CO₂ annually from exhaust gases. The company hopes to build its first facility near the natural-gas-fired power plant and gas-processing facilities at Kårstø in the southwestern Norwegian county of Rogaland. By connecting the carbon-capture plant to both emission sources, continuous CO₂ removal can take place, even if the gas-fired plant is shut down for periods.

IPG Photonics Achieves Deep-Penetration Welds on Thick Stainless Steel Plates

IPG Photonics Corp.’s application center in Germany recently achieved record high-quality deep-penetration welds on thick stainless steel plates at high speeds. Using the company’s 20-kW continuous-wave, 1070-nm commercial fiber laser, it was possible to weld 1-in.-thick stainless steel at a speed of 0.85 m/min and ⅝-in. samples at a speed of 2 m/min using a 200-micron fiber cable with a 420-micron focus spot size.

In other experiments, IPG was also able to produce high-quality welds on 2-in.-thick 304 stainless steel samples by applying laser beams from both sides with a penetration depth of 54–56 mm per pass.

Indonesian Welding Market Faces Strong Competition from China

The Indonesian welding equipment and consumables market is in its medium growth stage and is facing strong competition from low-cost suppliers based in China. Future market expansion will depend on continued demand from various end-user industries, according to a new analysis from Frost & Sullivan (industrialautomation.frost.com).

The report, Indonesian Welding Equipment and Consumables Market, shows that the market earned revenues of $82.7 million in 2006 and is estimated to reach $202.6 million in 2013.

“Revenues are set to rise due to steady orders from the shipbuilding, power, and heavy machinery industries,” notes Archana Chauhan, a Frost & Sullivan research analyst. “Domestic manufacturers are trying to expand by procuring new projects from construction and the oil and gas sectors, even while significant changes in the Indonesian automotive industry augur well for stable long-term growth.”

Most end-user industries continue to use older technology and are apprehensive about replacing manual welding techniques with mechanized processes. A key reason is lack of sufficient capital to invest in such technologies.

TEAM® Purchases European Industrial Services Business

TEAM® Industrial Services, a multinational company that maintains, services, and inspects piping systems used in the petrochemical industry, power plants, and other businesses, recently announced it has acquired Leak Repairs Specam (LRS) from the GTI Group in The Netherlands, an affiliate of the Suez Group.

LRS is headquartered in Vlissingen, The Netherlands, and has locations in The Netherlands and Belgium. It provides a range of services similar to those offered by the company’s TMS division, including on-stream leak sealing, hot tapping, fugitive emissions monitoring, field machining, and bolting.

The entire management team of LRS and its 90 employees will join TEAM®.

German Company to Build Welding Technology Center in West Bengal

Lorch Welding Technique GmbH, a German welding technology company, is establishing a welding center in West Bengal in collaboration with Ellenbarrie Industrial Gases Ltd. Lorch holds 51% and Ellebarrie 49% of the joint venture.

The new facility will be located at Uluberia in the Howrah district in West Bengal. The first stage will include a welding solutions center; production of welding machines will take place in the second phase. A training center for welders is also scheduled.

State Commerce and Industry Minister Nirupam Sen said the arrival of German innovation in the welding sector will boost the growth of manufacturing in the area.
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WELCOME AND OVERVIEW OF ALUMINUM WELDING  
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC  
An overview covering the various applications of aluminum welding, the numerous alloys, appropriate welding processes, and fundamental differences between the welding of aluminum and other materials.

THE ALUMINUM DESIGNATION SYSTEM & CHARACTERISTICS OF ALUMINUM ALLOYS  
Pete Polak, The Aluminum Association, Inc., Washington, DC  
Presentation explains AA's aluminum alloy and temper designation system, as well as the physical and mechanical properties of aluminum alloys.

ALUMINUM WELDING METALLURGY  
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC  
The basics of aluminum alloy metallurgy and the effects of welding on alloy properties.

METAL PREPARATION FOR ALUMINUM WELDING  
William Christy, Novelis Inc., Kingston, Ontario  
Metal preparation is one of the key steps in producing good quality welded joints.

FILLER ALLOY SELECTION PRIMARY CHARACTERISTICS  
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC  
Attendees will gain an understanding of the various filler alloy selection variables, including welded component service requirements and the characteristics of the base alloy being welded. The understanding of these variables is essential when designing a successful welding procedure specification.

GAS METAL ARC WELDING OF ALUMINUM ALLOYS  
Mark Burke, Indalco, Mississauga, Ontario  
Talk considers metal transfer modes, shielding gas types, wire feed systems, and power source selection — constant voltage, constant current, pulse or variable polarity.

GAS TUNGSTEN ARC WELDING AND VARIABLE POLARITY PLASMA ARC WELDING OF ALUMINUM  
William Christy, Novelis Inc., Kingston, Ontario  
Mr. Christy will discuss the application of gas tungsten arc welding and variable polarity plasma arc welding to the welding of aluminum.

EXPLOSION BONDING WITH ALUMINUM  
Don Butler, High Energy Metals  
Mr. Butler will describe the explosion bonding process along with the processes strengths and weaknesses. He will also discuss and show examples of how and why aluminum is explosion bonded to dissimilar metals.

ROBOTIC APPLICATIONS  
Jay Ginder, ESAB Welding & Cutting Products, Florence, SC  
This speaker discusses the latest developments in arc welding power source design and wire feeding concepts for robotic arc welding of aluminum. New programmable power source output wave forms for popular aluminum wire chemistries offer additional flexibility for those seeking to optimize production applications.

HIGH ENERGY DENSITY BEAM WELDING OF ALUMINUM  
William Christy, Novelis Inc., Kingston, Ontario  
Mr. Christy will discuss laser and non-vacuum electron beam welding of aluminum alloys.

CUTTING METHODS FOR ALUMINUM ALLOYS  
Jay Ginder, ESAB Welding & Cutting Products, Florence, SC  
The speaker will discuss the advantages and disadvantages of various cutting methods for aluminum (plasma, water jet, laser, grinding etc.).

OVERVIEW OF SOLID STATE JOINING PROCESSES FOR ALUMINUM  
Kyle Williams, Alcoa Technical Center, Alcoa Center, PA  
Overview of solid state joining processes used on aluminum including ultrasonic, upset butt, flash, friction, high frequency and explosive welding.

FRICITION STIR WELDING—CHALLENGES FOR AEROSPACE ALUMINUM  
Leanna M. Micona, The Boeing Company, Seattle, WA  
Friction stir welding (FSW) is a viable solid-state technology for joining aluminum alloys. Certain challenges present themselves when applying FSW to aerospace applications. Possible opportunities and associated challenges for implementation in aerospace will be presented.

EXPLOSION BONDING WITH ALUMINUM  
Don Butler, High Energy Metals  
Mr. Butler will describe the explosion bonding process along with the processes strengths and weaknesses. He will also discuss and show examples of how and why aluminum is explosion bonded to dissimilar metals.

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- Aluminum Standard and Data - 2006  
- Pink Sheet - Designation and Chemical Composition Limit for Aluminum Alloys in the Form of Casting and Ingot, April 2002  
- Teal Sheets - International Alloy Designations and Chemical Composition Limits for Wrought Aluminum Alloys, 2006

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Take advantage of the specially negotiated rate of $159 for single or double occupancy ($169 for triple and quad).
New Welding Training Center Opens at Odessa College

Odessa College (OC), Odessa, Tex., held a grand opening/open house and ribbon cutting ceremony on January 11 for its new Welding Training Center. During the event, which attracted approximately 150 people, college administration, faculty, and staff welcomed area industry, current students, and prospective high school and community students to tour the renovated center.

American Welding Society Vice President John Mendoza attended the event along with Patrick Fagerquist, southwest regional manager, The Lincoln Electric Co.; Kevin A. Ford, regional manager – south, PlymoVent; and Dennis Walker, Gary W. Mahan, Ronnie Riggs, David Dunn, and Larry Bailey, the management team of Praxair Westair, who have supported the endeavor from the beginning with supplies and equipment donations.

James R. Coffey, technical sales representative, The Lincoln Electric Co., brought a demonstration truck and performed shielded metal arc, gas metal arc, and gas tungsten arc welding demonstrations. Additionally, Lester Purdham, district manager, Thermadyne Industries, performed demonstrations and let attendees try the latest models of plasma arc cutting machines from the Thermal Dynamics demonstration truck.

“The initial response of industry was phenomenal. Everyone was very complimentary of our facility saying, ‘It is one of the finest and best equipped in the country,’” said Jim Mosman, Odessa College Welding Training Center coordinator.

OC welding training instructor Gloria De Los Santos said, “Odessa College is operating its current credit welding program at maximum student capacity. Developing the Welding Training Center was necessary to offer short-term, customized welding training in order to meet the immediate industry need for skilled welders.”

The facility is a 7500-sq-ft classroom consisting of 30 welding booths equipped with 21 Lincoln V-275 and 10 V-350 multiprocess machines, 6 oxyfuel cutting stations, and 2 Lincoln Statiflex-6000-MS self-cleaning low-vacuum air filter systems. This new facility is in addition to the college’s existing Welding Technology labs.

The center provides customized training to novice students, adult welders, and incumbent workers. It trains up to 60 welding students per eight-week training session.

The college applied for a grant from the U.S. Department of Labor in September 2006 in response to the Odessa Workforce Initiative Task Force report stating there was an area need for sufficiently trained entry-level welders. In January 2007, the college was awarded a $1,751,178 grant from the U.S. Department of Labor’s Community-Based Job Training Initiative in the manufacturing industry.
Superflash Compressed Gas Equipment Moves to New Location

At the Superflash IBEDA open house in Westlake, Ohio, Westlake Mayor Dennis Clough got the events rolling by cutting the chain with an oxyacetylene torch. Assisting the mayor in this unique ribbon cutting ceremony is company CEO and owner David J. Marquard II.

Superflash Compressed Gas Equipment, IBEDA, Inc., recently moved its headquarters and North America plant from North Olmsted to Westlake, Ohio. The renovated 27,000-sq-ft building has double the manufacturing capacity of the previous facility. About 100 officials and guests from Westlake and neighboring communities toured the building. The company makes flashback arrestors, quick connectors, check valves, and other safety products that help prevent injuries and equipment damage when using oxyfuel gas equipment.

TSI Group Adds Three Brazing Companies

TSI Group, Inc., North Hampton, N.H., a supplier of custom-engineered electronic assemblies and thermal management products, enclosures, and interconnect solutions, has acquired three companies. ADB Industries manages a dip brazing and machining operation; CGR Technologies employs brazing technologies; and Thompson Industries has advanced machining and vacuum brazing capabilities. All three companies are located in the greater Los Angeles metropolitan area.

Metalforming Educational Foundation Awards $88,000 in Grants

A total of $88,000 in grants has been awarded by the Precision Metalforming Association Educational Foundation board of trustees for seven programs created to enhance the U.S. metalforming workforce. The winners are as follows:

• $28,000 to Vincennes University, Vincennes, Ind., for curriculum development for beginning and advanced die-protection courses, working with PMAs Indiana District.
• $15,000 to the Center for Polytechnical Education for the development of manufacturing-oriented high schools in Chicago.

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• $15,000 to Riverworks Development Corp. to offer advanced training programs for press operation and setup in Milwaukee, Wis., working with PMA’s Wisconsin District.
• $10,000 to the Connecticut Business and Industry Education Foundation to support the 2008 Manufacture Your Future Careers Expo II, a one-day career-awareness event in Hartford.
• $10,000 to the California Coalition for Manufacturing, Education, and Government to support two projects — $5000 for designing a framework for podcasts of NIMS-based curriculum, and $5000 for a public image campaign to support manufacturing careers.
• $5000 to Red Education Consulting Services, Apex, N.C., to achieve NIMS credentialing for high school and community college instructors throughout the state.
• $5000 as a challenge grant to Naugatuck Valley Community College, Waterbury, Conn., for the purchase of a rotary machine for sheet metal training, contingent on the school’s ability to secure the remaining funds needed.

Technip Awarded Two Contracts for Deepwater Developments

Technip, Paris, France, has been awarded two contracts by Petrobras America worth a total of more than $300 million to develop the Cascade and Chinook gas fields located in the Walker Ridge area of the Gulf of Mexico in 8200 and 8800 ft of water, respectively.

The first contract covers the engineering, procurement, construction, and installation of five free-standing hybrid riser systems for both fields. The second contract covers the installation of the Cascade infield flowlines and gas export pipeline, and includes welding of approximately 120 km of 6- and 9-in.-steel pipelines.

The company’s operating center in Houston, Tex., will execute the contracts. The pipelines will be welded at the group’s spoolbase in Mobile, Ala. Offshore installation is scheduled to commence in the third quarter of next year.

Hobart Welding Products Redesigns Web Site

Hobart Welding Products recently launched a redesign of its Web site at HobartWelders.com. Among the new features is a navigation menu with process-specific icons that direct visitors to welding, cutting, and accessory product pages. It further enables viewing on screen resolutions of 1024×768. By visiting the E-Learning section, Welding 101 literature can be downloaded. Weld Talk, the company’s online user-forum, was redesigned as well to improve speed and access for its members. Forums of interest were organized under a new set of categories, and the site has improved search capabilities and several new tools.
Northwire Cable is ‘Uplifting Addition’ to Stillwater Bridge

When the engineers involved in refurbishing the Stillwater Bridge needed a reliable signal cable to control the bridge’s vertical lift span, they called upon Northwire, Inc., Osceola, Wis. The lift span of the highway bridge, which crosses the St. Croix River and connects Minnesota and Wisconsin, is raised and lowered at least 20 times a day during navigation season, and the cable that controls it is unwound and rewound as many times. “Northwire visited the site, designed a solution, provided the design to the Minnesota Department of Transportation, got approval, and produced the cable,” said Bob Quist, project manager, A.A. Hanson Electric in Osceola, Wis.

ArcelorMittal Enters Agreement to Acquire Unicon

ArcelorMittal, Luxembourg, a large steel company, has entered a definitive agreement to acquire Unicon, a manufacturer of welded steel pipes in Venezuela. The acquired company supplies the oil, gas, industrial, and construction sectors domestically and overseas. In addition, Unicon employs 2445 people in six pipe-making facilities in Venezuela.

Lincoln Electric Obtains Vernon Tool Co.

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has acquired the assets and business of Vernon Tool Co., Ltd., San Diego, Calif., a privately held manufacturer of computer-controlled pipe cutting equipment used for precision fabrication purposes. The acquired company’s annual sales are approximately $9 million.

Northwest Pipe Co. Awarded $30 Million Casings Contract

Northwest Pipe Co., Portland, Ore., has been awarded an approximately $30 million contract by Major Tool & Machine Inc. of Indianapolis, Ind., to manufacture tubing for steel casings that will be used for centrifuge machines in USEC’s American Centrifuge Plant in Piketon, Ohio. The company will begin manufacturing the tubing this year at its Parkersburg, W.Va., division. The contract will continue until 2012.

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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, 2008. The committee looks forward to receiving these nominations for 2009 consideration.

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee
GEDİK WELDING TECHNOLOGY

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WELDING MACHINES
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Web: www.gedikwelding.com E-mail: gedik@gedik.com.tr

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SPC-1000 is a wheel-mounted fume filtration unit that meets OSHA requirements for hexavalent chromium. Vapors from welding, brazing, and soldering are collected and filtered up to 99% efficiency at 0.5 microns. Its features include the following: nominal 1000 ft³/min @ 5.5 in. of static pressure powered by a 115-V, single-phase 1.5-hp TEFC motor with 8-ft cord and switch; 6-in. by 10-ft externally supported extraction arm; 11- and 14-gauge metal construction with a Kelly green textured powder coat finish; dimensions of 36 × 20 × 53.5; 10-in. rear wheels and 5-in. front swivel wheels with push handle; dust collection drawer; horizontally mounted filter with low center of gravity; and 177-sq-ft filter area, flame retardant, HEPA-type filter that changes without tools.

AER Control Systems LLC
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(866) 265-2372

Soldering Kits Promote Heat Transfer, Long Iron Life

Soldering Iron Maintenance Kits include everything necessary to remove flux residue, contamination, and oxidation that build up between the inside of an iron’s heating element and the surface of a heavy-duty tip. Packaged in storage cases, they each contain a spiral brush, steel wire brush, and flexible nonwoven abrasive pads that wrap around a tip’s shank. The spiral brushes have ½-in. hex shanks to fit most drills as well. Five individual kits for servicing 40- to 550-W soldering irons, and a complete kit for all sizes is offered.

American Beauty Soldering Tools
www.americanbeautytools.com
(800) 550-2510

Bead Blast System Cleans Brazed Parts

The company offers an automated rotary blast system to remove scale and flux residues from brazed components. The RXS-900 bead blast system has six ball bearing spindles around the perimeter of its 42-in.-diameter indexing turntable. A precision cam indexer conveys the fixed component from the front load/unload stations through blasting at two stations within the finishing enclosure, followed by air washing at a separate station inside the cabinet. At each blasting station, four or more blast guns are bracketed in fixed positions at the correct angles and distances for concentrated impact treatment of target surfaces. During the timed blast cycle, the component is rotated at controlled speed, enabling uniform 360-deg coverage. The control console of the rotary blast system features a touch screen interface that displays essential process data, graphically and in text, indicating the status of key system functions.

Guyson Corp. of U.S.A.
www.guyson.com
(800) 633-6677
Low-Temp Alloy Simplifies Brazing Aluminum

ChannelFlux ZA-1 is a low-temperature braze alloy for aluminum. The patent-pending material is a combination of zinc-aluminum with a noncorrosive flux. The product is available in spooled wire, rod, and preform rings. It simplifies the braze process by expanding the available temperature range for brazing.

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(708) 532-5000

Extension Die Grinders Available in Three Lengths

The company’s line of extension die grinders allow for efficient work within long pipes, castings, and other places where an extended reach is needed. The 1-hp straight-line air tools feature a rear exhaust air motor and are available in 3400 or 18,000 rev/min. Three lengths are offered — 19 3/4, 28 1/8, and 36 1/2 in. long. Each tool extension is constructed of steel for durability. The tools run at 80 dB(A) to minimize noise in the workplace.

Dynabrade, Inc.
www.dynabrade.com
(800) 828-7333

Electrodes Provide Resistance to Intergranular Corrosion, Pitting

SelectAlloy 2209-C is a metal cored wire utilized to weld duplex stainless steels of 22Cr-9Ni-2Mo-N type. The weld deposit has a duplex microstructure of austenite and ferrite and normally gives ferrite in the range of 25–40 FN. This electrode is suited for making small butt joint, lap, and fillet welds on thin material at elevated speeds. Also, SelectAlloy 2553-AP is a flux cored, all-position electrode with a nominal composition of 25.5% chromium, 9.5% nickel, 3.5% molybdenum, and 0.15% copper. The weld metal in this product exhibits high strength with corrosion resistance, especially to pitting attack from chlorides in seawater. Both electrodes produce little or no slag, virtually no spatter, and give a smooth, stable arc transfer.

Select-Arc, Inc.
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Autodarkening Welding Helmets Offer Three View Sizes

All VISTA® autodarkening helmets include a full-featured cartridge, including four arc sensors, variable shades (9 up to 13), variable sensitivity, and variable delay. The VISTA 3000 features a welding view of 3¼ x 3¾ in.; the VISTA 2000 offers a welding view of 1¾ x 3½ in.; and the VISTA 1000 has a welding view of 1¾ x 3½ in. Light-to-dark switching time is 1/10,000 s. The line also includes a cover/spatter plate. Welders can custom fit the helmet with the Push-N-Turn™ headgear, and the patent-pending tilt mechanism adjusts the viewing angle and helmet down stop. This is backed by the Positive Lock-Up™, which holds the helmet up until it is time to weld. The line launches with four designs — basic textured black, stars and stripes Patriot, iridescent paint NASCAR® design, or Heavy Metal graphic.

The Lincoln Electric Co.
www.lincolnelectric.com
(216) 481-8100

Sanders Come in Vacuum, Nonvacuum Models

The company is offering a line of Dynorbital Spirit Random Orbital Sanders. The tools, in vacuum and non-vacuum models, are available in diameters ranging from 3 to 6 in. The sander in-
cludes a comfort platform that provides additional hand and wrist support for the tool operator. This 12,000-rev/min air tool has many features — the throttle lever is recessed into the housing; each tool includes a vibration-absorbing grip; a double-row pad bearing improves bearing life and reduces tool vibration; and a muffling system is built into every sander.

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Named for Rosie the Riveter, Rosies is a line of coveralls and overalls for working women, including those in industries such as welding. The 100% cotton fabric is soft, durable, and lightweight in a wide range of colors and fabrics. Cut full to slip over clothing, they have Velcro® closures and are long in the draw for reaching and stretching. Removable knee pads are made of flexible foam. Packaged in plastic tote bags, Rosies come as a three-piece set — coveralls, kneepads, and polka-dot bandanas. The coveralls come in two styles — full-length, featuring long sleeves with cuffs, and Capri length with a ¾ length sleeve. The following five sizes are available: PS, S, M, L, and XL.

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(866) 767-4344

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The Champion 10,000 welding machine/generator, powered by a 20-hp OHV, twin-cylinder Kohler engine or a 22-hp OHV Subaru engine, produces 10,000 W of peak auxiliary power and a 210-A constant current, DC weld output at 60% duty cycle. It has 9500 W of continuous power (while not welding) from four 120-V (20-A) receptacles and one 120/240-V (50-A) receptacle. The product features the company’s patented Field Current Control technology for smooth shielded metal arc starts with minimal sticking of the rod. It has a 50 to 230 A output for welding with 6010, 6011, 6013, and 7018 rods up to ⅜ in., and 7014 and 7024 rods up to ⅝ in. Additionally, the
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machine is suitable for general scratch start DC gas tungsten arc and limited flux cored welding (CC flux cored welding only).

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Kanefusa saw blades allow material to be cut faster and with less material loss due to kerf. The tooth geometry of these blades points to lower cutting forces, high blade rev/min, high resistance to chipping, and good swarf curling. Also, to ensure that plates are free from distortion and have uniform thickness, they are precision flattened and ground. A variety of saw blades is offered — ST-4, Ti-4, and TA-4SUS — for cutting bearing steel, drive shafts, rails, and pipes.

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EVERY FAMILY HAS A KNUCKLEHEAD. MEET OURS.

Pete is a welding engineer and works for Thermadyne. He’s also a skilled welder and he’s pretty excited about the new technology from Tweco, called KNUCKLEHEAD, that allows welders to work more efficiently from all angles. Tweco is among the family of brands from Thermadyne. Pete’s a member of our family too. Both knuckleheads are worth getting to know.

We mean this in the most affectionate sense of the word. Like your ingenious cousin Joey, who looks like a numskull but can fix anything, the makers of the world’s most popular MIG guns, Tweco, has developed a new product using a patent pending mechanical ball and socket joint design that enables users to virtually infinite adjustments and firm positioning. According to tests performed by the Tweco engineering lab, the KNUCKLEHEAD flexible conductor tube outperforms the leading competitor by a factor of ten. Don’t be a blockhead. Work smarter with the KNUCKLEHEAD by Tweco.

The leading competitor’s flexible conductor tube showed signs of failure after as few as 348 cycles.* After 700 cycles the competition failed completely.

*According to laboratory tests, performed by the Tweco engineering lab in Denton, Texas.

Pete Anderson
Thermadyne
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www.tweco.com

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Beginning in 1976 with the Certified Welding Inspector program, the American Welding Society has developed a variety of certification programs to support the needs in the welding industry. The certification programs are designed to give individuals and organizations the credentials needed to demonstrate their competence and knowledge in specific welding or welding-related disciplines.

AWS certification programs provide credentials many contractors, manufacturers, and governmental institutions require, thus enhancing an individual’s career opportunities and providing a valuable service to the industry. But, first, let’s clarify what we mean by certification. It is documented evidence, by means of a certificate or other credential, that adequate training, experience, knowledge, and/or competence to practice a particular trade or profession has been demonstrated.

Certification is achieved by satisfying a combination of defined education, experience, and/or examination requirements. Certification, however, is not an assurance of future competence or ability.

The Current AWS Certification Programs

Following are the certifications the American Welding Society currently offers, along with the number of persons certified through most of the programs as of January 1.

• Certified Associate Welding Inspector (CAWI), 3174
• Certified Welding Inspector (CWI), 20,295
• Senior Certified Welding Inspector (SCWI), 343
• Certified Welder (CW), 2049
• Certified Welding Educator (CWE), 1371
• Certified Welding Supervisor (CWS), 248
• Certified Radiographic Interpreter (CRI), 95
• Certified Robotic Arc Welding Operator/Technician (CRAW), 5
• Certified Welding Engineer (CWEng), 18
• Certified Welding Fabricator (CWF), 70
• Accredited Test Facility (ATF), 83

Following are details on each of the programs.

Certified Welding Inspector

The CWI program contains several levels of inspectors and career opportunities abound for the CWI and SCWI in all industries that use arc welding as their primary joining technique. Also, there is great opportunity for starting one’s own inspection business centered around the CWI/SCWI credentials.

The Certified Welding Inspector and Senior Certified Welding Inspector certifications are widely recognized, both nationally and internationally, in the welding industry. Successful companies and the U.S. government have come to rely on this AWS certification to ensure the highest level of quality workmanship.

The specifications for qualification for these programs are identified in AWS B5.1, Specification for Qualification for Welding Inspectors, while the specification for certification for these programs are identified in AWS QC1, Standard for AWS Certification of Welding Inspectors. To qualify for exam registration, the candidate must determine if he or she meets the qualification and certification requirements of these standards. Both are available as free PDF downloads from the AWS Web site www.aws.org/w/a/certification/CWI/. The qualification requirements for becoming a CAWI, CWI, or SCWI are shown in Sections 5.1 through 5.3 of AWS B5.1.

The Welding Inspector Exam Application and the supporting documentation required by these standards (AWS B5.1 and QC1) must be submitted to the AWS Certification Department and approved for qualification before any candidate is permitted to attend an exam. Applications with incomplete or missing information will be considered unqualified unless the applicant can provide the missing documentation within two weeks of being notified (via telephone or e-mail) that the application is incomplete. If the applicant fails to meet the qualification criteria for the exam, the exam fee (or the exam portion of a seminar/exam...
**Certified Welding Supervisor.** Blake Craft strongly believes in the Certified Welding Supervisor program, so much so that he serves as chair of the subcommittee overseeing the program. He is director, Welding Technology & Administration, Trinity Industries, Inc., Dallas, Tex. In that position, Craft, who is also a Senior Certified Welding Inspector, Certified Welding Educator, and member of the AWS Certification Committee, evaluates training programs for the company’s welding-related workers.

“The Certified Welding Supervisor program offered by the AWS provides excellent insight into the application and science of welding. It teaches welding personnel how to make smart decisions taking quality and productivity to the next level,” he said. Craft called the CWS program “a good resource and training tool for welding supervisors to learn about the economics of welding and how that relates to manufacturing efficiency.”

Craft’s intention is for key employees at Trinity to obtain the AWS certification and for others to learn the principles outlined in the program.

**Certified Welding Inspector, Certified Welding Educator, and Certified Robotic Arc Welding/Technician.** Larry Gross, a welding instructor at Milwaukee Area Technical College (MATC), has earned all three of these AWS certifications and for him, the learning he did in pursuit of each one was a benefit itself. “The certification means I know or know how to do something. That’s the real benefit,” he said. “The certification is acknowledgment of skill or knowledge by a governing body like AWS.”

Gross has been with MATC full time since 1994 and part time for another ten years prior to that. His work falls within the Welding, Welding Technology, and Workforce Development Departments. He also consults with businesses for welding automation implementation and process development. MATC has an enrollment of 60,000 students attending classes at four campuses. Welding is taught in two programs: a one-year diploma and a two-year associate degree. The CWE credential is recommended in the job description for anyone teaching welding at MATC.

Welding students at MATC range from young people just out of high school who are looking for a field to enter to older workers looking for additional training or who wish to change careers. “My CWI (certification) is useful for certifying welders through contracts with the school and the CRAW-T authorizes me to administer tests for others seeking that certification,” Gross said. “The associate degree from MATC has a strong robotic component and the skill of our graduates is well-known locally. This certification will expand graduates’ opportunities and enhance industry confidence during the hiring process.”

Gross is a member of the AWS D16 Committee on Robotic and Automatic Welding, which worked on development of the closed-book written and performance segments of the CRAW exam. The exam “is used by industry to verify that those in charge of robotic welding have both the knowledge and skill to produce quality products. The number of Certified Robotic Arc Welding Technicians is modest now, but is being embraced as an industry standard,” he said.

Gross’s advice for anyone considering pursuing certification is that “industry is increasingly credential driven. By all means, get certifications appropriate to the work you want to do.”

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**Thoughts on Being a ...**

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**Certified Welding Supervisor**

Welding supervisors can make a valuable contribution to the four most important metrics in welding operations: quality, cost, productivity, and safety. Yet, the position of welding supervisor is often an overlooked resource.

Oftentimes the underlying cause of a supervisor’s inability to improve productivity can be traced to inadequate knowledge and skill levels, and the minimal amount of time that a supervisor actually spends working with the welders to understand their needs. The AWS Certified Welding Supervisor program was instituted between 2003 and 2004 to rectify these conditions by offering welding supervisors and their companies the opportunity to put the welding supervisor in a support position for the welders, making the welders the most productive and best they can be. This program identifies a body of knowledge all welding supervisors should know and understand in order to increase productivity and improve weld quality. It is a useful program for any industry that uses welding as its primary joining technique.

AWS, along with the National Shipbuilding Research Program (NSRP), released a report on the advantages of training welding supervisors and its effect on production cost efficiency. The research was supported through a trial project at a shipyard in Alabama. The results of the trial program are as follows:

- Projected costs per welder were reduced by $17,000 annually. Labor hours on successive modular construction sequences were reduced by 1000 hours per module.
- The potential savings of the program totaled $2 million annually.
- On a multiple-ship order, the typical improvement in efficiency averaged 200–300 hours when a module is repeated. After the welding supervisor training, the first repeated module was done with 600 fewer labor hours; the second showed 1000 fewer labor hours.

Operational goals for achievement and their estimated savings were as follows:

- Reduce weld metal volume. Estimated potential savings: $3319 per welder
- Reduce arc time per weldment. Estimated potential savings: $4280 per welder
- Reduce rework and scrap. Estimated potential savings: $3244
- Reduce work effort and motion and delay time. Estimated potential savings: $6200.

For anyone seeking work with a cost-conscious employer or contractor, the Certified Welding Supervisor (CWS) serves as an excellent credential.

Certified Radiographic Interpreter

The Certified Radiographic Interpreter (CRI) program, based upon requirements contained within AWS B5.15:2003, Specification for the Qualification of Radiographic Interpreters, is designed to provide evidence of the ability of individuals to properly interpret and evaluate welding-related indications produced on radiographic film and related media.

Candidates seeking certification are required to successfully pass three examinations — one on general knowledge, one on specific knowledge related to the required quality and acceptance criteria as contained in the most common codebooks, and a practical examination requiring interpretation of actual radiographs. An AWS-approved training program is available that covers 40 hours of instruction.

Individuals who meet the examination, education, experience, and training requirements as specified in AWS B5.15 are awarded the designation of AWS Radiographic Interpreter. The holders of this certification have a valuable tool for demonstrating their qualifications to interpret radiographs of weldments. The CRI program complements the CWI program and offers certified individuals many of the same opportunities.

Students taking the AWS training course receive instruction on the following subject areas:

- Nature and properties of X-ray and gamma radiation
- Photographic aspects such as types of film and paper used in industrial radiography and characteristics such as speed, contrast, definition, and density
- Fundamental aspects of radiographic quality such as optimum working densities, radiographic contrast, and objective and subjective contrast
- Radiation safety principles
- Information on X-ray and gamma-ray equipment such as the effects of equipment change on radiographic quality
- Geometry of image formation, including geometric unsharpness; control of source-to-object distance, object-to-film distance, and source-to-film distance; penetrometer sensitivity; and selection of beam angle
- Exposure calculations
- Application to welds, including interpretation of radiographs of welds in different materials and joint geometries; multiple-film techniques; welds in small-bore tubes; and determination of the depth of a flaw from one surface in a specimen by the practical use of the tube or source shift method (triangulation method)
- Viewing radiographs
- Welding technology

To download AWS B5.15, visit the Certification page of the AWS Web site.

Certified Welder

The Certified Welder (CW) program is a performance-based program with no prerequisite courses or certifications required. Final certification will provide “transferable” credentials that you may take with you wherever you go.

Candidates for the certification perform the tests to procedures used in the structural steel, petroleum pipelines, sheet metal, and chemical refinery welding industries. There is a provision to test to a company-supplied or AWS Standard Welding Procedure Specification (SWPS). To find a facility near you, access the list of Accredited Test Facilities on the AWS Web site or call AWS at (800) 443-9353, ext. 475.

Following is how you can “demonstrate” your skill:

At an AWS Accredited Test Facility, you will physically demonstrate your ability to deposit a sound weld in a standard test joint that will be inspected and evaluated by an AWS Certified Welding Inspector. Your ability to properly adhere to the Welding Procedure Specification, including fit-up, assembly, and positioning, will also be demonstrated before, during, and after welding of the test assembly.

You will learn if you passed the test immediately after inspection by the CWI or SCWI. However, due to the processing and mailing time required after AWS receives your application, test results, and $30 registration fee, your card certifying your qualification and a supply of certification maintenance forms will require several weeks to process and ship.

The certification remains valid as long as you submit your certification maintenance forms indicating that you have used the process for which you were tested in every six months (one year for AWS D9.1) as typically required by the code, specification, or standard of acceptance that governed your test. As long as you can verify (have your employer sign the form) that you are still performing the same welding to which you originally tested and submit this proof for renewal to AWS, your certification will be renewed semiannually or as specified by the governing code or specification.

If you fail the test, the codebook used for the test dictates when and how you can retest. Here are two examples:

1. Immediate retest may be made consisting of two welds of each type and position that the welder failed.
2. A retest may be made provided there is evidence that the welder had further training or practice.

If needed, the AWS Accredited Test Facility representative can assist you in scheduling a new test date.

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<th>Table 1 — The Principal Requirements for Taking the CRAW Examination</th>
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(a) Current CWI certification is a requirement for the CRAW-T certification. Failure to achieve and/or maintain CWI certification will result in the CRAW-O certification only.

WELDING JOURNAL 29
Certified Welding Educator

The Certified Welding Educator (CWE) program is geared for the welding professional specifically in the welding education field. This AWS certification confirms your ability, talent, and knowledge to specifically direct and perform operations associated with welder training and classroom instruction. The CWI and CWE exams are identical; however, the Part C, codebook portion is not a requirement for the CWE certification.

Along with passing two parts of the CWI exam, the applicant must have a welder performance certification from a national organization.

Both certifications (CWI and CWE) may be achieved simultaneously. The applicant must check the appropriate box located on the top-left corner of the CWI/CWE Exam Application to indicate whether he or she is applying for one or both certifications. It is mandatory that the CWE Welding Instructor Credentials form be submitted along with the completed CWI/CWE Exam Application. QC5-91, AWS Standard for Certification of Welding Educators, is the certification document governing the certification requirements.

If you are currently a SCWI, CWI, or CAWI, and you meet the Certified Welding Educator criteria, no testing is required for the CWE certification. You should simply meet the following criteria:

• Complete the CWE Short Form Application.

• Teach full or part time in a classroom environment.

• Hold a valid welder certificate.

• Present a written recommendation from your teaching supervisor attesting to your teaching qualifications and ability.

Certified Welding Fabricator

An appropriate welding quality system is the foundation for delivering a quality welded product or service. When designed for the welding fabricator’s unique products and suitably committed to paper and practice, the daily manufacturing operations of the welding fabricator are more consistent and traceable when problems arise. An increasing trend is that customers and some codes require manufacturers and fabricators to have a documented and active welding quality system. Having and using a quality system for welding operations helps ensure that the welding fabricator and the fabricator’s subcontractors are capable of producing welded products that meet their specifications and expectations on a consistent basis.

The core of a welding quality system is a quality manual that will identify the duties and responsibilities of management, supervisors, and welders, and will provide the customer with accurate information about who is responsible to ensure that the welding meets specifications. Companies of all sizes can benefit substantially through the systematic improvements encouraged by state-of-the-art quality systems.

Fabricator Program Requirements.

Responding to industry demand, AWS has provided a welding certification program for companies that use welding as a joining process. The requirements for this program are set forth in AWS B5.17, Specification for the Qualification of Welding Fabricators. This specification defines the requirements for a company’s compliance with welding-related functions and ensures, through third party assessment, that the Welding Fabricator has the personnel, organization, experience, procedures, knowledge, equipment, capability, and commitment to meeting the customer’s expectations right through delivery.

The certification program for applicant companies involves several steps.

1. Downloading the application form, B5.17 standard, QC17 standard, and a manual and on-site audit checklist. You must study all of the materials to become familiar with the program requirements.

2. The application, along with your quality manual, must be submitted to the AWS Certification Department. AWS will assign an assessor to review your quality manual and to work with you to improve it, if necessary.

3. After the quality manual has been accepted, an assessor will contact you and arrange for a date for your on-site audit. The assessor will use the same on-site audit checklist that you have, so you will know what the assessor will be looking for.

4. The on-site audit consists of an opening meeting, a review of your facility’s quality manual, an inspection and assessment of the facility itself, and a closing meeting to discuss any findings and concerns observed by the assessor.

5. Your facility will have one month to respond to any outstanding actions to the satisfaction of the assessor and the AWS Certification Committee.

6. Upon successful completion of all requirements and satisfaction of all fees due, the facility will be accredited as an AWS Certified Welding Fabricator. This certification remains in effect for a period of three years, with annual self-audit renewals in the second and third year, after which the process repeats itself.

Certified Robotic Arc Welding Operator/Technician

The American Welding Society’s newest certification program, which became fully functional in 2007, is Certified Robotic Arc Welding — Operators and Technicians (CRAW). This certification allows welding personnel employed in various welding sectors to measure themselves against standards for their occupation. It also signifies that the CRAW operator or technician has demonstrated the capability of working with various codes, standards, and specifications. Since proof of active practice or reexamination is required every three years, certification also signifies that the CRAW operator or technician is current with the welding industry.

If you are involved in an industry that uses robotics for arc welding its products, you should consider obtaining the CRAW certification.

AWS D16.4:2005, Specification for the Qualification of Robotic Arc Welding Personnel, and AWS QC19, Standard for the AWS Certification of Arc Welding Personnel, set the principal requirements for taking the CRAW examination. These requirements are outlined in Table 1.

This two-part exam is comprised of Part A, a multiple-choice test consisting of 136 questions, and Part B, a performance test that covers the practical demonstration of knowledge and ability involving a robotic system. A pass mark of 75% is required on Part A in order to meet the minimum requirements for certification as CRAW operator or technician. Both parts of the exam are conducted at the same AWS-approved test site. To achieve certification, all applicants must successfully pass both parts of the exam.

Performance Test Candidate Information Booklet can be downloaded from the AWS Web site. In addition, to prepare applicants for the CRAW examination, training is being offered at the following AWS-approved test sites: ABB Inc., Auburn Hills, Mich., contact Keith Lloyd, senior training instructor, (248) 391-8421, e-mail keith.r.lloyd@us.abb.com; Rimrock-Wolf Robotics, Fort Collins, Colo., contact Darren Pape, customer support manager, (970) 225-7736, e-mail DarrenPape@wolfrobotics.com; and The Lincoln Electric Co., Cleveland, Ohio, contact Geoff Lipnevicius, engineering manager, (216) 383-8027, e-mail geoff_lipnevicius@lincolnelectric.com.

For further information on becoming an AWS Authorized Test Center for the CRAW program, please contact Frank Lopez del Rincon at (800) 443-9353, ext. 211, e-mail flopec@aws.org.

For further information on any of the AWS certification programs, visit the Certification page of the AWS Web site or call AWS at (800/305) 443-9353.
The application of magnesium alloys has been expanded in the past years. Magnesium alloys are used in many different industrial fields such as aerospace, automobile production, and for the chassis of portable electronic devices. The use of these materials, though, demands appropriate joining technologies. Up to now, brazing of magnesium and magnesium alloys was considered problematic since direct wetting of the filler metal was hindered by an oxide layer on the surface of the brazing parts. Previously, different efforts were made to remove this oxide layer by means of fluxes (Refs. 2–10). After brazing, a considerable effort was spent removing fluxes from the surface of the brazed joint (Refs. 3, 4). But fluxes cannot be removed completely because they also remain in the molten zone of the brazed joint and remain there after solidification. If these parts come under corrosive attack, chloride ions cause additional corrosive problems (Refs. 1, 11–13). Filler metals used in those conditions have a high magnesium content and thus a high liquidus temperature of 560°C or more. Only pure or low-alloyed magnesium alloys could be brazed with these filler metals.

To avoid deterioration of the joint by corrosive conditions, a fluxless joining process was developed by the use of ultrasonic soldering. Filler metals used with this process have a relatively low melting temperature, allowing high-alloyed magnesium also to be brazed this way.

Filler metals based on Zn-Mg-Al offer a high potential since they possess, on the one hand, a low electrochemical difference in comparison to the magnesium base metal. On the other hand, they are appropriate from a metallurgical point of view. Soldering temperatures are about 350°C. Thus the filler metals can be applied to many of the magnesium-based alloys as well as to joints of dissimilar metals, such as aluminum.

These filler metals are produced as amorphous tapes, since solidification at nonequilibrium conditions results in a new structure, and thus the mechanical properties are completely different. Amorphous filler metal tapes are easy to handle when applied to the solder joint opening. Another advantage of amorphous filler metals is their homogeneity.

Details of the Experiment

Filler metal compositions containing 55 mass-% Zn, 42% Mg, and 3% Al were produced by continuous casting, and the elemental composition was examined using electron diffraction X-ray spectroscopy (EDXS). The production of amorphous tape was carried out under an argon atmosphere after induction melting of the prealloyed rods. The alloy was melt spun by solidification on a rotating water-cooled copper wheel with a speed of 27.5 m/s. The tapes have a width of 1.5 mm and a thickness 50–60 μm — Fig. 1. Afterward, the filler metal tapes were characterized. Different...
tial scanning calorimetry (DSC) measurements were carried out on Netzsch STA 409. The heating and cooling rate was 5 K/min. Heating was carried out at temperatures between ambient and 400°C.

Microstructural examinations were conducted with light microscopy and scanning electron microscopy (LEO 1455 VP).

**Investigation Results**

**Development of Filler Metals**

After premelting and subsequent continuous casting, the Zn-Mg-Al alloy showed a fine-grained eutectic microstructure with only a few intermetallic precipitates, which are related to the ternary composition Mg₃₂(Zn,Al)₄₉ — Fig. 2.

After melt spinning even at very high resolutions, no microstructure was observed with the scanning electron microscope. The sample appeared homogeneously gray.

Figure 3 shows the heating and cooling curves of the alloy directly after melt spinning. The crystallization takes place during two crystallization steps. The first one starts at a temperature of 100°C and is finished at a temperature of 116°C. The second crystallization step shows an onset temperature of 180°C and a peak temperature of 216°C. Both crystallization peaks can only be observed during the first heating, but they neither occur during the cooling nor during the second heating. Thus, it is evident that both peaks belong to irreversible crystallization processes. The crystallization peaks are evidence of the amorphous state of the sample.

**Microstructure of Soldered Joints**

Figure 4A–E represents microstructures of soldered joints with different magnesium base metals. It can be seen that there is no restriction concerning the alloying elements of the base metals. Depending on the composition of the base metals, different interface formations and phases within the soldered joint were observed.

Soldered joints obtained using dissimilar base metals form microstructures like those shown in Fig. 5. The soldered joint consists of magnesium solid solution, which appears dark, and several intermetallic phases, which appear lighter gray. At the interface to the magnesium base metal, a diffusion zone can be observed containing higher amounts of zinc than AZ31. An Mg₁₇Al₁₂ layer containing zinc on substitutional lattice sites can be observed at the interface to the aluminium base metal. During the soldering process, the magnesium as well as the aluminium content of the filler metal increased, while the zinc content decreased. The overall composition within the soldered joint was 59 Mg, 21 Al, and 20 Zn (in mass-%). The influence of the filler metal composition...
Conclusions

Previous research has shown that soldering is an appropriate joining technology for magnesium alloys, as well as for aluminum alloys. For this purpose, systematic optimizations of the joining systems are necessary. For soldering, this means particularly the development of the filler metals. The results shown represent an essential research step for later industrial applications. At this point, it is necessary to gain detailed information about the joints in a component-related application.

Acknowledgment

At present, appropriate research is carried out within the DFG-priority program 1168 (InnoMagTec). The authors are very grateful to the German Research Foundation (DFG — Deutsche Forschungsgemeinschaft) for funding this study within the scope of priority program 1168 (reference numbers WI688/68-2 and HA1005/14-2).

References

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Aluminum matrix composites (AMCs) are characterized by excellent strength-density ratio and improved wear resistance. Because of the rather expensive production of composites, they are applied only locally in places where their special characteristics are necessary. Thus, suitable joining techniques are very important. Soldering offers some advantages in comparison to other joining processes. Compared to welding, the thermal influence on the base material is clearly lower. Also, compared to bonding, soldering is characterized by higher strength and thermal resistance of joints.

The production of composites with equal channel angular extrusion (ECAE) allows a very fine-grained structure to be achieved (Refs. 1–4). These materials are characterized by very high strength. To avoid grain growth and the associated decrease in strength, the joining temperature must be kept low. For this purpose, Sn-based solders are suitable because of their low melting point, which is below 300°C. To improve the mechanical properties of the joint, the solders can be reinforced with ceramic particles.

In the current study, the optimized joining parameters for solders reinforced with SiC or Al₂O₃ particles are presented. The microstructure and properties of the filler metals are investigated using differential thermal analysis (DTA), scanning electron microscopy (SEM), and energy-dispersive X-ray analysis (EDX). Tensile tests were carried out on cylindrical specimens with a diameter of 10 mm — Fig. 1.

Materials for the Experiment

The solders reinforced with SiC and Al₂O₃ particles are produced by high energy milling (HEM). A maximum of hard particles up to 35 vol-% can be obtained using this method. As matrix material for the filler, near-eutectic alloys with 3.5 wt-% Ag or 3 wt-% Cu are used. These materials are characterized by a low melting point of approximately 230°C. An average particle size of SiC and Al₂O₃ is approximately 2 μm. The HEM production method permits a homogeneous structure for the solder composition.

An ultrasonic soldering process (Fig. 2) was used (Ref. 7) to join AMCs in this experiment. The flux-free procedure consisted of two steps: solder application and joining. In the first process stage, the solder layers (200–500 μm thick) were ap-

**BRAZING & SOLDERING TODAY**

Joining of High-Strength Aluminum-Based Materials with Tin-Based Solders

Microstructure, thermal behavior, and mechanical properties of soldered joints were investigated

BY S. WEIS, I. HOYER, AND B. WIELAGE

S. WEIS, I. HOYER, and B. WIELAGE are with the Institute of Composite Materials and Surface Technology, University of Technology Chemnitz, Chemnitz, Germany.
plied on the base material surfaces by friction soldering. The second step was a combination of ultrasonic and heat treatment processes for joining the specimens. The time for additional ultrasonic treatment was about 10 s.

Results of the Experiment

Production of Reinforced Solders

The metallographic investigations showed a good connection between the ceramic particles and the matrix in the solders produced by HEM. No pores were detected on the interface by SEM observations — Fig. 3. Nevertheless, the distribution of the reinforcing particles is nonuniform. Homogeneity can be significantly improved by the use of ultrasonic treatment during the joining process.

The heating curves obtained by differential thermal analysis (DTA) of different reinforced filler metal alloys are shown in Fig. 4. The comparison of the onset and peak temperatures between conventional and modified solder exhibited no noticeable change in the melting range by the addition of ceramic particles. This proves that on the interface between the matrix and the particles, only mechanical anchoring is the bonding mechanism without the occurrence of new phase formations. The melting temperature of about 227°C determined a joining temperature range of 250°–280°C.

Microstructure of Soldered Joints

The microstructures of typical soldered joints in which filler metals with different reinforcing particles were used are shown in Fig. 5B and C. For comparison,
Fig. 5A exhibits a conventional soldered joint without ceramic particles. As base materials, the aluminum Alloy En-AW 2017 and the aluminum matrix composite EN-AW 2017SFB + 5 vol-% (Al₂O₃)ₚ are used.

A good bond between the matrix and reinforcement component can be observed. This is a determining factor in the intended increase of joint strength. The microstructure and the distribution of the phases in the solder joint correspond to the structure of the solder after application. No new phases were detected. In addition to reinforcement particles, the Al₂O₃ particles from the base material can be observed in the soldered joint. They are larger (10–25 μm) than the ceramic particles in the solder (approximately 2 μm) and uniformly distributed. This transfer of the particles from the base material can be explained by the influence of the ultrasonic treatment.

**Mechanical Properties**

A tensile test was used to determine the joining strength in the temperature range of 20°–150°C. The results are shown in Fig. 6.

From the results of tensile tests (Fig. 6), it was shown that the joining strength decreased when the testing temperature increased. This effect was for all investigated material combinations. It also can be seen that the addition of reinforcement particles provides a significant improvement in joining strength at all test temperatures (20°–150°C). The best results (joint strength: 32 MPa) were at a testing temperature of 50°C for the joining of EN-AW 2017SFB + 5 vol-% (Al₂O₃)ₚ with SnAg 3.5 + 35 vol-% (Al₂O₃)ₚ. The reason for the improvement in joint strength was the dislocation movement restriction due to the ceramic particles. Also, the soldered joint thickness increased because of the addition of ceramic particles — Fig. 6.

**Conclusion**

Tin-based solders modified by the addition of reinforcement particles (max. 35 vol-% SiC or Al₂O₃) were used to join aluminum matrix composites. A flux-free joining process based on a combination of ultrasonic and heat treatment was used. With this process, the problem of the oxide layer removal from the surface of the base material was solved. The experimental results indicated a clear improvement in mechanical properties when increased temperatures were reached. The exposed solder materials and joining procedure provided little thermal influence on the base material due to the low melting point of approximately 230°C, and it can be recommended for soldering of composites produced by ECAP.

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A Look at the Development of Magnesium-Based Filler Metals

**BY K. BOBZIN, E. LUGSCHEIDER, F. ERNST, D. JÄGER, A. SCHLEGEL, AND J. RÖSING**

The traditional machining process for magnesium-based parts is casting. Those parts can be found in various products such as cell phone covers, laptop cases, and drill machine structures. These also demonstrate the most important features of this material — the combination of noble looking surface with high strength in relation to its weight.

The consumption of primary magnesium increased from about 250,000 tons to 364,000 tons in 2002 — Fig. 1.

Recently, magnesium-alloy plates have been put on the market in industrially utilizable quantities. The automotive sector especially has a high interest in these semi-finished products, mostly produced with the Alloy AZ31B (3 wt-% Al, 1 wt-% Zn). The high specific strength enables weight reductions in relation to steel of up to 60%, and in addition, constructions using aluminum alloys can be lightened by 25%. Easy recycling possibilities are a second advantage of this group of materials.

A suitable joining technology and especially a convenient filler metal have to be found to integrate these plates in complex products (Refs. 2, 3).

**Development of Suitable Filler Metals**

The following three basic requirements have to be fulfilled:

- To minimize contact corrosion, Mg is preferred as base material. Industrially used Mg-based alloys usually contain Al. Therefore, this element was taken as the second part of the filler metal.
- The joining temperature must be lower than the critical temperature of the basic material; this leads to a liquidus temperature <450°C.
- The third element should build a ternary eutectic. This enables a very small melting range and enables a fast soldering process.

Theoretical investigations showed that Ag, Be, Bi, Ce, Co, Cr, Cu, Ga, Ge, L, Li, Mn, Nd, Ni, Pb, Pr, Sb, Si, Sn, Sr, Ti, Y, and Zn fulfill all the needs listed above (Ref. 4).

Considering price and medical restrictions, a suitable joining technology for magnesium-based parts needs a filler metal fulfilling the requirements. The following three basic requirements have to be fulfilled:

- The joining temperature must be lower than the critical temperature of the basic material; this leads to a liquidus temperature <450°C.
- The third element should build a ternary eutectic. This enables a very small melting range and enables a fast soldering process.
- Easy recycling possibilities are a second advantage of this group of materials.

The following eight ternary systems fulfill all the needs listed above:

<table>
<thead>
<tr>
<th>No.</th>
<th>System</th>
<th>Mg (wt-%)</th>
<th>Al (wt-%)</th>
<th>XX (wt-%)</th>
<th>T_lq (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Mg-Al-Ag</td>
<td>53.0</td>
<td>19.0</td>
<td>Ag: 28.0</td>
<td>404</td>
</tr>
<tr>
<td>L2</td>
<td>Mg-Al-Zn</td>
<td>30.0</td>
<td>58.0</td>
<td>Zn: 12.0</td>
<td>447</td>
</tr>
<tr>
<td>L3</td>
<td>Mg-Al-Sn</td>
<td>57.3</td>
<td>31.3</td>
<td>Sn: 10.0</td>
<td>428</td>
</tr>
<tr>
<td>L4</td>
<td>Mg-Al-Cu</td>
<td>47.0</td>
<td>3.0</td>
<td>Zn: 50.0</td>
<td>425</td>
</tr>
<tr>
<td>L5</td>
<td>Mg-Al-Ga</td>
<td>38.7</td>
<td>51.3</td>
<td>Ga: 8.0</td>
<td>425</td>
</tr>
<tr>
<td>L6</td>
<td>Mg-Al-Tl</td>
<td>63.3</td>
<td>32.5</td>
<td>Cu: 1.2</td>
<td>425</td>
</tr>
<tr>
<td>L7</td>
<td>Mg-Al-Y</td>
<td>33.4</td>
<td>65.4</td>
<td>Cu: 1.2</td>
<td>448</td>
</tr>
<tr>
<td>L8</td>
<td>Mg-Al-Ga</td>
<td>37.3</td>
<td>53.9</td>
<td>Ga: 8.8</td>
<td>400</td>
</tr>
<tr>
<td>L9</td>
<td>Mg-Al-Tl</td>
<td>58.0</td>
<td>15.2</td>
<td>Sn: 26.8</td>
<td>380</td>
</tr>
<tr>
<td>L10</td>
<td>Mg-Al-Y</td>
<td>44.7</td>
<td>20.7</td>
<td>Ga: 34.6</td>
<td>370</td>
</tr>
</tbody>
</table>

**Fig. 1 — Increasing consumption of primary magnesium (Ref. 1).**

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K. BOBZIN, E. LUGSCHEIDER, F. ERNST, D. JÄGER, A. SCHLEGEL, and J. RÖSING (roesing@iot.rwth-aachen.de) are with the Surface Engineering Institute, RWTH Aachen University, Aachen, Germany.

Based on a paper presented at the third International Brazing & Soldering Conference (IBSC) 2006 in San Antonio, Tex.
tions Ce, La, Nd, Pr, Y, Ge, Sr, Be, Pb, and Sb were not considered in further investigations. The elements Ni, Co, and Bi were not examined due to their bad corrosion behavior. Table 1 summarizes the ternary eutectics, which were tested further.

To wet the surface of the base material, it is necessary to crack the very stable oxide skin on Mg alloys. Since no commercial flux is known, which possesses a suitable acting temperature for AZ31B, investigations on the wetting behavior had to be carried out.

Two commercial and two experimental fluxes as follows showed promising wetting performance:

- FLUX 900, J. W. Harris Co. (Mason, Ohio), corrosive acting flux for brazing and welding of Mg alloys, working temperature 510°–705°C
- AluBraze F 30/70, BrazeTec GmbH (Hanau, Germany), corrosive acting flux for brazing of Al and Al alloys, working temperature 520°–660°C
- EXP 1, investigated by Watanabe (Ref. 5), 61.7 wt-% CaCl₂, 14.6 wt-% LiCl, and 23.72 wt-% NaCl with T_{liq} ≈ 475°C
- EXP 2, own consideration, 54.2 wt-% KCl, 34.8 wt-% LiCl, and 11.1 wt-% CaCl₂, T_{liq} ≈ 425°C.

### Table 2 — Properties of Fluxes on AZ31B

<table>
<thead>
<tr>
<th>Flux</th>
<th>Wetting</th>
<th>Redution of oxide skin</th>
<th>T_{liq} (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 FLUX</td>
<td>Good</td>
<td>Passed</td>
<td>430</td>
</tr>
<tr>
<td>AluBraze</td>
<td>Good</td>
<td>Good</td>
<td>410</td>
</tr>
<tr>
<td>F30/70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXP 1</td>
<td>Outstanding</td>
<td>Satisfactory</td>
<td>455</td>
</tr>
<tr>
<td>EXP 2</td>
<td>Outstanding</td>
<td>Satisfactory</td>
<td>380</td>
</tr>
</tbody>
</table>

Wetting and Joint Filling Properties

All tests were carried out on a heating plate under an inert atmosphere (Ar). Both the heating plate temperature and the surface temperature of the sample were recorded. With this experimental setup, the basic properties of the various fluxes on AZ31 were detected — liquidus temperature, wetting behavior, and reduction of the oxide skin. The wetting behavior and the reduction of the oxide skin were classified qualitatively as “outstanding,” “good,” “satisfactory,” and “passed.”

The two experimental materials (EXP 1 and EXP 2) had very good flowing behavior, but they could not reduce the oxide skin completely. Flux 900 could also not manage to reduce the oxide skin. The best
choice seems to be AluBraze F 30/70. The wetting behavior is good and, especially, the oxide skin was completely reduced to enable a good wetting of the filler metals.

Table 2 summarizes the results of the flux examinations.

After these examinations, the wetting behavior and the joint clearance filling properties (joint clearance size = 200–250 μm) were qualitatively detected. The fluxes 900 FLUX, EXP 1, and EXP 2 showed only unsatisfactory wetting behavior. It took a long time to achieve the needed flowing of the filler metal, and the contact zone between filler and base material turned out to be very porous.

With AluBraze F30/70, a wetting angle of < 30 deg could be demonstrated. The contact zone between AZ31B and filler metals L6, L7, and L9 showed no pores. The joint clearance filling behavior was best with L9, but cracks in the joining zone could be seen in this case. Filler metals L1, L4, L5, L7, L8, and L10 showed partial poor joint clearance filling behavior.

Table 3 merges all the results of the accomplished examinations.

Looking at the overall results, L3 (Mg-Al-Zn), L6 (Mg-Al-Cu), and L9 (Mg-Al-Ga) seem to be adequate candidates for further investigation.

Figure 2 shows the joining zones of filler metals L3, L6, and L9. L3 exhibits fusion penetration, and L6 shows strong erosion at the contact zone. This could be proven in all investigations.

**Mechanical Properties**

Shear stress tests were carried out to enable a comparison between the filler metals. Straps of AZ31 were soldered, and tensile tests showed a mean maximum shear stress of 28 to 40 MPa. L6 and L9 showed comparable values, while L3 exhibited lower ones. Figure 3 visualizes the measured results.

**Conclusions**

It was shown that ternary alloys containing magnesium and aluminum are suitable for joining magnesium sheets, especially the commonly used AZ31B. After theoretical investigations, various ternary alloys were tested as filler metals with various fluxes. The promising combinations were used to produce lap joints and to measure basic mechanical properties.

The most important demand on a suitable filler metal is to fulfill corrosion requirements. First tests in water and in NaCl-solution show that the base material is attacked much more than the joining zone. These first indications have to be analyzed in more detail before bringing this category of filler metals onto the market. To achieve this, future investigations have to focus on quaternal alloy systems.

**Acknowledgment**

The investigations were carried out as part of the joint industrial research promoted by the German Ministry of Economics and Labor as part of the Innonet-Program (IN3569). Our thanks are due for this support.

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1. International Magnesium Association, also see www.intmag.org.


Advantages of Flux Cored Alloys for Open Air Brazing

Flux cored wire creates a high-strength joint while limiting the amount of flux used and creating less waste

BY CREED F. DARLING

Brazing is an important process used in many industries today including heating, ventilation, air conditioning, refrigeration, automotive, aerospace, construction, and electronics. Brazing’s versatility allows numerous different assemblies and base metals to be joined together. Several brazing methods can be employed ranging from torch brazing in open air to vacuum furnace brazing. Torch and induction brazing are two of the most common brazing methods used in industry. These processes are typically performed in open air with the use of a Ag-Cu-Zn-based alloy and a flux. Traditionally, separate fluxing of the assemblies to be brazed has been a prebraze step that increases process time, postbrazee cleanup time, and safety concerns, and often reduces the quality and consistency of the resulting braze joint. In recent years, Ag-Cu-Zn- and Al-based flux cored products have been introduced to the brazing industry for torch and induction brazing applications. Flux cored alloys reduce brazing process times and safety/environmental concerns while improving braze joint quality and strength.

The application of external flux when brazing with solid wire is typically performed manually by an operator prior to brazing. The solid braze alloy is then often applied by hand during heating or pre-placed in the joint prior to heating. Flux cored alloys reduce the two steps of applying the flux and alloy prior to brazing into one. For flux cored products, the flux is proportionally added to the inside of a braze alloy wire so that no external flux application is required. Flux cored alloys can also be applied during heating or pre-placed in the joint region prior to brazing.

Figure 1 shows an example of the stages a flux cored ring goes through during heating. After the ring is placed on the assembly (1), heat is applied during brazing and the flux inside the wire becomes molten and flows out of the wire into the joint interface (2). The flux that flows into the joint interface removes and prevents oxide formation during heating allowing the molten braze alloy to wet the base material and capillary into the joint (3). Capillary attraction pulls the alloy through the joint, forcing the flux out of the joint interface and completes the braze (4). Flux cored products consisting of various braze alloy compositions and flux chemistry combinations can be produced by alloy manufacturers. Manufacturers can also vary the flux to alloy ratio within the product, providing more versatility to the end user.

The study described in the following sections was performed to provide data and support for the many claims that are made in regard to the advantages of flux cored brazing products.

Outline of Study and Methods

The study analyzed the characteristics of 304L stainless steel joints brazed with solid wire and a paste flux vs. joints brazed with a flux cored alloy. All assemblies were brazed using an oxyacetylene torch. The primary characteristics analyzed were consistency of product application, waste produced during brazing, and joint strength. The braze alloy used for the solid and flux cored wires was Braze 505™ (AWS A5.8 BAg-24). The paste flux used in conjunction with the solid wire was Handy Flux® Type B-1 (AWS 5.3 FB3C), while the flux used in the cored wire was a proprietary boron modified flux in powder form. The flux cored alloy used was Lucas-Milhaupt’s Handy One® 505.

Test 1: Consistency of Flux Application and Waste Produced during Brazing

The use of flux cored alloys not only reduces process steps and time but also provides a more consistent method of flux application to the base materials being joined. Providing a consistent amount of flux to an assembly prior to brazing will re-

CREED F. DARLING (cdarling@lucasmilhaupt.com) is brazing applications engineer, Lucas-Milhaupt, Inc., a Handy & Harman company, Cudahy, Wis.
duce process waste and improve braze joint quality. The first test in this study looked at how much flux was applied prior to brazing using solid wire and flux cored wire along with the amount of waste produced for each form. This test was performed by torch brazing a series of 304L stainless steel coupons with a flux cored wire and also with a solid wire and paste flux. The coupons brazed were 1 in. in width with a joint overlap of 0.5 in. and were mechanically cleaned prior to brazing.

The first set of specimens was brazed with solid wire and was manually fluxed with an acid brush. The amount of paste flux applied was kept as uniform as possible by the operator. A precut slug of Braze™ 505 solid wire (0.055 in. diameter) was placed on one side of the lap joint. For the second set of specimens brazed, only a precut slug of Handy One® Braze 505 (0.053 × 0.092 in.) oval wire was placed on one side of the joint. No external flux was applied. Measurements of the amount of alloy and flux applied for each specimen were recorded. The amount of alloy applied for both sets of specimens was consistent because precut slugs of alloy were applied to the assembly. The amount of flux applied, however, between both sets of samples varied greatly. The average weight of flux applied to each specimen brazed with external flux was 0.150 g while the average weight of flux applied with the flux cored product was 0.073 g. These values and the percent difference between each set of specimens are shown in Table 1. It should also be noted that the consistency of the amount of flux applied varied between both forms. The maximum amount of flux applied for the external flux was 0.196 g while the minimum was 0.100 g. This difference in the amount of flux used can significantly affect the brazing/heating process and the overall quality of the resulting braze joint. The maximum and minimum amounts of flux applied with the flux cored slugs were 0.074 and 0.071 g, respectively. This translates into a much more consistent brazing process and braze joint when using flux cored products.

After all the specimens were brazed with the solid and flux cored wires, each assembly was weighed in order to determine the weight lost during brazing. The majority of weight lost can be attributed to the loss of flux. Flux loss can occur due to spitting and vaporization during heating. It can be seen in Table 1 that there was 84.3% less weight loss during heating when using the flux cored alloy. This limits the amount of fume exposure to the environment and operator. Each set of specimens was then cleaned in a 600-mL bath of hot water for an initial time period of 10 min. The hot water bath was held at a temperature of approximately 150°F (66°C). After the initial water soak, weights were again measured to determine the amount of weight lost during cleaning. The same
procedure was repeated for a second hot water soak for 10 min. The resulting weight losses are recorded in Table 1. These weight losses, again, were primarily considered to be flux residue.

The results of these tests revealed a significant decrease in the amount of flux used and flux residue produced when brazing with flux cored wire vs. a solid wire and an external flux. The amount of residue produced per braze joint directly impacts the amount of cleaning required after brazing has to be removed. As shown by the values in Table 1, flux cored alloys reduced the total amount of losses during the brazing process by 48%. It should also be noted that 51% less flux was used with the flux cored alloys. On a production basis this can equate to a very significant decrease in waste removal and consumable cost to the end user. Table 2 shows an approximation of how much less flux would be used by a manufacturer during brazing when using flux cored rings vs. solid rings and paste flux. The data used to determine the values in Table 2 were taken from Table 1 and were calculated assuming a ring diameter of 0.32 in.

**Test 2: Braze Joint Strength for Solid and Flux Cored Alloys**

The second set of tests analyzed the resulting joint strengths of assemblies brazed with BAg-24 flux cored wire slugs and solid wire slugs with a paste flux. The method of evaluating the braze joint strength and the test samples and procedures used were based on the AWS C3.2 Standard (Ref. 1) for evaluating braze joint strength. The assemblies brazed consisted of 0.125 in. thick × 1.250 in. wide × 5 in. long 304L stainless steel specimens. Similar to the procedure used in Test 1, alloy slugs were applied to one side of the lap joint. Handy Flux® Type B-1 was applied as uniformly as possible across the stainless steel plates when using the solid BAg-24 alloy. The assemblies were heated by an oxyacetylene torch until the braze alloy melted and capillaried into the joint interface. Heating time, amount of alloy applied, joint dimensions, and base metal conditions were measured and recorded before and after brazing to ensure that the brazing process used was consistent. After brazing, the specimens were cleaned, sand blasted, and machined to the dimensional requirements stated in AWS C3.2. An example of the specimens used for testing is shown in Fig. 2.

After the assemblies were brazed and prepared for testing, ten pull specimens for each form of alloy used were tested...
tension by an Instron 3369 machine. Figure 3 shows the machine and setup that was used to test the braze joint specimens. The brazed assemblies were pulled until failure. Failure occurred in the braze joint for all specimens. A joint overlap of two times the thickness of the base metal (2T) was used so that the braze joint failed rather than the base metal. Joint failure allowed comparison of the joint strengths for assemblies brazed with flux cored material and those brazed with solid wire and paste flux.

Break load values for each set of specimens are recorded in Tables 3 and 4. Using these values, the resulting shear stress in the filler metal was computed by dividing the break load obtained by the area of each joint. Data were compiled for lap joints of approximately 2T and joint clearances of 0.002 and 0.004 in. Shear stress values that were obtained for both sets of specimens were similar. The joints brazed with flux cored material exhibited slightly higher average shear strength values for both joint clearances as illustrated in Fig. 4. The impact flux cored products provide in joint quality and strength is realized to an even greater extent in a manufacturing setting vs. a lab environment due to the variance between operators who manually apply flux. Excessive and varying amounts of flux applied to the braze joint area in the manufacturing setting cause inconsistencies in the brazing process and joint quality. When the amount of flux is varied from one joint to another, heating cycles will vary due to the insulating effect of the flux. Excess flux in the joint interface can lead to flux entrapment and excessive voids. Flux cored alloys provide a more consistent application of flux that stabilizes the joining process and reduces the amount of flux voids/inclusions within the joint interface that will increase joint strength. Consumers who have switched from using solid wire and manual flux application to flux cored alloys have reported significant decrease of joint voids that directly impact joint integrity (leak tightness) and strength.

Summary and Conclusion

Traditionally, solid wire and an external flux have been predominately used for torch and induction brazing in many industries. External flux is typically applied manually by an operator prior to brazing. This step increases process time and introduces inconsistency in the amount of flux applied. Oftentimes the operator applies more flux than is required, which also increases the overall cost of the brazing process. Varying amounts of flux applied can cause inconsistent braze quality and fluctuating heating cycles. With its introduction, flux cored products have helped manufacturers who utilize torch and induction heating to improve their joining process consistency and braze quality, while limiting the amount of brazing consumable used. The studies documented in this paper illustrate and confirm the many benefits that flux cored products offer. The flux cored wire used provided a more consistent amount of flux to the assemblies brazed, creating a high strength joint while limiting the amount of flux used and the waste produced during heating.

Acknowledgments

The author would like to thank and acknowledge Jeff R. Rude, Alexandria Britis, and Joseph Platek of Lucas-Milhaupt, Inc., for the help and contributions they provided during the testing and analysis.

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High-Temperature Lead-Free Solder and Soldering Paste for the Manufacture of Semiconductor Devices

High-temperature solders of the Sn-Sb-Ag-Cu system have been announced by Hitachi Corp., Japan (Ref. 1). The invention intends to provide joining of a semiconductor element with a metal electrode in a power semiconductor device (such as IGBT or MOSFET) using high-temperature lead-free solder alloys having heat resistance at >280°C (536°F), and soldering temperature up to 400°C (752°F). The solders exhibit excellent wetting of copper and nickel, high-temperature storage reliability, and temperature cycling resistance.

The Sn-35Sb-11Ag-8Cu solder provides good wetting on both nickel-plated film and copper at the soldering temperature range 360°–400°C (680°–752°F). The mass ratio of Sb to Sn is critical in such solders; for example, the ratio Sb/(Sn+Sb) = 43 showed good wettability, while the area of spreading becomes smaller as the content of Sb increases. Worse flow of the solder is caused by a jump of solidus temperature from 230°C (446°F) to 350°–370°C (662°–698°F) at the ratio Sb/(Sn+Sb) from 43 to 50. The solder hardness is up to 130 HV, and thermal stresses, which are generated in the semiconductor device bonded to an electrode of different thermal expansion, can be reduced.

Silver-Depositing Solutions for Improving Solderability of a Metal Surface

It is difficult to keep conductive surfaces of printed circuit boards (or wiring boards) clean and free of tarnishing (oxidation) during the soldering process. Several chemical solutions were developed by R. F. Bernards for improving solderability of copper or nickel-plated surfaces by electroless deposition of silver (Ref. 2). One of them contains the following: a) 1.1 wt-% of a 70% aqueous solution of methanic sulfonic acid, b) 1.5 g/L of silver (added as silver nitrate), and c) 1 g/L of sodium tolyltriazole. The pH of the solution was less than 2. Silver was deposited onto a copper surface to a thickness of 8.3 microns for 1 min at 50°C (122°F).

An alternative silver-depositing solution contains a) 1.3 wt-% of 60% nitric acid, b) 1.5 g/L of silver (added as silver nitrate), and c) 0.6 g/L of 5-aminotetrazole. Two moles of HEDTA chelator (as a complexing agent) per one mole of silver can be added to improve the appearance of the silver coating. Also, 0.3 g/L of 1,2,3-benzotriazin-4(3H)-one can be added to improve uniformity of silver film on copper substrate.
The resulting silver-plated surfaces exhibited very good tarnish inhibition and improved solderability.

**Application of Nocolok® Flux Modified with Potassium Fluorozincate for Brazing Aluminum Heat Exchangers**

The widely used Nocolok® flux (based on the KAlF<sub>4</sub>-K<sub>3</sub>AlF<sub>6</sub> system) was modified with KZnF<sub>3</sub> and the new flux was studied in VALEO Engine Cooling, France (Ref. 3). It was expected that the zinc-modified flux may improve corrosion resistance of aluminum joints brazed with Al-Si filler metal. The modified flux is melted and decomposed to form zinc particles during brazing in a controlled atmosphere furnace. Zinc reacts with the aluminum surface during the brazing cycle and creates an external layer with better corrosion resistance due to change of local corrosion potential. The reaction of fluxing can be described as follows:

\[
6\text{KZnF}_3 + 4\text{Al} \rightarrow 3\text{KAlF}_4 + \text{K}_3\text{AlF}_6 + 6\text{Zn}
\]

The outside corrosion resistance was evaluated using the standard SWAAT (Seawater Acetic Acid Test), an accelerated salt spray test, where the brazed joints are exposed to acidified saltwater according to ASTM G85.

The study of aluminum evaporators fluxed with 2–3.4 g/m<sup>2</sup> of potassium fluorozincate showed that the external corrosion resistance decreased for 29% in comparison with the standard Nocolok® flux. Supposedly, the zinc enrichment occurs in brazing fillets and creates a cathodic effect in this area of the brazed joints. On the other hand, the zinc fluxing provides the same brazeability as the standard Nocolok® flux concerning mechanical behavior of joints, filler metal flow, and diffusion profile.

**Wear-Resistant Coatings Deposited on Titanium by Brazing**

Despite the high strength-to-weight ratio up to 600°C (1110°F) and great corrosion resistance, titanium alloys exhibit low wear resistance that limits their application in modern industry. An innovative brazing technology was tested in the Institute of Surface Technique, RWTH (Aachen, Germany) for depositing wear-resistant carbides on the surface of a widely used Ti-3Al-2.5V alloy and a turbine alloy Ti-6Al-2Sn-4Zr-2Mo (Refs. 4, 5). Thin wear-resistant coatings were deposited by a “suspension process” using carbide powder individually or in the mixture of WC-12Co 79.7 wt-%, B4C 5.2 wt-%, NbC 4 wt-%, TaC 5.4 wt-%, and TiC 5.6 wt-% as the hard phase. Particle sizes of carbide powders were in the range of 15–45 μm. Two brazing filler metals, a) TiBraze®375 (Ti-37.5Zr-15Cu-10Ni) and b) Brazette D7200.4 (Ag-Cu eutectic), were mixed with carbide powders and an organic binder to prepare the pastes. The content of carbide particles in the pastes was 15–30 vol-%.

The pastes were applied onto titanium surfaces and heated in a vacuum furnace up to the brazing temperature 940°C (1724°F) for TiBraze®375 and 830°C (1526°F) for Brazette D7200.4. Dense composite coatings on titanium were obtained at the coating thickness ~0.1 mm with TiBraze®375 as the matrix and at ~0.2 mm with Ag-Cu matrix. The coatings were characterized by hardness and standard ball-on-disc tribology tests with 6-mm alumina balls as counterbodies.

Coatings based on Ag-Cu matrix with B<sub>4</sub>C particles and based on Ti-Zr-Cu-Ni matrix with TiC particles exhibited the best wear resistance, which is twice as large as that of the base metals. The optimal content of carbide particles in coatings is in the range of 20–30 vol-%. Significant porosity appeared at the carbide content over 30 vol-%.

**Manufacture of Sn-Ag-Cu-Ge Solder with Improved Strength of Soldered Joints**

The solder contains 1.5–3.5 wt-% of Ag, 0.4–1 wt-% of Cu, 0.1–0.2 wt-% of Ge, and Sn in the balance, preferably Sn-2.5Ag-0.7Cu-0.15Ge. Germanium is added to improve strength of soldered joints in electronic applications. A traditional method of making solders includes mixing solid components, adding a flux, melting, and casting. However, if the solder is made by a traditional method, germanium coagulates in coarse phases and does not work properly. A new method of preparing the Ge-containing solder was developed in Toliatti State University (Russia). This method allows manufacturing the Sn-2.5Ag-0.7Cu-0.15Ge solder containing fine, uniformly distributed Ge-phase that results in significant strength improvement (Ref. 6).

Firstly, tin is mixed with silver and copper, the mixture is placed in a graphite crucible, and an alcohol solution of rosin is added. The crucible is placed in a furnace and heated to melt the alloy. Then the temperature is maintained to 600°C (1110°F), and germanium is added into the melt with a portion of Nocolok® flux based on potassium fluorozincate. The resulting melt is mixed for 8 min at this temperature, and then it is poured on aluminum sheet or in the cast mold for cooling and solidification.

The resulting solder exhibits tensile strength 72.86 MPa (10.6 ksi) and elongation of 38.54%, while the solder made ac-

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Vibration Fracture Behavior of Sn-9Zn-xCu Lead-Free Solders

The effect of copper content on the microstructure and mechanism of vibration deformation of lead-free solder Sn-9Zn-xCu (x = 0.2, 0.5, 0.7, and 1 wt-%) was examined in National Cheng Kung University, Tainan, Taiwan (Ref. 7). A simple cantilever beam vibration system was used for testing solders at frequency of 76–83 Hz and dumping measurements of rectangular 100 × 20 × 4 mm solder specimens. Two circular notches were made near the clamp for observing microstructural evolution in the vicinity of the crack front.

An increase of Cu content in the solder changes the phase composition in microstructure. The amounts of Sn-rich phase and Sn-Zn eutectic decreased, while Cu-Zn intermetallics and proeutectic phase and Sn-Zn eutectic decreased, changes the phase composition in microstructure.

Two circular notches were made near the clamp for observing microstructural evolution in the vicinity of the crack front.

An increase of Cu content in the solder changes the phase composition in microstructure. The amounts of Sn-rich phase and Sn-Zn eutectic decreased, while Cu-Zn intermetallics and proeutectic Sn-rich phase increased with increasing the Cu content from 0.2 to 1 wt-%. The hard Cu$_2$Zn$_8$ phase exists mostly among dendrites of said Sn-rich phase in solders with 0.7 and 1 wt-% of copper. The Zn-rich phase is distributed unevenly such that deteriorates the tensile strength and ductility of the solder.

The high copper solders have a higher vibration damping capacity able to absorb more vibration energy, and thus possess a greater vibration fracture resistance. Also, the lamellar structures and Cu$_2$Zn$_8$ phase are able to increase the crack tortuosity, which in turn increases the resistance to crack propagation.

SiC-Particle-Reinforced Active Brazing Metal for Joining Silicon Nitride Ceramic Composite to Steel

A mismatch in the coefficient of thermal expansion (CTE) between base materials and braze alloy is one of the biggest problems in the manufacture of ceramic-to-metal joints. The use of ceramic particles for lowering CTE of the brazing filler metal was studied in the Laboratory for High Performance Ceramic, EMPA, Switzerland (Ref. 9). Silicon carbide particles with CTE = 5.2 × 10⁻⁶ K⁻¹ have been used as reinforcements in the active brazing filler metal Incusil® ABA (Wesgo Metals) having CTE = 18.2 × 10⁻⁶ K⁻¹.

The ceramic base material was a hot-pressed Si$_3$N$_4$ ceramic composite (CTE = 3.8 × 10⁻⁶ K⁻¹) reinforced with 30 wt-% of TiN particles. The base metal was a 14NiCr14 steel, DIN 1.5752 (CTE = 3.8 × 10⁻⁶ K⁻¹). The effect of particle reinforcement of the brazing filler metal on flexural strength of ceramic-to-steel joints has been investigated at room temperature and at 200–400°C.

Three types of brazed joints were tested: a) joints brazed with pure Incusil® ABA, b) joints brazed with Incusil ABA reinforced with 10 vol-% SiC, and c) joints brazed with Incusil® ABA + 30 vol-% SiC in a sandwiched Incusil® foils.

The flexural strength of joints brazed with pure Incusil® was 329 MPa (47.7 ksi) at room temperature. The reinforcement of Incusil® with 10 vol-% SiC resulted in lower flexural strength of joints 284 MPa due to detrimental effect on plastic strain in the joint. However, the joint strength at 250°C was 523 MPa (75.8 ksi), which is significantly higher than that at RT. The use of Incusil® ABA + 30 vol-% SiC in the sandwiched foil system resulted in a higher flexural strength of 390 MPa at RT and low residual thermal stresses due to an increase in allowable plastic strain and in a change of fracture behavior.

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Information provided by LEO A. SHAPIRO and ALEXANDER E. SHAPIRO (ashapiro@titanium-brazing.com), Titanium Brazing, Inc., Columbus, Ohio.
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For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form in this issue of the Welding Journal. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2008. The Committee looks forward to receiving numerous Fellow nominations for 2009 consideration.

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee
Q: We fabricated a heavy-wall pressure vessel of 304L stainless for a seawater application. Out of concern for stress corrosion cracking in the seawater, we performed a stress relief heat treatment at 800°C (1475°F) for 12 hours. After the heat treatment, we found many cracks in the 308L welds made with all-position flux cored electrodes around nozzles, but none in the 308L submerged arc (SA) welds that assembled the main body of the vessel. We gouged out the cracked welds, welded with FCAW again, inspected the welds thoroughly without finding any cracks, then stress relieved again. After this second stress relief, we again found extensive cracking in the FCAW deposits only. We are aware that carbide precipitation and sigma phase precipitation can occur at the stress relief temperature. Since the welds and base metal are low carbon and since both the SA and FCA welds contained only about 8 to 10 FN before stress relief, we don’t think that carbide precipitation or sigma phase precipitation are the causes of the cracking. Something seems to be different about the flux cored arc welds. What else could be the cause?

A: While it is true that a 12 hour “stress relief” at 800°C (1475°F) will produce both carbide precipitation and sigma phase precipitation in 308L weld metal, the damage to properties in low-carbon weld metal at about 10 FN is unlikely to be serious enough to cause cracking. I believe you are correct to suspect that something is different about the FCAW deposits.

To put things in perspective, it is useful to review briefly the history of development of flux cored stainless electrodes. The first stainless steel electrodes for FCAW were developed in the late 1950s. These were relatively large-diameter electrodes (% in. [2.4 mm] and larger), used mainly calcium fluoride (fluorspar) base or titanium dioxide (rutile) base slag systems, and were limited to welding in the flat and horizontal positions. Although some were designed for gas shielded welding, the vast majority were designed to be run without shielding gas. These self-shielded flux cored stainless electrodes dominated the flux cored stainless electrode market throughout the 1960s and 1970s. The self-shielded flux cored stainless electrodes to this day are limited to the flat and horizontal positions, largely because the metal transfer is by a large droplet that is strongly affected by gravity. In the late 1970s, smaller-diameter gas shielded flux cored stainless electrodes began to appear in the market. Sizes of % in. (1.6 mm) were followed by even smaller diameters. In contrast to the large droplet metal transfer with the self-shielded electrodes, these electrodes produced a near spray transfer, especially in argon-CO₂ gas mixtures. Faster-freezing slag systems were developed that permit welding in the vertical and overhead positions. And the Japanese introduced a slag system high in SiO₂ that produces very attractive welding characteristics, slag detachment and weld surface appearance with such electrodes. However, the Japanese development, as described in the 1982 U.S. Patent No. 4,345,140, Composite Wire for Stainless Steel Welding, granted to Godai et al., introduced the inclusion of a small amount of certain low-melting oxides to obtain the attractive slag removal. This patent mentions lead oxide, bismuth oxide, and antimony oxide as possibilities for obtaining this effect. Variants on this patent were introduced by other electrode manufacturers, and the industry seems to have standardized on the addition of small amounts of bismuth-bearing compounds as the slag-removal additive. By about 1990, perhaps even earlier, the usage of small-diameter gas shielded flux cored stainless electrodes in the United States had exceeded that of the larger-diameter self-shielded flux cored stainless steel electrodes. Today, the small-diameter gas shielded flux cored stainless electrodes are by far the dominant stainless steel flux cored electrodes.

The vast majority of stainless steel weld deposit are put into service in the as-welded condition and see service at temperatures below about 250°C (480°F). However, there are certain notable exceptions, including casting repairs that are normally annealed, and weldments in the power-generation and process industries that see extended service at temperatures of 480°C (900°F) or higher. It is in these latter weldments that bismuth (and other similar elements) create problems. Although it may have been reported earlier in Japanese literature, perhaps the first publication of elevated-temperature problems with these FCAW weldments in the western literature was by Nishiyama et al., Flux-Cored Wires for Stainless Steel Welding, in Welding in the World, Vol. 36, pp. 103–123, June 1995. This article describes premature creep failures in such weldments at temperatures as low as 650°C (1200°F).

The report by Nishiyama triggered a number of other investigations of the behavior of stainless steel FCAW deposits containing bismuth. On behalf of Commission IX of the International Institute of Welding, Farrar et al. (Position Statement on the Effect of Bismuth on the Elevated Temperature Properties of Flux Cored Stainless Steel Weldments, Welding in the World, Vol. 45, NS/6, pp. 25–31, 2001), summarized the reports available as well as the results of a round-robin of bismuth measurement in stainless steel FCAW deposits. They cited reports of reheat cracking at temperatures as low as 550°C (1020°F) in weldments containing approximately 200 ppm bismuth, the bismuth level that seems to be standard in such FCAW stainless steel electrodes. They further noted that experience and experimental data are lacking for stainless steel FCAW electrodes at temperatures below 1020°F. They also noted that there are certain stainless steel FCAW electrodes formulated without bismuth (less than 20 ppm) whose deposits do not exhibit reheat cracking or premature creep failure. Unfortunately, this information has not been well publicized, although the American Petroleum Institute has incorporated this 20 ppm limit for bismuth in stainless steel FCAW deposits in its Recommended Practice 582, Welding Guidelines for the Chemical, Oil and Gas Industries.

Your experiences seem quite clearly to be cases of reheat cracking. I understand that subsequent investigation has determined that the FCAW electrodes used did indeed contain bismuth additions.

For stainless steel weldments being designed for high-temperature service or intended to be given a PWHT, FCAW electrodes producing less than 20 ppm of bismuth in the deposit should be selected. Since electrode manufacturers do not generally publicize the bismuth level in their electrodes, I suggest that you contact a technical representative of any prospective FCAW stainless steel electrode manufacturer who might be chosen to supply electrodes for high-temperature service, or for PWHT. You should seek a supply of electrodes guaranteed to be FCAW electrodes containing less than 20 ppm of bismuth (and similarly free of any other element that can cause reheat cracking or premature creep failure).

There is no reason to impose this restriction on stainless steel FCAW electrodes that are not to be used for high-temperature service or PWHT.
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Daniel G. Sechler, Carolina Energy Solutions

Welding Automation – Solutions to Common Design & Application Challenges
Geoff Lipnevicius, The Lincoln Electric Company, Automation Division

Real-Time Quality Monitoring Using Data Fusion Techniques
Ta-Chieh Huang, Edison Welding Institute, Design, Controls & Automation Group

Innovations in Robotic Welding
Doug Rhoda, Wolf Robotics

Laser Hybrid Welding – What, Why, Where and How
Craig Bratt, Fraunhofer Center for Coatings and Laser Applications

Magnetic Pulse Welding – Automating the Next Generation of Welding
Michael Blakely, Hirotec America Inc., C3 Magnetic Pulse Division

Design for Manufacturing with Robotic Welding
Terry O’Connell, Genesis Systems

Understanding the Nature of Hazardous Welding Fumes in the Workplace and Steps that Can Be Taken to Reduce Exposures
Susan Fiore, Edison Welding Institute

Innovations in Submerged Arc Welding
John DeLoach, Naval Surface Warfare Center

Basic Control of Hot-Wire Gas Tungsten Arc Welding for Procedure Development and Production Applications
Jonathan T. Salkin, Arc Applications, Inc.

Friction Stir Welding of Aluminum, Titanium, and Magnesium
Dr. Jorge F. dos Santos, GKSS Forschungszentrum GmbH, Institute for Materials Research, Geesthacht, Germany

Friction Stir Welding of Steels
Russell J. Steel, MegaStir Technologies

The Impact of Fiber Lasers on the Material Processing Market
Bill Shiner, IPG Photonics Corp.

Thermal Stir Welding
Jeff Ding, NASA Marshall Space Flight Center

The Disk Laser Welding Process
Speaker TBA, TRUMPF, Inc.

CONFERENCE CODE: COAWC
AWS Members: $550 • Nonmembers: $680
Registration deadline: April 12, 2008

To register or to receive a descriptive brochure, call (800) 443-9353 ext. 455, (outside North America, call 305-443-9353), or visit www.aws.org/conferences

Each nonmember attendee will receive a two-year complimentary membership in AWS. Your conference registration fee includes all conference sessions, two continental breakfasts, two lunches, and refreshment breaks.

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Take advantage of the specially negotiated rate of $149 for single or double occupancy ($169 for triple and $189 for quad). This special rate is also extended to you three days before the conference and three days after the conference (depending on hotel availability). Be sure to mention the American Welding Society to receive this rate. The deadline for reservations at this special price is April 11, 2008. Each reservation must be guaranteed with a first night’s deposit or a major credit card. Any room reservation cancelled via the website can be done 24 hours in advance. Any other reservations must be cancelled five days in advance of the arrival date and must be done directly with the hotel. There is no charge for valet or the self-parking garage.
COMING EVENTS

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


WESTEC 2008 Advanced Productivity Expo and Conf. March 31–April 3, Los Angeles Convention Center, Los Angeles, Calif. Contact Society of Manufacturing Engineers. Call (800) 733-3976 or visit www.sme.org/westec.


Ohio Safety Congress & Expo. April 1–3, Columbus Convention Center, Columbus, Ohio. Sponsored by Ohio Bureau of Workers Compensation, Div. of Safety and Hygiene. Call (800) 644-6292; or visit www.ohiobwc.com.

Metf-Foundeq Conf. and Show. April 9–12, Garda Exhibition Centre, Montichiari, Brescia, Italy. Featuring international aluminium exhibition, high-tech die casting, foundry, extrusion, and finishing. Visit www.metef.com/ENG/home.asp.


INTERTECH 2008. May 5–7, Contemporary Resort, Walt Disney World, Orlando, Fla. Topics to include practical applications for superabrasives for machining, grinding, drilling, polishing, wear parts, wire dies, etc. Visit www.intertechconference.org.


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


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

IIW Int’l Regional Congress, 2nd Latin America Welding Congress. May 18–21, Club Transatlantico, São Paulo, Brazil. Visit abs-soldagemlorg.br.


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


Educational Opportunities

ASME Section IX Seminars. April 8–10, Las Vegas, Nev. Contact: ASME Continuing Education Institute. Call (800) 843-2763, or visit www.asme.org/education.

ASME Practical Welding Technology Seminar. May 5–7, Orlando, Fla. Designed to meet the needs of engineers and QC personnel who want to better understand welding technology, welding symbols, processes, metallurgy, weld defects, inspection, procedures, and welder qualifications. Contact: ASME Continuing Education Institute. Call (800) 843-2763, or visit www.asme.org/education.


Boiler and Pressure Vessel Inspectors Training Courses and Seminars. Columbus, Ohio. Call (614) 888-8320, or visit www.nationalboard.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. Contact: Welder Training & Testing Institute (WTTI). Call (800) 223-9884, info@wtti.edu; or visit www.wtti.edu

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For info go to www.aws.org/ad-index
### AWS Certification Schedule

**Certification Seminars, Code Clinics and Examinations**

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

#### Certified Welding Inspector (CWI)

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SEMINAR DATES</th>
<th>EXAM DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas, TX</td>
<td>Mar. 30-Apr. 4</td>
<td>Apr. 5</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Mar. 30-Apr. 4</td>
<td>Apr. 5</td>
</tr>
<tr>
<td>Springfield, MO</td>
<td>Apr. 6-11</td>
<td>Apr. 12</td>
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<tr>
<td>Baton Rouge, LA</td>
<td>Apr. 6-11</td>
<td>Apr. 12</td>
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<td>San Francisco, CA</td>
<td>Apr. 6-11</td>
<td>Apr. 12</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>EXAM ONLY</td>
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<tr>
<td>Portland, ME</td>
<td>Apr. 13-18</td>
<td>Apr. 19</td>
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<tr>
<td>St. Louis, MO</td>
<td>EXAM ONLY</td>
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<td>Nashville, TN</td>
<td>Apr. 20-25</td>
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<td>Jacksonville, FL</td>
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<td>Detroit, MI</td>
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<td>May 4-9</td>
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<td>Corpus Christi, TX</td>
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<td>May 10</td>
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<td>Oklahoma City, OK</td>
<td>May 18-23</td>
<td>May 24</td>
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<td>Birmingham, AL</td>
<td>May 18-23</td>
<td>May 24</td>
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<td>Long Beach, CA</td>
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<td>Hartford, CT</td>
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<td>Pittsburgh, PA</td>
<td>Jun. 1-6</td>
<td>Jun. 7</td>
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<td>Fargo, ND</td>
<td>Jun. 1-6</td>
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<tr>
<td>New Orleans, LA</td>
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<td>Miami, FL</td>
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<tr>
<td>Louisville, KY</td>
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<tr>
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<td>Jul. 19</td>
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<td>Beaumont, TX</td>
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<td>Jul. 20-25</td>
<td>Jul. 26</td>
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<tr>
<td>Denver, CO</td>
<td>Jul 27-Aug. 1</td>
<td>Aug. 2</td>
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<tr>
<td>Miami, FL</td>
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<tr>
<td>San Diego, CA</td>
<td>Aug. 3-8</td>
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<tr>
<td>Charlotte, NC</td>
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<td>San Antonio, TX</td>
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<td>Rochester, NY</td>
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<td>Salt Lake City, UT</td>
<td>Aug. 17-22</td>
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<tr>
<td>Houston, TX</td>
<td>Sept. 7-12</td>
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<td>Pittsburgh, PA</td>
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<td>Seattle, WA</td>
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<td>Miami, FL</td>
<td>EXAM ONLY</td>
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<td>Minneapolis, MN</td>
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<td>St. Louis, MO</td>
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<tr>
<td>Anchorage, AK</td>
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<td>Sept. 20</td>
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<tr>
<td>Miami, FL</td>
<td>Oct. 19-24</td>
<td>Oct. 25</td>
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<tr>
<td>Tulsa, OK</td>
<td>Oct. 19-24</td>
<td>Oct. 25</td>
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</table>

#### 9-Year Recertification Seminar for CWI/SCWI

<table>
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<tr>
<th>LOCATION</th>
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<td>Miami, FL</td>
<td>Dec. 1-6</td>
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</tbody>
</table>

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

#### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SEMINAR DATES</th>
<th>EXAM DATE</th>
</tr>
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<tbody>
<tr>
<td>Philadelphia, PA</td>
<td>Apr. 14-18</td>
<td>Apr. 19</td>
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<tr>
<td>Nashville, TN</td>
<td>May 19-23</td>
<td>May 24</td>
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<tr>
<td>Manchester, NH</td>
<td>Jun. 9-13</td>
<td>Jun. 14</td>
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<td>St. Louis, MO</td>
<td>Aug. 18-22</td>
<td>Aug. 23</td>
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<tr>
<td>Denver, CO</td>
<td>Sept. 15-19</td>
<td>Sept. 20</td>
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<tr>
<td>Seattle, WA</td>
<td>Nov. 17-21</td>
<td>Nov. 22</td>
</tr>
<tr>
<td>Jacksonville, FL</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
</tr>
</tbody>
</table>

CWS exams are also given at all CWI exam sites.

#### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SEMINAR DATES</th>
<th>EXAM DATE</th>
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<tbody>
<tr>
<td>Philadelphia, PA</td>
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<td>Apr. 19</td>
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<td>Nashville, TN</td>
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<td>Manchester, NH</td>
<td>Jun. 9-13</td>
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<td>St. Louis, MO</td>
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<td>Denver, CO</td>
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<td>Nov. 17-21</td>
<td>Nov. 22</td>
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<tr>
<td>Jacksonville, FL</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
</tr>
</tbody>
</table>

#### 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.

#### Code Clinics & Individual Prep Courses

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

#### On-site Training and Examination

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

#### International CWI Courses

Please contact international seminar & testing locations directly.

---

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

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[www.aws.org](http://www.aws.org)
Brazing Safety: Combustibility of Metal Powders

In the form of powders and pastes, brazing filler metals are potentially explosive. Safe handling requires estimation of risk level, proper handling technique, explosion and fire prevention methods, and fire fighting techniques.

The U.S. Bureau of Mines ranks the probability of explosion as severe, strong, moderate, weak, or none. Aluminum and magnesium powders have a severe rating. They are aggressive reducing agents whose reactions occur with a drastic release of energy (see Table 1). Therefore, aluminum or magnesium dust is five to ten times more dangerous than the coal or flour dusts that cause destructive explosions in mines and silos. An aluminum dust cloud will ignite with as little as 9% oxygen with the balance being nitrogen, and 3% oxygen with the balance being carbon dioxide.

Because stainless steel, copper, and nickel do not oxidize readily, they and their powders are low on the explosivity list. Titanium and zirconium powders have a strong risk of self-combustion and are considered highly flammable. Zinc is also on the list of pyrophoric metals, but it will burn in air only at elevated temperatures.

Ignition temperatures of titanium dust clouds in air range from 63°F to 109°F (32°C–58°C), and titanium dust that has accumulated on the floor or equipment from 720°F to 950°F (382°C–510°C).

The explosibility of powders depends on particle size. For example, aluminum powder having less than 10 vol-% of particles with the size <200 mesh has no explosion hazards, but above 40 vol-%, the explosion probability is severe.

How Explosions Can Occur

Fire or explosion typically occurs when metallic dust or micron-sized powders accumulate in an area containing the following:

1. Ignition sources such as working torches, electrical devices, gaseous furnaces, and spark-generating equipment
2. A weak ventilation system
3. Vapors of flammable liquids such as alcohol, acetone, organic binders, or cleaning liquids
4. Oxygen-containing agents such as metal peroxides, inorganic nitrates, chlorates, perchlorates, persulfates, bromates, cyanurates, and azines; pyrophoric materials, leakage from an oxygen pipeline; etc.
5. Cleanliness requirements are particularly exacting for reactive fine metal powders such as aluminum, magnesium, titanium, and zirconium since concentrations as low as 23–40 g/m³ can lead to ignition (Table 1).

How to Prevent Fire or Explosions of Brazing Powders

Preventive measures include the following:

1. Preventing the formation of dust clouds when handling explosive powders
2. Not allowing dust to accumulate from grinding, screening, or brazing operations
3. Using natural hair brushes (not plastic or metal brushes) to clean up the work area


### Table 1 — Relative Explosibility of Various Dusts

<table>
<thead>
<tr>
<th>Material</th>
<th>Lower Explosive Limit (oz/ft³, g/m³)</th>
<th>Rate of Pressure Rise (lb/in.²/s, MPa/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.045 (35.33)</td>
<td>20,000 (138)</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.030 (23.00)</td>
<td>15,000 (103)</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.051 (40.00)</td>
<td>N/A</td>
</tr>
<tr>
<td>Bronze</td>
<td>0.955 (750.00)</td>
<td>1,494 (10)</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.318 (250.00)</td>
<td>6,024 (42)</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.020 (15.70)</td>
<td>7,500 (52)</td>
</tr>
<tr>
<td>Corn flour</td>
<td>0.050 (39.25)</td>
<td>3,700 (26)</td>
</tr>
<tr>
<td>Coal</td>
<td>0.050 (39.25)</td>
<td>2,000 (14)</td>
</tr>
</tbody>
</table>


4. Refraining from using plant air to blow away powder residues and dust
5. Eliminating and controlling ignition sources
6. Prohibiting smoking
7. Electrically grounding all equipment
8. Ensuring all switches are dust tight and explosion proof
9. Prohibiting arc and torch welding or brazing in the powder handling area
10. Using tightly closed metal containers for powder storage.

What to Do in the Event of a Fire or Explosion

1. Evacuate the area and let the fire run its course.
2. For small, localized fire, initiate the alarm procedure and try to extinguish the fire using only Class D fire-fighting means such as dry salt (NaCl) powder, dry graphite, talc, dolomite and limestone powders, or specialized means like graphite-based Pyrene G-I powder, and NaCl-based Met-L-X and Pyromet powders. Clean, dry cast iron chips or borings, and copper powder are also suitable as extinguishing agents.
3. DO NOT USE WATER or carbon dioxide for such powders as aluminum, magnesium, titanium, and zirconium. Flooding with the noble gases helium or argon will extinguish burning magnesium.
4. Use proper protective clothing and respirators because some metals are toxic if they enter the bloodstream or their smoke fumes are inhaled.

A fire of brazing filler metals in paste form usually begins as a paste fire. If the fire accelerates after the extinguishing agent is applied, which should be very evident, the use of Class B extinguishing agent should be discontinued and dry Class D agents should be used because the fire then will be considered a powder fire. It is dangerous to use a water hose stream to fight a paste fire.
President Lawson Speaks at India Congress

American Welding Society President Gene Lawson was a speaker at the International Congress 2008 of the International Institute of Welding, held Jan. 8–10 in Chennai, India. The Congress attracted close to 750 delegates from all over the world, and Lawson made a welcoming speech on the part of the AWS at the Inaugural Session on the 8th. His presentation on the 9th was made in the Education, Training, and Standardization Session where he spoke of the worldwide shortage of skilled welding personnel and the steps the American Welding Society is taking to address that shortage in the United States. He noted the AWS has initiated specific programs such as the Welder Workforce Development initiative that is being funded by the AWS Foundation to alleviate the shortage through welder training nationwide.

In addition to his activities with the International Congress, Lawson was asked to make a technical presentation (Fig. 1) at the local AWS Section meeting in Chennai. His topic was flux cored welding wires and the productivity gains that are realized from their use. More than 55 members attended the presentation, which generated extensive interest in the follow-up question and answer period. Section Chairman S. Baskaran introduced President Lawson — Fig. 2. Baskaran’s company, Industrial Quality Concepts, has a business relationship with the AWS to provide certification seminars and tests in India.

Weld India 2008, an international welding technology exhibition, was held in conjunction with the International Congress at the Chennai Trade Center. More than 150 exhibitors participated in the event. The AWS was represented at the exhibition with a booth staffed by Andrew Cullison and Rhenda Mayo of AWS and Ray Cravy of WEX Ltd., the publications provider for AWS. During the three days of the exhibition, there was intense interest in AWS publications, certifications, and membership, indicating the Indian market is one of potential growth for the AWS.

Both the International Congress and Weld India were sponsored and promoted by the Indian Institute of Welding, an organization of more than 3500 members. The AWS, through a previous agreement, provides editorial content from the Welding Journal to the Institute’s own publication, the Indian Welding Journal. President Lawson met with leaders of the organization to discuss ways of further cooperation in this area.

Beaufils Retires as International Institute of Welding Chief Executive Officer

Daniel Beaufils (center), retiring International Institute of Welding CEO, accepts an engraved clock from Ray Shook (right), AWS executive director, and Tom Mustaleski, IIW American Council chairman. Presented during the January IIW meetings held at the Institut de Soudure (French Welding Institute) near Paris, the clock commemorates Beaufils’s seven years as IIW CEO and 42 years of service at the Institut de Soudure. Succeeding him as IIW CEO is André Charbonnier.
Listed are the members participating in the 2007–2008 AWS Member-Get-A-Member Campaign for the period between June 1, 2007, and May 31, 2008. For campaign rules and a prize list, see page 69 of this Welding Journal. Standings are as of 1/17/08. If you have any questions regarding your member proposer points, call the Membership Department, (800) 443-9353, ext. 480.

**Winner’s Circle**

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

J. Compton, San Fernando Valley
E. Ezell, Mobile
J. Merzthal, Peru
G. Taylor, Pascagoula
B. Mikeska, Houston
R. Peaslee, Detroit
W. Shreve, Fox Valley
M. Karagoulis, Detroit
S. McGill, NE Tennessee
L. Taylor, Pascagoula
T. Weaver, Johnstown/Altoona
L. Taylor, Northern Plains
J. Johnson, Northern Plains
D. Landon, Iowa
T. Moffitt, Tulsa
J. Nieto, Corpus Christi
F. Schmidt, Niagara Frontier
A. Sumal, British Columbia
R. Wright, San Antonio
P. Zammit, Spokane

**Student Member Sponsors**

Members sponsoring 3 or more new AWS Student Members.

S. Siviski, Maine — 45
D. Berger, New Orleans — 38
G. Euliano, Northwestern Pa. — 34
R. Evans, Siouxland — 34
M. Reiter, Columbus — 34
T. Zablocki, Pittsburgh — 28
M. Anderson, Indiana — 26
G. Smith, Lehigh Valley — 20
J. Daugherty, Louisville — 19
G. Seese, Johnstown-Altoona — 19
N. Goncalo, Milwaukee — 21
J. Kacic, Detroit — 18
C. Kipp, Lehigh Valley — 18
D. Ketler, Willamette Valley — 17
M. Arand, Louisville — 16
J. Ciaramitaro, N. Central Florida — 16
C. Donnell, Northwest Ohio — 15
T. Moore, New Orleans — 15
R. Briddell, St. Louis — 14
C. Overfelt, SW Virginia — 14
A. Stute, Madison-Beloit — 14

Nominees Sought for Robotic and Automatic Arc Welding Award

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

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

The Official Book of D1.1 Interpretations: 2008 and the expanded fifth edition of the AWS Brazing Handbook have been released. The D1.1 Interpretations is a compilation of the questions formally submitted by Code users over the years to the AWS Structural Welding Committee with the Committee’s official responses. The format groups the inquiries according to the Code date. To assist the reader, two indexes are provided. One index is compiled by subject matter, and the second is indexed by the various section numbers referenced in the document in numerical order, regardless of the Code date. This is the second edition of the publication; the first was published in 2000. The list price of the 54-page document is $64, $48 to AWS members.

The expanded fifth edition of the AWS Brazing Handbook is organized into three main sections, fundamentals, processes, and applications. Topics include brazement design, filler metals and fluxes, inspection of brazed joints, codes and standards, and safety and health issues. Two new chapters feature induction brazing and diamond brazing. The 740-page handbook includes 36 chapters, three appendices, 308 figures, and 116 reference tables. The list price is $136, $102 for members of the American Welding Society. The handbook is the result of years of work by the AWS C3 Committee on Brazing and Soldering, and AWS C3A Subcommittee on Brazing Handbook.

To order, contact Welding Engineering Exchange (WEX); www.awspubs.com; (888) 935-3464; (305) 824-1177.

Tech Topics

Interpretation
AWS D1.1:2006,
Structural Welding Code — Steel

Subject: Electrodes and Procedure Qualification
Code Provision: Table 4.6, Variable No. 5
AWS Log: D1.1-06-I01

Inquiry: Are the words ‘type of electrode’ intended to require a separate procedure qualification for each manufacturer’s filler metal designator? (Example: A change from “Filler metal No. 1 — AWS A5.20 Class E71T-1M, manufactured by ABC Co., called ABC WELDFLUXCORE-1” to “Filler metal No. 2 — AWS A5.20 Class E71T-1M, manufactured by ABC Co., called ABC WELDFLUXCORE-2”).

Response: Yes, see AWS D1.1:2006 Table 4.6, Variable No. 5.

Standards Approved by ANSI

Technical Committee Meetings
March 4–7, D1 Committee on Structural Welding. Charlotte, N.C. Contact: S. Morales, ext. 313.
March 6, A5K Subcommittee on Titanium and Zirconium Filler Metals. Charlotte, N.C. Contact: S. Borrero, ext. 334.
March 6, G2D Subcommittee on Reactive Alloys. Charlotte, N.C. Contact: S. Borrero, ext. 334.
April 8, D8 Committee on Automotive Welding. Novi, Wis. Contact: A. Alonso, ext. 299.

Brazing Handbook and Book of Official D1.1 Interpretations Published

Interpretation
AASHTO/AWS D1.5M/D1.5:2002, Bridge Welding Code

Subject: Annex A — Discontinuities
Code Provision: Section 6.26.2.1, Fig. 6.8
AWS Log: D1.5-02-I03b

Inquiry: (See figure below.) Is X4 unacceptable because it is too close to discontinuity X4, and if so, then should not X1 be unacceptable because it is located too close to X6?

Response: The Committee has determined that Annex A, 6th bullet, is in error in that X4 should be changed to X1, X3, or X4 is unacceptable as a result of their proximity to each other. X1 at 6 mm [1⁄4 in.] “B” size must have a “C” dimension of 58 mm [2 1⁄4 in.] from adjacent discontinuities.
New AWS Supporters

**Sustaining Companies**
Detroit Tool Metal Products
949 Bethel Rd.
Lebanon, MO 65536
(417) 532-2142; www.dtmp.com
Representative: Joseph W. DeWeese
Formed in 1947, Detroit Tool Metal Products has evolved into a company that is a full-service provider with processes that include tooling, stamping, fabrication, manual and robotic welding, painting, and modular assembly. A facility with 220,000 sq ft of manufacturing space, DTMP has maintained ISO 9001 certification since 1994.

Marinette Marine Corp.
1600 Ely St.
Marinette, WI 54143
(715) 735-9341; www.manitowoc.com
Representative: Daniel J. Roland
Marinette Marine Corp. (MMC) was founded along the Menominee River in Marinette, Wis., in 1942, to meet America’s growing need for naval construction. Since its first contract to build five wooden barges, MMC has built more than 1300 vessels. MMC is a full-service shipyard with in-house capabilities to design and construct the most complex vessels. It has earned an international reputation for its ability to build technologically advanced vessels.

Quality Components International
904 Downie Rd., Stratford
ON N5A 6T3, Canada
(519) 271-2711; www.steelcraft.ca
Representative: Cameron Kirkpatrick
Quality Components International manufactures fabricated and machined components and assemblies in low to medium production quantities for the transportation, forest products, off-road machinery, construction, mining, and heavy equipment industries. QCI is a division of Clemmer SteelCraft Technologies Inc., and is ISO 9001 registered.

**Supporting Companies**
Ernest-Spencer Metals, Inc.
3323 E. 82nd St.
Meriden, KS 66512

General Tool Co.
101 Landy Ln.
Cincinnati, OH 45215

LS Industries
710 E. 17th St.
Wichita, KS 67214

P2 S Plant Performance Service
5500 Cedar Crest Blvd.
Houston, TX 77087

Quality Honeycomb, Inc.
624 107th St.
Arlington, TX 76011

Seflon Steel, LP
1830 Aldine Mail Rte.
Houston, TX 77039

**Affiliate Companies**
Birmingham Drafting, Inc.
2598 A Alton Rd.
Birmingham, AL 35210

CC Fabrication & Machine Shop
839 Mackenzie Ave.
Canon City, CO 81212

Eastern Metal Works Inc.
333 Woodmont Rd.
Milford, CT 06460

FMI Addtek Inc.
1 Albert Judge Dr.
PO Box 220
Burford, ON NOE 1A0, Canada

Kaibab Steel, Inc.
850 E. Hwy. 89 A, Bldg. 1
PO Box 477, Fredonia, AZ 86022

MTQ Engineering Pte Ltd.
182 Pandan Loop 128373
Singapore

National Oilwell Varco, Inc.
12950 W. Little York, PO Box 1473
Houston, TX 77041 (77251)

Proyectos Industriales, S.A. (PINSA)
C/ Bethania #5 Sector/Avente
Santo Domingo, Dominican Republic

Sound Fighter Systems, LLC
PO Box 7216
Shreveport, LA 71137

Superior Fluid Systems, Inc.
30024 Beverly
Romulus, MI 48174

T. W. Dick Co., Inc.
PO Box 60, 1 Summer St.
Gardiner, ME 04345

**Welding Distributor**
Maverick Welding Supplies, Inc.
1737 Washington St.
Oregon City, OR 97045

**Membership Counts**

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<tr>
<td>Total members</td>
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</table>

**Educational Institutions**

Aiken Technical College
2276 Jefferson Davis Hwy.
Granteville, SC 29829

Haywood Community College
185 Fredlander Dr.
Clyde, NC 28721

Lakeshore Technical College
1290 North Ave.
Cleveland, WI 53015

Montana State University — Great Falls College of Technology
201 Culbertson Hall, MSU
Bozeman, MT 59717

North Iowa Area Community College
500 College Dr.
Mason City, IA 50401

Pine Ridge Job Corps Weld Shop
15710 Hwy. 385
Chadron, NE 69337

Weld-Ed National Center
1005 N. Abbe Rd.
Elyria, OH 44035

Wichita State University
1845 Fairmount, Campus Box 093
Wichita, KS 67260

Wrayco Industries, Inc.
5010 Hudson Dr.
Stow, OH 44224
District 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
JANUARY 7
Activity: The Boston Section members met at Assabet Valley Vocational School to see the students demonstrate their creative blacksmithing and welding skills. More than 40 welders, metallurgists, engineers, inspectors, small business owners, and metal artists attended the program. The event was coordinated by instructors Neil Mansfield and Mark Chuldenski.

CONNECTICUT
JANUARY 15
Activity: The Connecticut Section members toured the Magnatech plant in East Granby, Conn., to study demonstrations of its orbital pipe welding technology. John Emmerson, company president, hosted a dinner for the Section members and conducted the tour.

District 2
Director: Kenneth R. Stockton
Phone: (732) 787-0805

PHILADELPHIA
JANUARY 8
Activity: The Philadelphia Section members met at Sheet Metal Workers Local Union 19 in Philadelphia, Pa., for a tour of the training facility and a presentation by training coordinator Charles McClure. McClure discussed employment opportunities for high school graduates, and the welder training opportunities in the facility's apprenticeship program. Welding instructors Bill Coates and Paul Romano, both CWIs, conducted the tour of the welding shop.

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

District 4
Director: Roy C. Lanier
Phone: (252) 321-4285

District 5
Director: Steve Mattson
Phone: (904) 260-6040

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

District 7
Director: Don Howard
Phone: (814) 269-2895
DAYTON

OCTOBER 9
Activity: The Section members toured Hobart/PMI/ITW manufacturing plant in Troy, Ohio, to study the manufacture of commercial food cooking equipment.

NOVEMBER 13
Activity: Gary Ward, Southern Ohio Forge and Anvil Association, Troy, Ohio, discussed forging and forge welding for the Dayton Section members, then demonstrated several processes. Following the presentations, the Dayton Section members tried their skills at blacksmithing operations.

DECEMBER 11
Speaker: Ron Potter, senior director, distribution and emerging robot markets
Affiliation: Motoman
Topic: The business case for robotics
Activity: The Dayton Section members learned that robotic automation can make money for a company beyond the payback period making robots a worthwhile investment for small companies.

PITTSBURGH

JANUARY 8
Speaker: Vic Matthews, AWS vice president
Affiliation: The Lincoln Electric Co.
Topic: AWS and the Image of Welding
Activity: Tom White received the J. F. Minnott-H. E. Cable Service Award for his outstanding service to the Section.
Keith Simmons received his Silver Membership Award for 25 years of service to the Society. The meeting was held at Holiday Inn in Pittsburgh, Pa.
District 8
Director: Joe Livesay
Phone: (931) 484-7502

District 9
Director: George D. Fairbanks
Phone: (225) 673-6600

MOBILE
SEPTEMBER 13
Speaker: Craig Humphrey, district sales manager
Affiliation: Hypertherm, Hanover, N.H.
Topic: Improvements in plasma cutting and gouging
Activity: Calvin King received the Section Educator Award. This Mobile Section program was held at Saucy Q Restaurant in Mobile, Ala.

OCTOBER 11
Activity: The Mobile Section members toured Nilbrock, Inc., and its sister company, S. T. Alloys, LLC, in Chunchula, Ala., to study the production of cladded wear plate and the manufacture of the welding wire used in the cladding process. Phillip Keevan, company owner and president, conducted the program and tour.

NOVEMBER 8
Speaker: Jeff Bohannon, superintendent
Affiliation: Escambia County Road Prison, Escambia County, Fla.
Topic: Education and training of welders
Activity: This Mobile Section program was held at Saucy Q Restaurant in Mobile, Ala.

JANUARY 10
Speaker: Ron Borison, auditor
Affiliation: ABS Quality Evaluations, Houston, Tex.
Topic: ISO 9001 certification standards
Activity: This Mobile Section program was held at Saucy Q Restaurant in Mobile, Ala.

District 10
Director: Richard A. Harris
Phone: (440) 338-5921

DRAKE WELL
JANUARY 10
Speaker: Diane Thompson, principal metallurgical engineer
Affiliation: Joy Mining, Franklin, Pa.
Topic: The classification and weldability of stainless steels
Activity: AWS Treasurer Earl C. Liphardt presented an update on national events. Mike Owens announced that Joy Mining is hiring welders. The program was held at Double Play Sports Bar in Oil City, Pa.

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

DETROIT
JANUARY 10
Speaker: Sivakumar Ramasamy, product manager
JANUARY 10
Activity: The Section members toured the Stoelting Co. facility in Kiel, Wis., to study the manufacture of machinery for food service, cleaning, and cheese making. The major processes viewed were grinding, welding of stainless steel and plastics, press work, stamping, and assembly. Terry Thurk, production supervisor, conducted the program.

Eric Krauss, Chuck Hubbard, Rita Vondra, Marty Vondra, Hank Sima, Vernetta Sima, Cliff Iftimie, Angelina Iftimie, Sonia Harris, and Pete Harris. This Chicago Section meeting was held at The Flame Restaurant in Chicago, Ill.

SHOWN AT THE CHICAGO SECTION BOARD MEETING ARE (FROM LEFT) CHAIRMAN CRAIG TICHELAR, KIM TICHELAR, PETE HOST, ERIC KRAUSS, CHUCK HUBBARD, RITA VONDRA, MARTY VONDRA, HANK SIMA, VERNETTA SIMA, CLIFF IFTIMIE, ANGELINA IFTIMIE, SONIA HARRIS, AND PETE HARRIS.

SHOWN DURING THE CHICAGO SECTION’S FOUNDRY TOUR ARE (FROM LEFT) CHAIRMAN CRAIG TICHELAR, PRESENTER ROD BALITEWICZ, ALLEN ORTERY, AND PETE HOST.

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

ST. LOUIS
DECEMBER 7
Activity: The Section hosted its annual holiday party and awards-presentation ceremony at Royal Orleans Banquet Center in St. Louis, Mo. The event was attended by 175 members and guests.

DISTRICT 15
Director: Mace V. Harris
Phone: (952) 925-1222

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

KANSAS CITY
JANUARY 6
Speaker: Lori Cerny, safety and compliance specialist
Topic: Cylinder safety and storage
Activity: The program was held at Johnny C’s Restaurant in Kansas City, Mo.

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

NORTH TEXAS
JANUARY 15
Speaker: Ron Weisz
Affiliation: 3M Corp., OH & ESD Division
Topic: Welding fumes and respirator pro-
tection equipment
Activity: The North Texas Section members are working to support the Dallas Food Drive. The door prizes were donated by Matheson Tri-Gas and Charles Credicott, a teacher at Tarrant County College. The meeting was held at Spring Creek Barbeque in Irving, Tex. The program attracted 69 attendees.

District 18
Director: John Bray
Phone: (281) 997-7273

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

BRITISH COLUMBIA
NOVEMBER 14
Speaker: Chris Lear, manager, forest education
Affiliation: Council of Forest Industries
Topic: Impact of British Columbia’s mountain pine beetle epidemic
Activity: The British Columbia Section held a raffle of various items donated by its industry sponsors to benefit the scholarship fund. Larry Hunt was cited for his 25 years of membership in the Society. The program was held in New Westminster, B.C.

JANUARY 15
Speaker: Lindsay Langill, director, Red Seal programs
Affiliation: Industry Training Authority
Topic: New Welder Level C program
Activity: The British Columbia Section held a raffle of items donated by its industry sponsors to benefit the scholarship program. The meeting was held in New Westminster, B.C.

OLYMPIC
DECEMBER 4
Activity: The Section members toured Jesse Engineering Co., in Tacoma, Wash.

Lindsay Langill described the New Welder Level C program for the British Columbia Section members in January.

Speaker Chris Lear (right) is shown with Pat Newhouse, British Columbia Section chair, at the November meeting.
Activity: Hugh Adams received his Life Member certificate for 35 years of service.

Jesse Grantham received the District 20 Meritorious Award, and Chairman James Corbin received the District Dalton E. Hamilton CWI of the Year Award from Bob Teuscher.

District 21
Director: Jack D. Compton
Phone: (661) 362-3218

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

COLORADO
December 13
Speaker: James Corbin, Section chair
Affiliation: Steelstar Corp., director of quality and training
Topic: Preparing procedures and documentation to meet D1 specifications

Nominees Sought for Prof. Koichi Masubuchi Award

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

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

Submit your nominations to Prof. John DuPont at jnd@lehigh.edu.
Guide to AWS Services

550 NW LeJeune Rd., Miami, FL 33126
www.aws.org; phone (800)385-443-9533; FAX (305) 443-7559
(Phone extensions are shown in parentheses.)

AWS PRESIDENT
Gene E. Lawson
glawson@esab.com
ESAB Welding and Cutting
25108 Marguerite Pkwy. #165
Mission Viejo, CA 92692

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Deputy Executive Director
Cassie R. Burrell . cburrell@aws.org . . . (253)
Associate Executive Director
Jeff Webster .. jwebber@aws.org . . . . (246)
Executive Assistant for Board Services
Gricelda Manalich .. gricelda@aws.org . . (204)
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Director
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Database Administrator
Natalia Swain .. nswain@aws.org . . . . (245)
Human Resources
Director, Compensation and Benefits
Luisa Hernandez .. luisa@aws.org . . . . (266)
Manager, Human Resources
Dora Shade .. dshade@aws.org . . . . (235)

INT’L INSTITUTE OF WELDING
Senior Coordinator
Sissibeth Lopez .. sissibeth@aws.org . . . (319)
Provides liaison services with other professional societies and standards organizations.

GOVERNMENT LIASON SERVICES
Hugh K. Webster . hwebster@wc-h.com
Webster, Chamberlain & Bean, Washington, D.C.,
(202) 466-2976, FAX (202) 835-0243. Identifies funding sources for welding education, research and development. Monitors legislative and regulatory issues of importance to the industry.

Brazing and Soldering Manufacturers’ Committee
Jeff Webster .. jwebber@aws.org . . . . (246)

RWMA — Resistance Welding Manufacturing Alliance
Manager
Susan Hopkins .. susan@aws.org . . . . (295)

WEMCO — Welding Equipment Manufacturers Committee
Manager
Natalie Tapley .. natl@aws.org . . . . (444)

CONVENTION and EXPOSITIONS
Associate Executive Director
Jeff Webster .. jwebber@aws.org . . . . (246)
Executive Director, Exhibition Sales
Joe Kral .. jkral@aws.org . . . . . (297)

WELDING JOURNAL 75

Mothership: Welding Journal
Nominees for National Office

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

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

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

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

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

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

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

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

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

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

Honorary Meritorious Awards

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

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

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

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

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

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

AWS Foundation

The AWS Foundation, Inc., is a not-for-profit corporation established to provide support for educational and scientific endeavors of the American Welding Society. Information on gift-giving programs is available upon request.

Chairman, Board of Trustees
Ronald C. Pierce

Executive Director, AWS
Ray Shook

Executive Director, Foundation
Sam Gentry

550 NW LeJeune Rd., Miami, FL 33126
(305) 445-6628; (800) 443-9353, ext. 293
general information:
(906) 443-9353, ext. 689; vponzuky@aws.org

AWS Publications Sales

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

Welding Journal Reprints

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

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

AWS Mission Statement

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

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gene E. Lawson, as listed on the previous page.
THE 13TH
BEIJING ESSEN
WELDING & CUTTING FAIR

CHINA INTERNATIONAL EXHIBITION CENTER
in Beijing

MAY 14-17, 2008

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Mrs. Bai E-mail: bai@cmes.org
Tel: 0086–10–63972404 63972304 Fax: 0086–10–63980554

Please pre-register on http://essen.cmes.org. We will mail VIP badge to you in advance.
A Catalog of Welding Literature Released

The 20-page January 2008 Welding Marketplace is a full-color catalog of products and services for the welding and metal-fabricating industries. Presented are the latest products from 61 companies with contacts for more information. The products range from heavy-duty automated welding equipment to chip hammers, pipe cutting tools, abrasives, weld data loggers, stud welding equipment, borescopes, tungsten electrode grinders, computer software, cutting torches, anti-spatter products, and cold galvanizing sprays, among numerous other well-illustrated products from a cross section of the industry’s manufacturers.

American Welding Society
www.aws.org
(800/305) 443-9353

Poster Explains Welding Wire Classification System

A poster explains the AWS classification for four types of tubular wires. Detailed are mild steel flux cored wire, mild steel metal cored wire, low-alloy flux cored wire, and low-alloy metal cored wire, and the suitability of these filler metals for various welding applications is outlined. This is the third in a series of posters designed to increase knowledge of welding terms for students, hobbyists, and professionals. The full-size poster can be ordered by calling the telephone number. A smaller version of the poster may be downloaded from the Web site.

Hobart Brothers Co.
www.hobartbrothers.com
(937) 339-9425

Miller Releases Full-Line Product Catalog

New features in the full-color, 100-page Full-Line 2008 Catalog include a quick index of new products, new product guides for GMA industrial applications and multiprocess products, plus more.

— continued on page 81
POSTER ABSTRACT SUBMITTAL
Annual FABTECH International & AWS Welding Show
Las Vegas, NV – October 6-8, 2008
(Complete a separate submittal for each poster)

Primary Author (Full Name):
School/Company:
Mailing Address:

City: State/Province: Zip/Mail Code: Country:

Email:
Poster Title (max. 50 characters):
Poster Subtitle (max. 50 characters):

Co-Author(s):
Name (Full Name): Affiliation:
Address:
City: State/Province: Zip/Mail Code: Country:

Email:

Poster Requirements 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 techpapers@aws.org or print and mail.
- Maximum size – 44 inches tall x 30 inches wide. (Vertical format, please).
- Must be legible from a distance of 6 feet. A minimum font size of 14 pt. is suggested.
- Posters must be submitted to AWS as a single flat printed medium (e.g. laminated print or foam core board mount).
- 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.

Posters 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:

(A) Student
- Students enrolled in 2 yr. college and/or certificate programs at time of submittal.
- Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application is important and should be demonstrated.

(B) Student
- For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal.
- Poster should represent the student’s own experimental work. Emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application and/or potential relevance to the welding industry is important and should be demonstrated.

(C) Student
- For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal.
- Poster should represent the student’s own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented.
- Potential relevance to the welding industry is important and should be demonstrated.

(D) Professional
- For anyone working in the welding industry or related field.
- Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation.
- Potential relevance to the welding industry is important and should be demonstrated.

(E) High School
- Junior or Senior high school students enrolled in a welding concentration at the time of submittal.
- Presentation should represent technical concepts and application to the welding industry.
- Practical application and creativity are important and should be demonstrated.
Check the category that applies:

- (A) Student 2-yr. or Certificate Program
- (B) Student 4-yr. Undergraduate
- (C) Graduate Student
- (D) Professional
- (E) High School

**Poster Title (max. 50 characters):**

**Poster Subtitle (max. 50 characters):**

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**Abstract:**

*Introduction* (100 words) – Describe the subject of the poster, problem/issue being addressed and it's practical implications for the welding industry.

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**Technical Approach & Results** (200 words) – Explain the technical approach. Summarize the work that was done as it relates to the subject of the poster.

---

**Conclusions** (100 words) – Summarize the conclusions and how they could be used in a welding application.

---

Return this form, completed on both sides, via email to techpapers@aws.org

*MUST BE RECEIVED NO LATER THAN March 28, 2008*
guidance for selecting GTA and Millermatic GMA welding machines and Spectrum plasma arc cutting machines. Included is product information from Bernard, Hobart Brothers, Smith Equipment, Tregaskiss, and Weldcraft. Updated information is provided for welding machines, plasma arc cutting machines, welding generators, helmets, safety equipment, product selection charts, and accessories. Call to receive a copy in the mail, or download the PDF version from the Web site.

Miller Electric Mfg. Co.
www.millerwelds.com/service/lit_req.php
(800) 426-4553

Updated Book of D1.1 Interpretations Published

The Official Book of D1.1 Interpretations:2008 is a compilation of the questions formally submitted by Code users to the AWS Structural Welding Committee over the years with the Committee’s official responses. The format groups the inquiries according to the Code date. To assist the reader, two indexes are provided. One index is compiled by subject matter, and the second is indexed by the various section numbers referenced in the document in numerical order, regardless of the Code date. This is the second edition of the publication; the first was published in 2000. The list price of the 54-page document is $64, $48 to AWS members.

Welding Engineering Exchange (WEX)
www.awspubs.com
(888) 935-3464/(305) 824-1177

New Line of GMA Wires Pictured in Brochure

A brochure details the company’s new line of AristoRod® gas metal arc welding wires. Detailed are the features of this high-efficiency wire, including trouble-free feeding, low contact tip wear, low spatter, stable arc, and improved arc start properties, as well as improved weld appearance with less postweld cleaning. Call for a free copy of the literature.

ESAB Welding & Cutting Products
www.esabna.com
(800) 372-2123

AWS Brazing Handbook, Fifth Edition, Published

The expanded fifth edition of the AWS Brazing Handbook is organized into three sections, fundamentals, processes, and applications. Topics include brazement design, filler metals and fluxes, inspection of brazed joints, codes and standards, and safety and health issues. Two new chapters feature induction brazing and diamond brazing. The 740-page handbook includes 36 chapters, three appendixes, 308 figures, and 116 reference tables. The list price is $136, $102 for members of the American Welding Society. The handbook was prepared by the AWS C3 Committee on Brazing and Soldering, and AWS C3A Subcommittee on the Brazing Handbook.

Welding Engineering Exchange (WEX)
www.awspubs.com
(888) 935-3464/(305) 824-1177

Catalog Lists Laser Safety Training Courses

The 20-page, full-color, 2008 Laser Safety Training Catalog presents detailed descriptions of the Institute’s courses, including course overview, what the student will learn, who should attend, registration fees, course materials provided, and locations. Many courses can be completed online using either a PC or Mac. Course topics include laser safety officer training, medical laser safety officer, advanced concepts in laser safety, industrial lasers, laser safety for physicians, and a new course, Medical Laser Safety with Hands-on Demonstration.

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

Metals Buying Guide Posted Online

The ForeignTRADEX, Global Industrial Trade Directory, lists companies worldwide with their product specialties and Web site addresses. Included are all types of metal products in a wide range of forms, such as steel, iron, aluminum, stainless steel, wrought iron, welded mesh, steel angles, I-beams, steel billets and blanks, cast iron bars, cold-rolled sheet and rolls, ingots, aluminum and steel bars, strips, channels and beams, sheet metal, tungsten, machined metal parts, brazing and beryllium alloys, ferrous and nonferrous metals, and a broad variety of associated products.

ForeignTRADEX
www.foreigntradeexchange.com/suppliers/metals_alloys_steel.html

Want to be a Welding Journal Advertiser?

For information, contact Rob Saltzstein at (800) 443-9353, ext. 243, or via e-mail at salty@aws.org.
Two Key PostsFilled at CMW Inc.

CMW Inc., Indianapolis, Ind., a manufacturer of highly engineered metal alloys and composites, has named Stephen P. Schelonka company controller and Jeffrey L. Schemel major account manager in the resistance welding business unit. Prior to joining the company, Schelonka was division controller for IMMI, an Indianapolis-based materials company. Schemel most recently served as a technical salesman for REGO-FIX Tool Corp. for more than seven years.

Lincoln Expands Roles for Two Senior VPs

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has promoted Vincent K. Petrell, senior VP and CFO, and George Blankenship, senior VP, Global Engineering and U.S. Operations, to expanded roles within the company. Petrell, in addition to his former duties, is now responsible for Lincoln Electric Co. of Canada. Blankenship has been promoted to the newly created position of president, Lincoln Cleveland, with responsibilities for the company’s major domestic operations, including the Euclid and Mentor, Ohio, plants. In addition, he will continue to lead the company’s global R&D and technology transfer functions.

Schebler Co. Names President and CEO

The Schebler Co., Bettendorf, Iowa, has named Jim Anderson president and CEO. Before joining the company, Anderson served as executive vice president at ITW Miller Electric Mfg. Co.

Hobart Institute Appoints Skill Welding Instructor

Hobart Institute of Welding Technology, Troy, Ohio, has appointed John (Kris) Rahall as a skill welding instructor. Currently teaching gas metal arc welding classes, Rahall has six years of practical experience in welding and four years of service in the U.S. Marine Corps, including service in Iraq and Afghanistan.

LIA Announces 2008 Board

Laser Institute of America, Orlando, Fla., has announced its board members for 2008. Named were Rajesh Patel, president; Klaus Löffler, secretary; and Stephen Capp, treasurer. Serving on the 2008–2010 board are David Clark, Paul Crosby, Klaus Kleine, William Lawson, Yongfeng Lu, John Marshall, Nathaniel Quick, John Tyler, Frank Vollertsen, Richard Walker, and Dean Wilson.

Hypertherm Fills Two Key Posts

Hypertherm, Hanover, N.H., has appointed John Brennan to the newly created position of North American distribution director, and Randy McMurtry its new national distribution development manager. Previously, Brennan served as national distribution manager. McMurtry, with the company for 19 years, most recently served as a divisional manager.

Parlec Names Southeast Applications Engineer

Parlec, Inc., Rochester, N.Y., a supplier of CNC tooling, work-holding, and presetting solutions, has named Carlo Tomassetti southeast regional sales and applications engineer. With the company since 2005, Tomassetti previously managed sales in the eastern seaboard and parts of China.
Arc-Zone Appoints Director of Operations

Arc-Zone.com®, Inc., Carlsbad, Calif., a supplier of brand name and OEM replacement parts and accessories for welding and cutting applications, has named Scott Reiman director of operations. Prior to joining the company, Reiman worked as controller for a construction company.

AMT Hires Machine Vision Technology Engineer

Applied Manufacturing Technologies (AMT), Inc., Orion, Mich., has appointed David Wyatt as staff engineer for its machine vision automation technology business. Wyatt, with more than 25 years of experience in the industry, is the founder and former president of Midwest Integration.

OTC Makes Staff Additions

OTC DAIHEN, Inc., Tipp City, Ohio, has hired Lisa Humphres as special projects coordinator and Luke Kadota as a sales advisor for the northern region sales, replacing Harry Onguchi, who was reassigned to the company’s Nagoya branch in Japan. Jason Robinson, with 13 years of experience, was hired as a field service technician for the Tipp City headquarters, and Keith Shaver, with more than 30 years of welding industry-related experience, has joined the company as southern corporate strategic accounts manager. Previously, Humphres worked in sales and marketing with Omega Automation and Kadota served 14 years with the DAIHEN Group in Japan.

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Obituaries

Olieus Joseph Templet

Olieus Joseph ‘O. J.’ Templet, 78, an AWS Life Member, active in the Baton Rouge Section for more than 50 years, died Dec. 27, 2007, in Baton Rouge, La. Mr. Templet served as District 9 director (1999–2001) and filled many officer positions in the Baton Rouge Section, including chairman 1972–1973 and 1996–1997. He received the District 9 Meritorious Award in 1987 and the AWS Distinguished Member Award in 2007. Mr. Templet was the retired owner of TNT Welding Supply and a U.S. Navy veteran of WW II. He attended the University of Louisiana and McNeese State University. He served as a coach at Redemptorist Catholic Diocesan High School and as a high school football referee. He was a member and past district governor of the Lions Club, a member and past grand knight of the Knights of Columbus, a past member and director of the Optimist Club, and a devoted member of St. Alphonsus Catholic Church.

He is survived by his wife, Margaret, four daughters, three sons, 10 grandchildren, eight great-grandchildren, a sister, and several brothers. The family requests donations in his name be sent to the AWS O. J. Templet Scholarship Fund, c/o TNT 2020 N. Third St., Baton Rouge, LA 70802, the Lions Club Eye Foundation, or a charity of your choice.

Terry Lee Bush

Terry Lee Bush, 60, died Oct. 17, 2007, at his home in Boise, Idaho. Born and raised in Baker, Ore., he served in the U.S. Marine Corps then pursued a career in welding with United Airlines in San Francisco, Calif. Later, he worked in Boise for Hobson Sheet Metal and also taught welding through the Boise State Trade School program. He worked in Georgia, and for Super Steel in Milwaukee and in New York, building a locomotive for the Long Island Railroad. His survivors include his mother, Christine, two daughters, a son, two brothers, and his best friend Glenda Self.
Industry Notes

- **Jackson Safety**, St. Louis, Mo., has acquired the assets of Safe-master OY, Tampere, Finland, a designer and manufacturer of welding helmets in the Nordic Region.
- **Air Products’** new fleet of Microbulk Solutions delivery trucks, equipped with upgraded supply capabilities, are to be rolled out in North America this year.
- **Ameriforge Group Inc.** and **Superior Holdings Inc.** have reached an agreement for Ameriforge to acquire Superior and its subsidiaries — SMI Manufacturing Inc., a provider of machining, welding, and cladding, and PK Manufacturing, Inc., which specializes in advanced welding procedures.
- **Vintage Air**, San Antonio, Tex., recently procured and installed its own CuproBraze production line. Now it brazes its own copper-brass heater cores.
- **Johnson Manufacturing Co.**, Princeton, Iowa, has acquired certain assets of The S.A. Day Mfg. Co. The newly named S.A. Day Buffalo Flux Facility will continue to operate at the same location in Buffalo, N.Y. Products included in the sale are fluxes for soldering and high-purity fluxes for brazing.
- Three representatives from the U.S. Occupational Safety and Health Administration recently visited New Berlin, Wis., to present **ABB** with the Voluntary Protection Program Star Award.
- **Flomerics**, Marlborough, Mass., a provider of engineering simulation software, is celebrating its 20th anniversary as an independent company this year.
- **Valley National Gases, LLC**, Washington, Pa., has acquired Wolfenden Industries, a distributor of industrial, medical, and special gases with three operating locations in northeast Ohio.
- Structural engineers **Myers, Houghton & Partners** won a Merit Award prize from the Structural Engineers Association of California for their research testing conventional welded steel frame buildings subject to terrorist air blast attack and subsequent progressive collapse.
- The board of trustees of **Hutchinson Community College**, Kansas, accepted a bid of $505,200 from A&A Builders for renovations to the Reno County Industrial Center. This will add more classroom and workspace for the welding program.
- **Behlen Mfg. Co.**, Columbus, Neb., has purchased Distefano Tool & Mfg. Co., Omaha, Neb., a fabricator of metal components and welded assemblies for a variety of industries.
- **Motoman Inc.**, West Carrollton, Ohio, has been named “Manufacturing Business of the Year for 2007” in the sixth annual Business of the Year program sponsored by the **Dayton Business Journal** and Soin International.
- **Arcos Industries, LLC,** will open a new warehouse and distribution center in Houston, Tex. The 20,000-sq-ft facility commenced operations in January.
- **Wind Point Partners**, Chicago, Ill., a private equity investment firm, has completed the acquisition of Taylor-Wharton International, Mechanicsburg, Pa., which serves through four divisions including American Welding & Tank.
- **CMW Inc.**, Indianapolis, Ind., has received a Safety Award from workers compensation carrier AmComp for working more than 12 months without a lost-time incident.
- **Technogenia** has opened a new Lasercarb® Technology Center in Conroe, Tex. This facility houses a machine that deposits antiabrasion material onto industrial parts.
- The Metal Fabrication program at **Kwantlen University College**, Surrey, B.C., Canada, has received a $1200, 5000-lb capacity electronic crane suspended scale donated by Brenco Industries Ltd.
## TECHNICAL PROGRAM ABSTRACT SUBMITTAL

**Annual FABTECH International & AWS Welding Show**  
Las Vegas, October 6-8, 2008  
*(Complete a separate submittal for each paper to be presented.)*

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| City: | State/Province: | Zip/Mail Code: |
| Country: | E-Mail: |

### Answer the following about this paper

- Original submittal? Yes [ ] No [ ]  
- Progress report? Yes [ ] No [ ]  
- Review paper? Yes [ ] No [ ]  
- Tutorial? Yes [ ] No [ ]

What welding processes are used?  
What materials are used?  
What is the main emphasis of this paper? Process Oriented [ ] Materials Oriented [ ] Modeling [ ]

To what industry segments is this paper most applicable?  
Has material in this paper ever been published or presented previously? Yes [ ] No [ ]

If “Yes”, when and where?  
Is this a graduate study related research? Yes [ ] No [ ]

If accepted, will the author(s) present this paper in person? Yes [ ] Maybe [ ] No [ ]

### 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 techpapers@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.

- Applied Technology  
  - New or unique applications.  
  - Selection based on technical merit.  
  - Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways.  
  - Preference will be given to submittals with clearly communicated benefit to the welding industry.

- Education  
  - Welding education at all levels.  
  - Emphasis is on education/training methods and their successes.  
  - Papers should address overall relevance to the welding industry.

- Check the category that best applies:
  - [ ] Technical/Research Oriented  
  - [ ] Applied Technology  
  - [ ] Education
Proposed Title (max. 50 characters):
Proposed Subtitle (max. 50 characters):

Abstract:
Introduction (100 words max.) – Describe the subject of the presentation, problem/issue being addressed and it’s practical implications for the welding industry. Describe the basic value to the welding community with reference to specific communities or industry sectors.

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. For other papers, elaborate on why this paper is of value to the community, describe key work in the field and provide an integration of these separate activities into a “continuum.”

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: Presentations should avoid the use of product trade names.

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your professional development through hundreds of educational programs and events

October 6-8, 2008
Las Vegas Convention Center
Las Vegas, Nevada USA

www.aws.org/show
FIRST ANNOUNCEMENT and CALL FOR PAPERS

4th International Brazing & Soldering Conference (IBSC)

Conference dates: April 27-29, 2009

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

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

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

The technical program will include a special ½ day session focused on practical and innovative applications of brazing and soldering. The Tabletop Exhibit will provide a forum for commercial presentations and demonstrations of state-of-the-art brazing and soldering materials, processes and equipment. Check our website for details. The Poster Session will allow yet another opportunity to present the interesting developments in brazing and soldering technologies.

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

Below are some of the topical areas covered at IBSC

<table>
<thead>
<tr>
<th>Aircraft and Aerospace</th>
<th>Furnace / Vacuum Brazing</th>
<th>Power and Electrical Equipment</th>
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<td>Joint Design and Reliability</td>
<td>Sensors / Micro-Electronics</td>
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<td>Brazing and Soldering Standards</td>
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<td>Ceramic / Glass to Metal Joining</td>
<td>Light Metals</td>
<td>Special / Advanced Brazing Processes</td>
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<td>Chemical and Petroleum Production</td>
<td>Materials and Process Design / Control</td>
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<td>Composite Materials</td>
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<td>Test Methods and Evaluation</td>
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<td>Electronic Packaging / Sensors</td>
<td>Mining &amp; Heavy Equipment</td>
<td>Thermal Management</td>
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<td>Modeling and Process Control</td>
<td>Vacuum Brazing</td>
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<td>Fluxes and Atmospheres</td>
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<td>Gasses and Plumbing</td>
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<td>Fixture Design and use</td>
<td>Factory Automation</td>
<td>LEAN Brazing Processes</td>
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<tr>
<td>Musical Instruments</td>
<td>Job-Shop &amp; Process Customization</td>
<td>Low Volume Critical Components</td>
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To submit your work for consideration, visit our website at www.aws.org/ibsc then follow the instructions at “Click here to submit your abstract.” All abstracts submissions must be completed by close-of-business on Wednesday, April 30, 2008. Before submitting your abstract, we ask that you carefully consider your ability to present your work at the conference. Speakers are required to pay a (reduced) conference registration fee, and are totally responsible for their travel, housing and any related expenses.

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

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

Endorsing Sponsors:
Highlights of the new AWS Brazing Handbook edition — available now:

- Invaluable technical reference prepared by world-class experts
- Three sections — Fundamentals, Processes, and Applications — encompassing 36 chapters
- Expanded coverage from the history of brazing to braze design and latest technologies
- Revised chapter on brazing safety
- Unique new chapter on diamond brazing
- Richly illustrated with photographs, figures, and tables
- Fully indexed and referenced to facilitate research at all levels

Order your copy at http://www.awspubs.com
Career growth takes vision.

NDE professionals and current AWS CWIs:

Get certified as an AWS Radiographic Interpreter.

The AWS Radiographic Interpreter training and certification program assures employers and practitioners alike that the principles of radiographic interpretation are reliably applied to the examination of welds. If your job responsibilities include reading and interpretation of weld radiographs, this program is for you. You’ll learn proper film exposure, correct selection of penetrators, characterization of indications, and use of acceptance criteria as expressed in the AWS, API and ASME codes.

NEW! If you are a CWI, certification as an Radiographic Interpreter (CRI) can now exempt you from your next 9-Year CWI Recertification Exam.

For more information on the course, qualification requirements, certification exams, and test locations, visit our website at www.aws.org/certification/cri or call 1-800-443-9353 ext 273 (outside U.S., call 305-443-9353).
SALES REPRESENTATIVE FOR METAL WORKS FABRICATION

We are seeking a sales representative with a minimum of 2-3 years experience in selling metal works fabrication and welding jobs. Must have ability to read blueprints, familiarity with steel product and preparing cost estimates for projects. Location: Houston, Texas. Local residents preferred. Submit resume: pablopinedo@sbcglobal.net. Salary + Commission.

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

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Welding Journal
High-Strength Steel Welding with Consumable Double-Electrode Gas Metal Arc Welding

BY K. H. LI, Y. M. ZHANG, P. XU, AND F. Q. YANG

ABSTRACT: Low heat input is typically desired for welding high-strength steels to ensure that the mechanical behavior of material in the HAZ would not change significantly after welding. However, a high current, and thus a high heat input, is required to melt more wire to achieve a goal of increased productivity through increased deposition rate. A novel process referred to as Consumable Double-Electrode GMAW or DE-GMAW has been developed to increase the deposition rate without increasing the heat input. This work studies the characteristics of the heat-affected zone (HAZ) including the HAZ size, microstructure, and the hardness of high-strength steel ASTM A514 welded by DE-GMAW. It is found that, to obtain the same deposition rate, the DE-GMAW process can significantly decrease the heat input using a low base metal current, in comparison with conventional GMAW, to achieve a small HAZ and low joint penetration. The low heat input caused a fast cooling rate and high hardness in the HAZ.

Introduction

High heat input is often not preferred because of possible adverse effects on the heat-affected zone (HAZ) (Refs. 1, 2) including degeneration of material properties in the HAZ such as microstructure, microhardness, and grain size (Refs. 3–5). Typically, the HAZ is desired to be small. While the most effective way to minimize the HAZ is to reduce the heat input (Ref. 6), the deposition rate in GMAW would be proportionally reduced and the productivity compromised. To resolve this issue, a novel welding method named Consumable DE-GMAW has been developed recently at the University of Kentucky (Refs. 7–9). This process based on conventional GMAW can improve the welding productivity by increasing the melting current but still controlling the base metal current at a desired low level using an added bypass GMAW gun. Experiments have been performed to demonstrate that this novel process can achieve independent controls of the melting current and base metal current. Hence, the Consumable DE-GMAW has the potential to reduce the heat input without compromising the welding productivity.

Consumable DE-GMAW Process

As illustrated in Fig. 1, Consumable DE-GMAW is designed by adding another GMAW gun and a constant current (CC) power supply to the conventional GMAW process. The CC power supply provides the bypass current while the CV (constant voltage) power supply provides the base metal current. Two consumable welding wires are fed in through two GMAW guns, respectively. There are two parallel welding arcs: the main arc established between the main wire (positive) and the workpiece (negative), and the bypass arc established between the main wire (positive) and the bypass wire (negative). Thus the total melting current \( I \) is decoupled into two parts: the bypass current \( I_1 \) and the base metal current \( I_2 \), or equally \( I = I_1 + I_2 \). It can be seen that the bypass wire is primarily melted by the bypass current while the main wire and the base metal are melted by the total melting current. This makes it possible to obtain a high deposition rate with the same heat input while the base metal current is maintained at a low level.

In Consumable DE-GMAW, the main welding arc needs to be ignited first, and then the bypass welding arc is ignited between the bypass wire and the main wire through the main arc. While the main arc is fundamental in the Consumable DE-GMAW, the bypass arc ensures this process functions properly. Because an unstable bypass arc may cause unexpected serious problems such as damaging the workpiece by melting through it, the bypass arc must be stable and always present to obtain a practical process. Studies have revealed that the bypass arc voltage can be used to characterize the bypass arc stability (Ref. 8). Furthermore, for a stable bypass arc, the optimal bypass arc voltage \( V_2 \) is found to be 1–3 volts larger than the main arc voltage \( V_1 \) as illustrated in Fig. 1. When the bypass wire feed speed (noted as WFS) is fixed, the adjustment in the bypass current will affect the bypass arc voltage. Thus, an interval-model-based controller has been designed to output the proper bypass current to maintain/control the bypass arc voltage at its optimal value such that a stable bypass arc is achieved (Refs. 8, 9).

At the mean time, the base metal current must be controllable or adjustable to

KEYWORDS

Heat Input
Indentation
HAZ
Double Electrode
DE-GMAW
High-Strength Steel
Deposition Rate
adapt different applications. It also requires that the base metal current be controlled at a desired level despite possible variations in manufacturing conditions. Based on the above design, the base metal current is controlled by adjusting the main wire feed speed (noted as WFS1). Any change in WFS1 will be reflected as a change in the needed total melting current when the main arc voltage is maintained at a constant. Based on the relationship \( I = I_1 + I_2 \), a change in the base metal current is possible considering that the bypass current is roughly fixed with a constant WFS2. Thus, another interval-model-based controller is designed and implemented taking the base metal current as the input and the main wire feed speed as the output. The above two parallel controllers function together to make the process stable and practical.

**Experiments**

A complete Consumable DE-GMAW system was established in the lab. Two parallel interval-model-based controllers were used to obtain a stable process and to control the base metal current at a desired level.

During experiments, the two welding guns were moved together horizontally. Only the main gun was shielded with 90% argon and 10% CO\(_2\) at a rate of 18.9 L/min (40 ft\(^3\)/h). No shielding gas was used for the bypass welding gun. Sensors for currents and voltages were used for monitoring purposes. An Olympus high-speed camera equipped with a 940-nm narrow-banded optical filter was adapted to observe the arc behavior and metal transfer.

All experiments were performed with 1.2-mm-(0.045-in.) diameter low-carbon welding wire (ER70S-6) on the high-strength steel ASTM A514, a quenched and tempered (Q&T) steel widely used in structural and pressure vessel applications because of its good ductility and weldability. The chemical compositions for the base metal (ASTM A514) and filler metal (ER70S-6) are presented in Table 1. For a practical application, the DE-GMAW process must be a stable process and present all the time with adjustable base metal current. Figure 2 shows the data waveforms recorded in 2-B.

**Table 1 — Chemical Composition (%) of Base Metal\(^{\text{a}}\)**

<table>
<thead>
<tr>
<th></th>
<th>A514</th>
<th>ER70S-6</th>
<th>A514</th>
<th>ER70S-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.15–0.21</td>
<td>0.06–0.15</td>
<td>Chromium</td>
<td>0.50–0.80</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.80–1.10</td>
<td>1.40–1.85</td>
<td>Molybdenum</td>
<td>0.18–0.28</td>
</tr>
<tr>
<td>Phosphorus (max)</td>
<td>0.035</td>
<td>0.025</td>
<td>Nickel (max)</td>
<td>—</td>
</tr>
<tr>
<td>Sulfur (max)</td>
<td>0.035</td>
<td>0.035</td>
<td>Copper (max)</td>
<td>—</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.40–0.80</td>
<td>0.80–1.15</td>
<td>Vanadium (max)</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^{\text{a}}\) Remainder is iron.

Results and Analysis

**Stability of Consumable DE-GMAW Process**

For a practical application, the DE-GMAW process must be a stable process first. That is to say, the bypass arc must be stable and present all the time with adjustable base metal current. Figure 2 shows the data waveforms recorded in 2-B.
In this experiment, the bypass wire feed speed \((WFS_2)\) was maintained at 11.43 m/min (450 in./min), and the bypass current was controlled to keep a constant bypass arc voltage of 39 V. The main arc voltage was set to 36 V, and the main wire feed speed \((WFS_1)\) was adjusted to obtain a uniform base metal current. From the waveforms it can be seen that the bypass arc was present all the time, thus the welding process was stable. The stability is also verified by the resultant weld bead as illustrated in Fig. 3. The weld bead is uniform and no spatter was observed.

### Heat-Affected Zone and Heat Input

During welding, the HAZ is heated to a high temperature (near the melting point) but not melted. The HAZ size is controlled by the heat input. The larger the heat input is, the larger the HAZ. After the workpiece cools down, the grains in the HAZ will coarsen remarkably, although a fine-grained region may also be observed in the outer HAZ region depending on the cooling rate (Refs. 6, 10). In welded structures with many alloys, the HAZ is the weaker region, thus, a small HAZ is typically preferred. For high-strength Q&T steels, a minimum heat input is desirable. If the heat input is too small, the cooling rate will be high resulting in the formation of untempered martensite, which can cause unacceptably high HAZ hardness and susceptibility to hydrogen cracking. Thus, the heat input must be controlled.

Traditionally, the HAZ is measured with its width in the cross section after the weld bead is cut, polished, and etched. However, this width varies significantly with the distance from the workpiece surface, and even with the same distance, the width in one side may be different from the other side. Thus, the authors propose to use the cross-section area of the HAZ to quantify the HAZ size. Since the HAZ is the base metal affected by the heat input, it is reasonable to expect that large heat input will affect more base metal in volume. In the cross section (2-D), the HAZ area can denote the volume. The HAZ area can be measured very easily by counting the pixels it contains with image processing tools, such as PhotoShop. The accuracy can be verified by comparing the measured filler metal area and the calculated filler metal area. Assuming no spatter, the filler metal area can be calculated as

\[
A = \frac{\pi d^2}{4} WFS \left[ \text{mm}^2 \right] \tag{1}
\]

where \(d (\text{mm})\) is the diameter of the welding wire, \(WFS \text{ (in./min)}\) is the total wire feed speed, and \(v_t (\text{in./min})\) is the travel speed. For the bead-on-plate experiments, the filler metal area can be easily located and measured as discussed later.

For traditional arc welding, the heat input is calculated as

\[
Q = \eta \frac{60 WFS \left[ WFS I \right]}{1000 v_t \left[ \text{in.} \right]} \tag{2}
\]

where \(V \text{ (volt)}\) is the welding voltage, \(I \text{ (A)}\) is the melting current, \(\eta\) is the efficiency depending on the welding process used (for GMAW, \(\eta = 0.9\)), and \(v_t (\text{in./min})\) is the travel speed. It can be seen that the smaller the melting current, the smaller the heat input for the same welding voltage and the same travel speed.

For the Consumable DE-GMAW, two power supplies provide two currents. Even though the bypass current does not flow through the base metal, the bypass energy will be transferred to the weld pool via the bypass droplets. One thus needs to modify the equation for calculating the heat input in the Consumable DE-GMAW. Assuming the same heat coefficient for the bypass arc and the main arc, the heat input in Consumable DE-GMAW can be calculated as

\[
Q = \eta \frac{60 \left[ VI_1 + VI_2 \right]}{1000 v_t \left[ \text{in.} \right]} \tag{3}
\]

Comparing Equation 3 to Equation 2, conventional GMAW is a special case of

### Table 2 — Welding Conditions for Bead-on-Plate Experiments

<table>
<thead>
<tr>
<th>No.</th>
<th>Total Current (A)</th>
<th>Base Metal Current (A)</th>
<th>(WFS_1) (in./min)</th>
<th>(WFS_2) (in./min)</th>
<th>Total Wire Feed Speed (in./min)</th>
<th>Voltage (V)</th>
<th>Travel Speed (in./min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A</td>
<td>345</td>
<td>345</td>
<td>550</td>
<td>0</td>
<td>550</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>1-B</td>
<td>311</td>
<td>196</td>
<td>350</td>
<td>200</td>
<td>550</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>2-A</td>
<td>422</td>
<td>422</td>
<td>700</td>
<td>700</td>
<td>1150</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>2-B</td>
<td>413</td>
<td>200</td>
<td>700</td>
<td>450</td>
<td>1150</td>
<td>36</td>
<td>30</td>
</tr>
</tbody>
</table>

### Table 3 — Welding Conditions for Butt Joint Experiments

<table>
<thead>
<tr>
<th>No.</th>
<th>Total Current (A)</th>
<th>Base Metal Current (A)</th>
<th>Voltage (V)</th>
<th>(WFS_1) (in./min)</th>
<th>(WFS_2) (in./min)</th>
<th>Travel Speed (in./min)</th>
<th>Heat Input (kJ/in.)</th>
<th>Number of Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-A</td>
<td>365</td>
<td>365</td>
<td>36</td>
<td>650</td>
<td>0</td>
<td>20</td>
<td>35.48</td>
<td>13</td>
</tr>
<tr>
<td>3-B</td>
<td>400</td>
<td>180</td>
<td>36</td>
<td>645</td>
<td>450</td>
<td>20</td>
<td>40.66</td>
<td>7</td>
</tr>
</tbody>
</table>
Consumable DE-GMAW where the bypass current is zero.

To study the heat input, the HAZ was evaluated after the specimens were polished with γ-alumina powders and etched with 2% Nital (nitric and hydrochloric) solutions. The measured macro dimensions are listed for comparison in Table 4. In the table, the item Filler Metal is the weld metal over the workpiece surface; and the Fused Metal refers to the weld metal under the surface of the workpiece. In the bead-on-plate experiments, the Filler Metal is the filler metal deposited, which can be calculated in Equation 1 for verification. The Fused Metal is the base metal melted during welding. The Filler Metal and Fused Metal together form the weld metal.

In the conventional GMAW experiments, the heat input (27.35 kJ/in.) in 2-A is 1.2 times of the heat input (22.36 kJ/in.) in 1-A after the wire feed speed was increased from 14.0 m/min (550 in./min) in 1-A to 17.8 m/min (700 in./min) in 2-A. Because of the change of the heat input, the HAZ area was also changed from 20.0 mm² in 1-A to 24.0 mm² in 2-A resulting in a ratio of 1.2, which is equal to the heat input ratio (1.2). That is to say the HAZ area depends on the heat input. More importantly, the ratio of HAZ area/heat input is about the same (0.88), suggesting a linear proportional relationship and any reduction in the HAZ area must be due to the use of less heat.

The data in Table 4 also illustrate another well-known conclusion that the penetration depth in conventional GMAW is proportional to the square of the base metal current. The penetration depth in 2-A is 1.6 times of that in 1-A, while the square of the base metal current in 2-A is 1.5 times of the one in 1-A. That is because the arc pressure is proportional to the square of the base metal current.

In experiments 1-A and 1-B, the deposition rates were the same because of the same total wire feed speed. In 1-B, the main wire feed speed was fixed at 8.89 m/min (350 in./min), and the bypass wire was fed in at a speed of 5.08 m/min (200 in./min). As a result, the base metal current in 1-B was only 196 A, and the heat input in 1-B (20.77 kJ/in.) was smaller than that in 1-A (22.36 kJ/in.). The weld beads from these two experiments are shown in Fig. 4, and the cross-sectional areas are illustrated in Fig. 5. Both weld beads are uniform and smooth, while they have different widths (11.3 mm for 1-A, 9.6 mm for 1-B) and similar reinforcements (3.6 mm for 1-A, 3.8 mm for 1-B) as given in Table 4. The HAZ area in 1-B is 18.2 mm², smaller than that in 1-A (20.0 mm²). The ratio (0.93) of these two HAZ areas is very close to the ratio (0.91) of the heat inputs in 1-A and 1-B. This suggests that the proposed HAZ area is a good measurement of the heat input. More importantly, Consumable DE-GMAW can have the same deposition rate and produce a smaller HAZ area.
rent in 1-A (345 A), thus the digging action from the base metal current in 1-B was much smaller than that in 1-A. In Consumable DE-GMAW, the bypass current may also have a small digging action, but the heat from the bypass droplets will definitely melt more metal to broaden and deepen the weld pool. As a result, the penetration depth (2.3 mm) in 1-B is smaller than that in 1-A (3.7 mm), and the bottom of the weld pool in 1-B is flatter than that in 1-A.

Figure 6 shows the cross-sectional area of the specimens 2-A and 2-B. Experiment 2-A was performed using traditional GMAW with a welding voltage of 36 V, and the obtained weld bead is illustrated in Fig. 7. The base metal current in 2-A was about 422 A when the wire was fed at a speed of 17.78 m/min (700 in./min). In experiment 2-B, the main wire feed speed was about 17.78 m/min (700 in./min) and the total wire feed speed (WFS1 + WFS2) about 29.21 m/min (1150 in./min) when the process was stable. The total melting current was 413 A, close to the total melting current of 422 A in 2-A. The increase in welding productivity is obvious. Although the base metal current in 2-B was only about 200 A, the heat input in 2-A and 2-B was approximately the same (27.35 kJ/in. for 2-A, 27.91 kJ/in. for 2-B) considering the heat transferred from the bypass droplets. But the stronger digging action from a larger base metal current in 2-A resulted in a deeper penetration (5.9 mm for 2-A, 4.7 mm for 2-B). As it has been observed in Nonconsumable DE-GMAW (Ref. 11), the weld bead in consumable DE-GMAW also tends to be narrow. In Experiment 2-B, even though the heat input was almost the same as 2-A, the weld bead in 2-B (11.5 mm) is narrower than that in 2-A (13.3 mm). But the HAZ area in 2-A at 24.0 mm² is smaller than the HAZ area (24.6 mm²) in 2-B. The ratio of the heat inputs in 2-A and 2-B is 1.02, which is roughly equal to the ratio (1.03) of the corresponding HAZ areas. Therefore, the HAZ area can truly reflect the heat input.

It should be pointed out that the weld beads in the above experiments are not symmetrical because the welding gun plane formed by the two guns was not perpendicular to the workpiece. As shown in Fig. 6B, a small subpenetration is observed. This is likely because the trajectory of the bypass droplets was not on the longitudinal axis of the weld bead and the heat transferred from the bypass droplets changed the shape of the weld pool.

**Indentation Test in the HAZ**

During welding, the base metal in the HAZ experiences a heating-cooling cycle with nonuniform heating away from the weld joint. This leads to the variation of microstructure and creates thermal residual stresses over the HAZ. It is expected that the material in the HAZ will have different mechanical behavior from the base metal and the weld metal.

To evaluate the deformation behavior of the material over the HAZ, microindentation tests were performed on a Micro-Combi tester (CSM Instruments), using a Vickers indenter and an indentation load of 1000 mN. The specimens were polished with γ-alumina powders and etched with 2% Nital (nitric and hydrochloric) solutions. A marker line was drawn from the center of the weld bead toward and passing the HAZ. The indentation hardness was measured on each point every 150 nm on the marker line. For each specimen, about 40 points were tested and measured. In each point, the Vickers tester increased the load slowly up to 1000 mN. Then the load was slowly decreased. Both the loading rate and the unloading rate were 2000 mN/min. During the loading-unloading course, the indentation depth was measured and recorded as shown in Fig. 8, where the three indentation loading-unloading curves represent the typical data from base metal, HAZ, and weld metal. The Vickers hardness is calculated as

\[
H = 1.854 \frac{F}{D_1 D_2}
\]

where \( F \) is the indentation load, and \( D_1 \) and \( D_2 \) are the diagonals of the impression mark. The indentation hardness is in the

---

**Table 4 — Macro Measurements of Bead-on-Plate Welds**

<table>
<thead>
<tr>
<th>No.</th>
<th>Heat Input (kJ/in.)</th>
<th>Filler Metal (mm²)</th>
<th>Fused Metal (mm²)</th>
<th>HAZ Area (mm²)</th>
<th>Width (mm)</th>
<th>Penetration Depth (mm)</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A</td>
<td>23.36</td>
<td>20.7</td>
<td>21.0</td>
<td>20.0</td>
<td>11.3</td>
<td>3.7</td>
<td>3.6</td>
</tr>
<tr>
<td>1-B</td>
<td>20.77</td>
<td>21.3</td>
<td>10.8</td>
<td>18.2</td>
<td>9.6</td>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td>2-A</td>
<td>27.35</td>
<td>26.7</td>
<td>34.9</td>
<td>24.0</td>
<td>13.3</td>
<td>5.9</td>
<td>4.0</td>
</tr>
<tr>
<td>2-B</td>
<td>27.91</td>
<td>43.9</td>
<td>26.7</td>
<td>24.6</td>
<td>11.5</td>
<td>4.7</td>
<td>5.5</td>
</tr>
</tbody>
</table>

---

**Table 5 — Vickers Hardness**

<table>
<thead>
<tr>
<th>No.</th>
<th>Weld Metal (HV)</th>
<th>HAZ (HV)</th>
<th>Base Metal (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A</td>
<td>261.06</td>
<td>368.6</td>
<td>249.32</td>
</tr>
<tr>
<td>1-B</td>
<td>256.27</td>
<td>410.2</td>
<td>254.00</td>
</tr>
<tr>
<td>2-A</td>
<td>256.24</td>
<td>334.8</td>
<td>247.19</td>
</tr>
<tr>
<td>2-B</td>
<td>248.60</td>
<td>339.1</td>
<td>267.55</td>
</tr>
</tbody>
</table>
unit of HV when the indentation load is in the unit of kg force and the diagonals $D_1$ and $D_2$ are in the unit of mm. One HV is equal to 9.8 MPa. Figure 9 shows the indentation hardness of the four specimens (1-A, 1-B, 2-A, and 2-B) across the HAZ, and Table 5 lists the mean indentation hardness of the weld metal, the HAZ, and the base metal.

In all four specimens, the base metal has the indentation hardness of about 250 HV, roughly the same as the weld metal, while the material in the HAZ has higher indentation hardness than both the base metal and the weld metal. It’s likely that the relatively low heat inputs caused a faster cooling rate resulting in the propensity to form untempered martensite (maybe some other lower temperature transformation products) and their concomitant. The increase in untempered martensite would also increase the hardness. The hardness increase is also likely due to the residual stresses created over the HAZ in the solidification process, since the indentation hardness increases with the increase in the residual stress (Ref. 12). The thermal gradient at the solidification front introduced local thermal stresses, which altered local mechanical response.

It is known that the evolution of thermal stresses depends on the cooling rate, which is controlled by the heat input. Fast cooling rate will create high residual stresses in the HAZ, which results in high indentation hardness (Refs. 13–17). As discussed in the previous section, the heat input to the specimen 1-B was the smallest. The specimen 1-B experienced the fastest cooling rate. This is consistent with the highest indentation hardness in the HAZ of the specimen 1-B. Comparing the indentation hardness in the HAZ of the specimen 1-A to the specimen 2-A, one can conclude that the heat input to specimen 2-A is larger than to the specimen in 1-A. In general, the less the heat input is, the higher is the indentation hardness. And the indentation hardness provides a useful approach to qualitatively evaluate the relative heat input during the welding process. The change in the hardness can also be verified by the microstates. Figure 10 demonstrates the HAZ microstructures of the four specimens. It can be seen that the grains in the HAZ of 1-A are much larger than those in 1-B where the heat input was lower. It is also true that specimens 2-A and 2-B have almost the same grain size. Hence, the microstructure supports the findings in microhardness.

The plastic energy is the energy dissipated in the indentation tests. Table 6 shows the plastic energy dissipated in the indentation tests for the four specimens.

<table>
<thead>
<tr>
<th>No.</th>
<th>Weld Metal (uJ)</th>
<th>HAZ (uJ)</th>
<th>Base Metal (uJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A</td>
<td>1.47</td>
<td>1.21</td>
<td>1.41</td>
</tr>
<tr>
<td>1-B</td>
<td>1.58</td>
<td>1.22</td>
<td>1.50</td>
</tr>
<tr>
<td>2-A</td>
<td>1.45</td>
<td>1.34</td>
<td>1.48</td>
</tr>
<tr>
<td>2-B</td>
<td>1.69</td>
<td>1.48</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Fig. 10 — Microstructures in HAZ. A — experiment 1-A, GMAW; B — experiment 1-B, DE-GMAW; C — experiment 2-A, GMAW; D) experiment 2-B, DE-GMAW.
pated during a loading-unloading cycle. It can be calculated from the area under the indentation curve shown in Fig. 8 as (Refs. 12, 18)

\[ E_{\text{plastic}} = \int_0^{\delta_{\text{max}}} F d\delta - \int_0^{\delta_{\text{r}}} F d\delta \]

(1)

where \( \delta_{\text{max}} \) is the maximum indentation depth at the maximum indentation load and \( \delta_r \) is the residual indentation depth after totally removing the load. The first term on the right side of Equation 5 represents the total energy input to the material and the second term is the elastic recovery energy during an indentation. The plastic energy is equal to the area enclosed in the indentations over the HAZ, and Table 6 lists the average energy dissipation in the base metal, the HAZ, and the weld metal. Less energy was dissipated in the HAZ, suggesting that less plastic deformation occurred during the indentation. This is consistent with the high indentation hardness in the HAZ. Under the same indentation load, the residual stresses in the HAZ caused the increase in the resistance to the indentation deformation. The specimens of 1-A and 1-B have the least energy dissipation due to the highest residual stresses created during the solidification.

Multipass Welding

The GMAW has a high deposition rate in comparison with other welding methods. It still requires multipass welding to avoid the overheating to the base metal for thick-plate applications. From the above discussion, it can be seen that the Consumable DE-GMAW process has the ability to deposit more metal without increasing the heat input. Thus it is possible for the Consumable DE-GMAW to fill the same groove with less passes without deteriorating the mechanical properties.

Figure 12 shows the cross section of a workpiece welded by the traditional GMAW process (experiment 3-A). In this experiment, the wire feed speed was 16.51 m/min (650 in./min) and the welding current was about 365 A. To fill up the groove, a total of 13 passes were required in 3-A. However, when the Consumable DE-GMAW process was used in 3-B as shown in Fig. 13, only seven passes were needed to fill the same groove because of the extra deposition from the bypass wire. As a result, the DE-GMAW process can significantly improve welding productivity.

In experiment 3-B, the base metal current was controlled at 180 A in each pass, but the heat input in 3-B was larger than that in 3-A considering the heat input from the bypass droplets. Due to the higher deposition rate, the weld bead in each pass in 3-B was larger than that in 3-A. The columnar grains formed in the former pass were not totally destroyed as can be seen in Fig. 13. From Fig. 12, the column grains are only observed in the last two passes because the column grains created in other passes were refined as the heat from each pass tempered the weld metal below it. Such a refinement may improve the mechanical behavior of the weld bead.

Conclusions

Experiments on high-strength steel ASTM A514 plates verified the following:

- Consumable DE-GMAW can achieve the same deposition rate with a reduced heat input as conventional GMAW. It can also increase the deposition rate without in-
creasing the heat input.

- For the high-strength steel ASTM A514, Consumable DE-GMAW is able to reduce HAZ size and penetration depth without decreasing the welding productivity even though the indentation hardness in the HAZ is increased. Consumable DE-GMAW can also increase the welding productivity and reduce the penetration depth without significantly affecting the HAZ size and the indentation hardness.

- Consumable DE-GMAW can be used in thick ASTM 514 plate welding to significantly reduce the number of passes with slightly higher heat input.

- The HAZ area in the cross section was proposed to denote the HAZ size. It is shown that the HAZ area is proportional to the heat input both in conventional GMAW and Consumable DE-GMAW.

Acknowledgment

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References


Nominees Solicited for Prof. Koichi Masubuchi Award

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

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

Submit your nominations to Prof. John DuPont at jad@lehigh.edu.
ABSTRACT. The use of high-strength steels (HSS) provides several potential advantages. However, the progress in steel technology continually demands new developments in welding processes and consumables to produce weld metals with mechanical properties equivalent to the base metal. To achieve this, however, a better understanding of chemistry and microstructure-property relationships in HSS weld metals is needed. In this study, the general compositional and microstructural characteristics of HSS weld metals, including nonmetallic inclusions, were experimentally characterized. The weld metals were deposited using different welding processes and commercially available welding consumables with nominal strengths ranging from 490 to 840 MPa (70 to 120 ksi).

Introduction

The use of high-strength steels (HSS) provides several potential advantages including lower weight, lower manufacturing costs, and ease of handling and transport. Therefore, major impetus for developments in high-strength steels has been provided by the need for higher strength, increased toughness, and improved weldability. The development of HSS with better properties has been supported by improvements in the steelmaking industry for production of clean steels, the use of microalloying elements in combination with normalizing, controlled rolling or quenching, and tempering. Since 1982, the control of the steel properties through thermomechanical processing (TMCP) and accelerated cooling (AC) and/or direct quenching (DQ) have enabled steels to be produced with increased strength and toughness, while maintaining good weldability (Ref. 1).

HSSs with yield strengths of 450 MPa (X70) and 550 MPa (X80) are increasingly specified for use in different structural applications, resulting in weight and cost savings through the use of thinner sections. The use of X80 pipeline steels has become common in Canada (Ref. 2) and parts of Europe (Ref. 3). Additional refinement of chemical composition and processing procedures resulted in the development of higher-strength X100 steel in the early and mid-1990s (Ref. 4). Laboratory- and full-scale testing of X100 pipe and seam welds have recently been reported (Ref. 5). These studies suggest that with some refinement of the steelmaking procedures, target X100 properties can be achieved, and successful results of experimental work on X120 have been reported.

The progress in steel manufacturing technology has continually called for new developments in welding processes and consumables to produce weld metal deposits with mechanical properties essentially equivalent to the base metal. To achieve this, however, proper control of numerous factors that interact during welding to produce a weld metal with a certain chemical composition and a particular microstructure with characteristic properties is required. Additionally, it has been established that some high-strength weld metals exhibit a high degree of variability in mechanical property test results. The variability of the properties of a weld metal could come from various sources such as consumable lot-to-lot variation, procedural variation, positional variation, and base material variation. Sometimes chemical composition variations may explain the differences, but in many cases, they do not. It is clear that a better understanding of chemistry and microstructure-property relationships in HSS weld metals is needed.

The main objective of this study was to experimentally characterize the general compositional and microstructural characteristics of HSS weld metals, including nonmetallic inclusions. In an attempt to cover a broad range of applications normally found in different industries, the weld metals were deposited using different welding processes and commercially available welding consumables with nominal tensile strengths ranging from 490 to 840 MPa (70 to 120 ksi). Applications for these welding consumables would include welding of API 5L pipeline steels such as X70, X80, and X100, as well as plate steels and structural shapes of similar strength levels.

Experimental Procedures

The characterization of the weld metals deposited with different welding processes and consumables included chemical composition, microstructural analysis, and evaluation of nonmetallic inclusions. Details regarding the materials and experimental procedures are summarized as follows.

Base Metals

Different materials ranging from low-strength A-36 steel plates to high-strength X80 pipe steels and X100 steel plates were used as base materials for this study, as
listed in Table 1. In most of the cases, the thickness of the base material was about 20 mm (0.75 in.). The base materials were cut into 152-×-711-mm (6-×-28-in.) sections to accommodate the various test welds and experimental specimens. The base materials were joined by the welding processes described below. Figure 1 shows a general view of a welded joint prepared for weld metal characterization in this study.

**Welding Procedures and Consumables**

In an attempt to cover a broad range of applications normally found in different industries, different welding processes and commercially available consumables were used in this program. Welds were produced using flux-shielded processes such as flux cored arc welding (FCAW) and shielded metal arc welding (SMAW) and gas-shielded processes such as gas metal arc welding (GMAW). FCA welding included both self-(T-8 Type) and gas shielded electrodes. Cellulosic and basic electrodes were used with the SMAW process. The nominal strength of the weld deposits ranged from 490 to 840 MPa (70 to 120 ksi). Table 1 provides a summary of the consumables, welding processes, and weld identifications (W1 to W14) used in this study. Welding parameters are summarized in Table 2.

**Weld Metal Chemical Analysis**

Samples for chemical analysis were taken from the reduced area of tensile specimens. Chemical analysis of the experimental welds was conducted using an optical emission spectrometer. LECO equipment was used to measure carbon, sulfur, oxygen, and nitrogen.

**Weld Metal Microstructural Characterization**

Microstructural analysis was conducted using light microscopy, conventional scanning electron microscopy (SEM), and high-resolution SEM. Due to the important role played by the inclusions on the microstructure development and the resulting mechanical properties of the steel weld deposits, particular attention was given to the inclusion characteristics, including volume fraction, size distribution, morphology, and chemical composition. Carbon replica extraction techniques were used for the chemical composition and morphology analysis of the inclusions. Cross sections were cut from each weld and prepared using standard metallo-
graphic techniques. For replica extraction, samples were prepared by grinding through 800-grit abrasive paper and then polishing using 6-, 3-, and 1-μm diamond paste. Final polishing of samples for light microscopy and SEM samples was done with 1- and 0.05-μm chromium oxide slurry. In this way, alumina contamination of the samples was avoided.

The weld metal microstructure was revealed by etching in a 2% Nital solution. Etching for replica extraction was done with a 5% Nital reagent. A light etching was used in order to expose the inclusions on the surface and permit their extraction. In order to avoid inclusion dissolution or damage during polishing and prior to replica extraction, ethyl alcohol was used at all times for diamond paste dispersion and sample cleaning. For the same reason, long ultrasonic cleaning times were avoided.

The samples prepared for inclusion size and size distribution measurements on the SEM were in the as-polished (unetched) condition. A minimum of 20 backscattered electron images from the as-polished samples, similar to the one shown in Fig. 2, were recorded on the SEM and analyzed to measure the inclusion size distribution. The backscattering electron images were obtained from the central region of the weld fusion zone at random locations in the through-thickness direction. SEM analysis was performed on a high-resolution field emission microscope coupled with XEDS for chemical analysis. The image analysis of the SEM images was performed with Image-Pro software.

Results and Discussions

Chemical Composition Analysis

The chemical compositions of the weld metals deposited with electrodes of E70X-E80X (W1 to W5), E90X (W6 to W8), and E100X-E120X (W9 to W14) nominal tensile strength are listed in Tables 3, 4, and 5, respectively. In general, the deposited HSS weld metals are based on a C-Mn system with additions of deoxidizers (silicon, manganese, aluminum, titanium) and balanced additions of various alloying elements (nickel, chromium, molybdenum, boron, niobium, vanadium, copper).

The chemical composition of weld metals is controlled by chemical reactions occurring in the weld pool at elevated temperatures, and is therefore influenced by the welding consumables (i.e., combination of filler metal, flux, and/or shielding gas), the base metal chemistry, as well as the welding conditions applied. Even small changes in the flux coating can result in large variations in the metallurgical behavior of the flux system (Ref. 6).

As expected, the level of alloying content in the weld metal increases as the nominal strength of the consumables increases. Alloying elements strengthen the weld metal through solid solution or precipitation strengthening. Alloying elements also affect the hardenability of the weld metal and play a significant role in defining the final weld metal microstructure. The effect of alloying levels on the hardenability of the weld metal is reflected in the carbon-equivalent numbers (CEIW and Pcm). The carbon equivalent of weld metals deposited with E70X-E80X, E90X, and E100X-E120X grade consumables range from 0.25 to 0.35, 0.31 to 0.54, and 0.47 to 0.73, respectively, as listed in Tables 3-5.

The carbon content of most of the deposited weld metals ranged from 0.05 to 0.1%. There were major differences in carbon content ranges among welds deposited with different welding processes or groups of welding consumables.

The welding process selected to join HSSs greatly influences the level of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals. Table 6 shows a summary of the different levels of oxygen and nitrogen in the weld metals.
decreases to about 860 ppm at 1500°C in delta iron. Most of the alloying elements present in liquid steel reduce oxygen solubility through deoxidation equilibrium. Steelmaking processes typically yield analytical oxygen levels in the range of 70 to 100 ppm. Welds typically pick up oxygen to levels of several hundred ppm, then deoxidize to lower oxygen levels with the formation of oxide inclusions.

The oxygen levels of weld metals are influenced by many factors such as the amount of deoxidizers present (silicon, manganese, aluminum, etc.), the types of welding materials used, the welding process (Refs. 9, 10), and the welding conditions. Weld metal deposited with flux-shielded processes or with active gas-shielded processes generally contains more oxygen than welds deposited with inert gas-shielded processes. The oxygen levels of weld metals deposited with SMAW, FCAW (gas shielded), and GMAW with 100% CO₂ ranged from 450 to 650 ppm. On the other hand, welding with the GTA process shielded with Ar-CO₂ mixtures resulted in an oxygen content range of 260 to 360 ppm in the weld metals. The oxygen level of weld metals deposited with self-shielded FCAW was 110 ppm.

Flux-shielded metal arc weld metals generally contain more nitrogen than those made with gas-shielded welding processes. The nitrogen content in weld metals deposited with flux-shielded processes ranged from 70 to 370 ppm. The weld metal with the highest nitrogen content corresponds to that deposited with the self-shielded flux-cored wire. Weld metals deposited with the GMA process contained nitrogen levels from 30 to 140 ppm. In general, a consumable/process could be classified as low, medium, or high nitrogen if the amount of nitrogen in the metal weld deposit is less than 70 ppm, between 70 to 120 ppm, or greater than 120 ppm, respectively (Refs. 11, 12).

Microstructure Characterization

In general, two major trends were observed in the change of the microstructure of the weld metal as the carbon equivalent increased. The fraction of low-temperature products increased and the microstructure became finer as the carbon equivalent increased.

Lean steel weld metals exhibit low hardenability, and the hardenability increases with alloy content. Weld metals lean in alloy content would be expected to transform at relatively high temperatures to produce a microstructure often consisting of ferrite and carbides having low strength. An increase in the amount of alloying elements, particularly the carbide formers, lowers the transformation temperature, and forms a bainitic structure having a smaller mean free-path in the ferrite. As additional quantities of alloying elements are introduced, further lowering of the transformation temperature occurs, producing a finer bainitic structure and a stronger weld metal. Finally, if the alloy content is increased to a point where martensite forms, the strength reaches a level primarily dictated by the carbon content in the weld metal.

The as-deposited weld metals with a carbon equivalent between 0.26 (W2) and 0.39 (W7) consist mainly of a ferritic microstructure with a decreasing fraction of grain boundary ferrite and an increasing fraction of lower temperature transforma-

<table>
<thead>
<tr>
<th>Welded Joint</th>
<th>Welding Consumable Root Pass</th>
<th>Welding Consumable Fill Pass</th>
<th>Preheat/Interpass Temperature, °C</th>
<th>Nominal Heat Input, kJ/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>E71T-1(a)</td>
<td>E71T-1(a)</td>
<td>RT/150</td>
<td>1.8 to 2.0</td>
</tr>
<tr>
<td>W2</td>
<td>E71T-1</td>
<td>E71T-1</td>
<td>RT/150</td>
<td>1.8 to 2.0</td>
</tr>
<tr>
<td>W3</td>
<td>ER70S-7</td>
<td>ER70S-7</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>W4</td>
<td>ER70S-6</td>
<td>ER70S-6</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>W5</td>
<td>E8010-G</td>
<td>E8010-G</td>
<td>RT/120</td>
<td>1.3</td>
</tr>
<tr>
<td>W6</td>
<td>E9010-G</td>
<td>E9010-G</td>
<td>RT/120</td>
<td>1.5</td>
</tr>
<tr>
<td>W7</td>
<td>ER70S-6, STT(b)</td>
<td>ER70S-6, STT(b)</td>
<td>RT/120</td>
<td>1.3</td>
</tr>
<tr>
<td>W8A(c)</td>
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<td>ER70S-6, STT(b)</td>
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<tr>
<td>W8B(d)</td>
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<td>ER70S-6, STT(b)</td>
<td>RT/120</td>
<td>1.2</td>
</tr>
<tr>
<td>W8C(e)</td>
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<td>W8D(f)</td>
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</tr>
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<td>ER100S-1</td>
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<td>50/150</td>
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<tr>
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<td>ER100S-1</td>
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<td>50/150</td>
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<tr>
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<td>ER100S-1</td>
<td>50/150</td>
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<td>W12</td>
<td>ER100S-1</td>
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<td>50/150</td>
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<tr>
<td>W13</td>
<td>ER120S-1</td>
<td>ER120S-1</td>
<td>50/150</td>
<td>0.85</td>
</tr>
</tbody>
</table>

(a) Microalloyed; (b) surface tension transfer®; (c) welder A; (d) welder B; (e) low interpass temperature (cold); (f) high interpass temperature (hot).
tion products such as sideplate ferrite and acicular ferrite. In the microstructure of weld metal W2 a high fraction of grain boundary ferrite was present, as shown in Fig. 3A. Increasing the carbon equivalent to 0.31 (W6) resulted in a microstructure consisting predominantly of sideplate ferrite with aligned second phases as shown in Fig. 3B. In the microstructure of the as-deposited weld metal W7 (CE_{IIW} = 0.39) a high fraction of acicular ferrite is present, as shown in Fig. 3C.

In general, the reheated region of these welds transformed to equiaxed polygonal ferrite as shown in Fig. 4. In the reheated zones of weld metal W5 and W6, a high fraction of second-phase precipitates that could be pearlite and/or carbide aggregates was present. This observation may be explained based on the high level of carbon present in these weld metals and on the segregation of carbon out of the ferrite grain during the retransformation induced during cooling of the weld metal. The carbon content of weld metal W5 and W6 was 0.1 and 0.15%, respectively. These observations clearly indicate that the influence of thermal cycles resulting from subsequent passes can cause significant changes in weld metal microstructure and resulting properties.

Acicular ferrite is the weld metal constituent that has been reported to best promote toughness in HSLA steels with around 600-MPa (85-ksi) yield strength or less because of its small grain size (typically 1 to 3 μm) and because of the random orientation of the ferrite laths and their ability to deflect cracks during propagation (Ref. 13). As such, a large amount of acicular ferrite optimizes the weld metal mechanical properties.

Hardenability of these steel weld metals is such that welds with a mainly bainitic and/or martensitic microstructure usually can be avoided, and the major problem becomes one of preventing the formation of grain boundary ferrite, while refining the acicular ferrite as much as possible.

Factors that affect the amount of grain boundary ferrite, such as specific microalloying additions like boron and titanium and the prior austenite grain size are important considerations (Ref. 14). Likewise, factors that directly affect the acicular ferrite transformation such as inclusion composition, inclusion size, and crystallographic or thermal disregistry between the inclusion and the austenite matrix become of crucial concern. The literature is not in agreement on the effect of specific types of inclusions on the austenite to ferrite phase transformation. However, the effectiveness of an inclusion in nucleating ferrite may not depend on its bulk composition, but on its surface composition and character (Ref. 15).

In weld metals with a carbon equivalent of 0.47 or higher (W8 to W14), an increasing fraction of lower transformation products, including martensite, were observed as shown in Fig. 5A. Additionally, it was observed that weld metals with higher alloying additions do not readily retransform during reheating induced during multipass welding. As shown in Fig. 5B, the microstructure

<p>| Table 3 — All Weld Metal Chemical Composition (wt-%) of E7X-E8X Weld Metals |</p>
<table>
<thead>
<tr>
<th>Element</th>
<th>W1 E71T-1(a)</th>
<th>W2 E71T-1</th>
<th>Welded Joint</th>
<th>W3 ER70S-7</th>
<th>W4 ER70S-6</th>
<th>W5 E8010-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.054</td>
<td>0.021</td>
<td>0.066</td>
<td>0.056</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>1.35</td>
<td>1.31</td>
<td>1.41</td>
<td>1.35</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.009</td>
<td>0.008</td>
<td>0.012</td>
<td>0.011</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.009</td>
<td>0.012</td>
<td>0.005</td>
<td>0.004</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>0.42</td>
<td>0.40</td>
<td>0.36</td>
<td>0.5</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.07</td>
<td>0.05</td>
<td>0.22</td>
<td>0.18</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.40</td>
<td>0.01</td>
<td>0.06</td>
<td>0.04</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>0.01</td>
<td>0.01</td>
<td>0.12</td>
<td>0.06</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.02</td>
<td>0.02</td>
<td>0.005</td>
<td>&lt;0.005</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>&lt;0.006</td>
<td></td>
</tr>
<tr>
<td>Nb</td>
<td>0.010</td>
<td>0.010</td>
<td>0.03</td>
<td>0.02</td>
<td>&lt;0.006</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>0.0520</td>
<td>—</td>
<td>0.046</td>
<td>0.046</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.0073</td>
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<td>0.003</td>
<td>0.008</td>
<td>0.021</td>
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</tr>
<tr>
<td>B</td>
<td>0.0053</td>
<td>0.0048</td>
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<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Zr</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>W</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>CE_{IIW}</td>
<td>0.326</td>
<td>0.257</td>
<td>0.353</td>
<td>0.319</td>
<td>0.268</td>
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</tr>
<tr>
<td>Pcm</td>
<td>0.177</td>
<td>0.131</td>
<td>0.172</td>
<td>0.157</td>
<td>0.151</td>
<td></td>
</tr>
</tbody>
</table>

(a) Microalloyed.
of the reheated weld metal is very similar to the microstructure of the as-deposited weld metal. The kinetics of grain boundary mobility may be significantly retarded in highly alloyed weld metal by substitutional alloy elements. Additionally, the high hardenability of these weld metals decreases the role of grain boundaries as nucleation sites of phase transformation during cooling.

Therefore, although the carbon equivalents were originally developed with the goal of evaluating the base metal cold cracking susceptibility, these empirical equations can also be useful for clarifying the complex relationship between the weld metal content of hardenability elements and the resulting transformation behavior of the deposit. However, there is the need to modify the carbon-equivalent equations by including the role of weld metal oxygen and the influence of welding parameters such that they become more effective in predicting weld metal properties (Ref. 16). More recent efforts in heat-affected zone (HAZ) studies have developed weldability expressions that include cooling rate (Ref. 13).

Nonmetallic Inclusion Characterization

Quantitative data obtained from measurements of inclusions in different weld metals, including average inclusion size, maximum inclusion size, inclusion density, and volume fraction are listed in Table 7.

Table 4 — All Weld Metal Chemical Composition (wt-%) of E9X Weld Metals

<table>
<thead>
<tr>
<th>Element</th>
<th>W6 E9010-G</th>
<th>W7 E9018-G</th>
<th>Welded Joint</th>
<th>W8 A E91T8-G</th>
<th>W9 C E91T8-G</th>
<th>W10 E91T8-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.154</td>
<td>0.06</td>
<td>0.071</td>
<td>0.084</td>
<td>0.074</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.73</td>
<td>1.55</td>
<td>2.07</td>
<td>2.30</td>
<td>2.18</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.017</td>
<td>0.017</td>
<td>0.010</td>
<td>0.009</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.013</td>
<td>0.006</td>
<td>0.007</td>
<td>0.008</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>0.17</td>
<td>0.47</td>
<td>0.25</td>
<td>0.29</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.023</td>
<td>0.126</td>
<td>0.06</td>
<td>0.043</td>
<td>0.062</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.69</td>
<td>0.72</td>
<td>0.69</td>
<td>0.86</td>
<td>0.75</td>
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</tr>
<tr>
<td>Cr</td>
<td>0.06</td>
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<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>0.06</td>
<td>0.02</td>
<td>0.06</td>
<td>0.02</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.78</td>
<td>1.02</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>&lt;0.012</td>
<td>0.008</td>
<td>0.006</td>
<td>0.006</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Nb</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>0.050</td>
<td>0.046</td>
<td>0.011</td>
<td>0.011</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.011</td>
<td>0.012</td>
<td>0.037</td>
<td>0.0323</td>
<td>0.0323</td>
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</tr>
<tr>
<td>B</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Zr</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>0.072</td>
<td>0.11</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>CE(IIW)</td>
<td>0.310</td>
<td>0.390</td>
<td>0.482</td>
<td>0.537</td>
<td>0.509</td>
<td></td>
</tr>
<tr>
<td>Pcm</td>
<td>0.200</td>
<td>0.156</td>
<td>0.203</td>
<td>0.228</td>
<td>0.215</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 — All Weld Metal Chemical Composition (wt-%) of ER100S-ER120S Weld Metals

<table>
<thead>
<tr>
<th>Element</th>
<th>W9 ER100S-1</th>
<th>W10 ER100S-1</th>
<th>Welded Joint</th>
<th>W11 ER100S-1</th>
<th>W12 ER100S-1</th>
<th>W13 ER120S-1</th>
<th>W14 ER120S-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.068</td>
<td>0.061</td>
<td>0.068</td>
<td>0.055</td>
<td>0.11</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>1.45</td>
<td>1.46</td>
<td>1.25</td>
<td>1.50</td>
<td>1.51</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.008</td>
<td>0.007</td>
<td>0.008</td>
<td>0.009</td>
<td>0.014</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.004</td>
<td>0.003</td>
<td>0.006</td>
<td>0.003</td>
<td>0.010</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>0.250</td>
<td>0.250</td>
<td>0.250</td>
<td>0.370</td>
<td>0.59</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.100</td>
<td>0.070</td>
<td>0.090</td>
<td>0.120</td>
<td>0.11</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>1.43</td>
<td>1.74</td>
<td>1.64</td>
<td>1.75</td>
<td>1.82</td>
<td>2.29</td>
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<tr>
<td>Cr</td>
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<td>0.09</td>
<td>0.09</td>
<td>0.040</td>
<td>0.34</td>
<td>0.41</td>
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<tr>
<td>Mo</td>
<td>0.33</td>
<td>0.33</td>
<td>0.31</td>
<td>0.420</td>
<td>0.45</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>0.01</td>
<td>0.01</td>
<td>&lt;0.010</td>
<td>0.020</td>
<td>0.01</td>
<td>&lt;0.010</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.01</td>
<td>0.009</td>
<td>0.010</td>
<td>0.010</td>
<td>0.01</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0.01</td>
<td>0.01</td>
<td>0.008</td>
<td>0.020</td>
<td>0.02</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>Nb</td>
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<td>0.007</td>
<td>0.010</td>
<td>0.008</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>O</td>
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<td>0.045</td>
<td>0.028</td>
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</tr>
<tr>
<td>N</td>
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<td>0.008</td>
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<td>0.004</td>
<td>0.006</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td></td>
</tr>
<tr>
<td>Zr</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>CE(IIW)</td>
<td>0.310</td>
<td>0.390</td>
<td>0.482</td>
<td>0.537</td>
<td>0.509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pcm</td>
<td>0.220</td>
<td>0.156</td>
<td>0.203</td>
<td>0.228</td>
<td>0.215</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 — Oxygen and Nitrogen Levels in Weld Metals Deposited with Different Welding Processes and Consumables

<table>
<thead>
<tr>
<th>Process</th>
<th>Consumables</th>
<th>Oxygen (ppm)</th>
<th>Nitrogen (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCAW</td>
<td>E70X, rutile, 100% CO2</td>
<td>520</td>
<td>70</td>
</tr>
<tr>
<td>FCAW</td>
<td>E90X, self shielded</td>
<td>110</td>
<td>370</td>
</tr>
<tr>
<td>SMAW</td>
<td>E80X, cellustic</td>
<td>650</td>
<td>210</td>
</tr>
<tr>
<td>SMAW</td>
<td>E90X, cellustic</td>
<td>500</td>
<td>110</td>
</tr>
<tr>
<td>SMAW</td>
<td>E90X, basic</td>
<td>460</td>
<td>120</td>
</tr>
<tr>
<td>GMAW</td>
<td>E70X, 100% CO2</td>
<td>460</td>
<td>30–80</td>
</tr>
<tr>
<td>GMAW</td>
<td>E100X, 100% CO2</td>
<td>560</td>
<td>70</td>
</tr>
<tr>
<td>GMAW</td>
<td>E120X, 100% CO2</td>
<td>450</td>
<td>60</td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E100X, 85Ar-15CO2</td>
<td>310 to 80 to 140</td>
<td></td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E120X, 85Ar-15CO2</td>
<td>280</td>
<td>90</td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E100X, 95Ar-5CO2</td>
<td>260</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 7 — Oxygen and Nitrogen Levels in Weld Metals Deposited with Different Welding Processes and Consumables

<table>
<thead>
<tr>
<th>Process</th>
<th>Consumables</th>
<th>Oxygen (ppm)</th>
<th>Nitrogen (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCAW</td>
<td>E70X, rutile, 100% CO2</td>
<td>520</td>
<td>70</td>
</tr>
<tr>
<td>FCAW</td>
<td>E90X, self shielded</td>
<td>110</td>
<td>370</td>
</tr>
<tr>
<td>SMAW</td>
<td>E80X, cellustic</td>
<td>650</td>
<td>210</td>
</tr>
<tr>
<td>SMAW</td>
<td>E90X, cellustic</td>
<td>500</td>
<td>110</td>
</tr>
<tr>
<td>SMAW</td>
<td>E90X, basic</td>
<td>460</td>
<td>120</td>
</tr>
<tr>
<td>GMAW</td>
<td>E70X, 100% CO2</td>
<td>460</td>
<td>30–80</td>
</tr>
<tr>
<td>GMAW</td>
<td>E100X, 100% CO2</td>
<td>560</td>
<td>70</td>
</tr>
<tr>
<td>GMAW</td>
<td>E120X, 100% CO2</td>
<td>450</td>
<td>60</td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E100X, 85Ar-15CO2</td>
<td>310 to 80 to 140</td>
<td></td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E120X, 85Ar-15CO2</td>
<td>280</td>
<td>90</td>
</tr>
<tr>
<td>P-GMAW</td>
<td>E100X, 95Ar-5CO2</td>
<td>260</td>
<td>40</td>
</tr>
</tbody>
</table>
metals. In general, the volume fraction of inclusions increases with an increase in oxygen plus sulfur content in the weld metal. However, the opposite trend was observed in the volume of nonmetallic inclusions with sulfur plus oxygen levels higher than 500 to 600 ppm. The inclusion density does not show a clear trend with oxygen plus sulfur levels in the weld metal of up to 550 ppm. However, the inclusion density decreases with increasing oxygen plus sulfur levels above 550 to 600 ppm. The inclusion density observed in the welds ranges from $1.2 \times 10^8$ to $5.4 \times 10^8$ particles per mm$^3$.

**Size Distribution**

From the data listed in Table 7, it may be seen that the average inclusion diameter ranged from 0.3 to 0.6 μm and maximum inclusion diameter from 0.9 to 1.7 μm in the deposited weld metals. Examples of measured inclusion histograms are presented in Fig. 7A and 7B. The histograms shown in Fig. 7A and 7B correspond to the nonmetallic inclusion population observed in welds W5 and W7, respectively. In weld W5, the average inclusion size, the maximum inclusion size, and the inclusion density were 0.49 μm, 1.48 μm, and $1.94 \times 10^8$ particles/mm$^3$, respectively. On the other hand, in weld W7, an average inclusion diameter, a maximum inclusion diameter, and an inclusion density equal to 0.31 μm, 0.95 μm, and $4.55 \times 10^8$ particles per mm$^3$, respectively, were observed.

As can be observed in Fig. 7, some histograms showed the presence of a sparse population of inclusions, which are coarser than that indicated by the tail of the upper end of the size distribution. The maximum size of this group of inclusions in the different weld metals ranged from 1.6 to 3.4 μm.

In welds deposited with SMAW, the particle size distribution was observed to be dependent on the flux basicity. Welds produced with cellulosic electrodes (W5 and W6) showed larger average inclusion size, larger maximum inclusion size, and lower inclusion population than welds produced with basic electrodes (W7). This finding is not surprising considering the high oxygen potential and low desulfurization capacity of slags formed by cellulosic electrodes. However, the volume fraction of inclusions is of the same order of magnitude in both cases (0.45 and 0.48%), indicating that the higher oxygen and sulfur concentrations of the weld deposited with cellulosic electrodes are mainly a result of a different inclusion size distribution as compared to basic welds.

A similar trend was observed in the size distribution of inclusions observed in weld metal deposited with gas-shielded FCAW electrodes (W1 and W2) compared to the weld deposited with self-shielded FCAW electrodes (W8). The narrower and finer size distribution of inclusions observed in FCAW-S welds compared to gas-shielded FCAW welds could be explained based on the lower oxygen plus sulfur concentration in the weld metal. The oxygen plus sulfur concentrations in welds W1 and W8 were 610 and 180 ppm, respectively.

Figure 8A and 8B show the average and maximum inclusion size as a function of oxygen plus sulfur content in the weld metal. As observed in Fig. 8A, the average inclusion size does not drastically change with oxygen plus sulfur levels up to about 400 ppm. However, above 400 ppm, the average inclusion size increases with an increase in oxygen plus sulfur level in the weld metal. On the other hand, the maximum inclusion size, as indicated by the tail of the upper end of the size distribution, is not greatly dependent on the level of oxygen and sulfur in the weld metal, as shown in Fig. 8B.

Additionally, the maximum size of the scarce population of inclusions, which are coarser than the size indicated by the upper end of the size distribution, seems to reach a plateau of about 3.2 μm at oxygen plus sulfur levels between 300 and 600 ppm. This observation may be explained based on the increasing ability of an inclusion to float to the surface of the weld pool as its size increases. From deoxidation of liquid steel, it is well established that the flotation rate of the oxides generally depends on their growth rates, since large inclusions separate much more rapidly than small ones, in agreement with Stokes’ law (Ref. 7).

The ability of inclusions to float to the surface of the weld pool as a function of their size also helps to explain the decrease in volume fraction and inclusion density of nonmetallic inclusions observed.
with increasing oxygen plus sulfur levels above 500 ppm. As the average inclusion size increases, the probability of more inclusions to float to the surface of the weld pool increases and, as a result, the volume fraction and inclusion density of nonmetallic inclusions may decrease.

**Shape and Composition of Weld Metal Inclusions**

Nonmetallic inclusions are almost always heterogeneous in nature both with respect to shape (angular or spherical particles) and chemistry (multiphase particles) as a result of the complex alloying systems involved.

Figures 9 and 10 show examples of inclusions of different shapes and textures observed in the weld metals. The observed inclusions present shapes that include spherical, faceted, and agglomerations of particles. The chemical compositions of some of the inclusions observed in differ-

---

**Table 7 — General Characteristics of Nonmetallic Inclusions Observed in Weld Metals W1 to W14**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Average Inclusion Diameter (μm)</th>
<th>Maximum Inclusion Size (μm)</th>
<th>Number of Inclusions per mm&lt;sup&gt;3&lt;/sup&gt; (×10&lt;sup&gt;9&lt;/sup&gt;)</th>
<th>Volumetric Fraction of Inclusion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>0.532</td>
<td>1.4 (2.43)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>1.21</td>
<td>0.34</td>
</tr>
<tr>
<td>W2</td>
<td>0.517</td>
<td>1.6 (2.43)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>1.36</td>
<td>0.4</td>
</tr>
<tr>
<td>W3</td>
<td>0.391</td>
<td>1.16</td>
<td>4.0</td>
<td>0.57</td>
</tr>
<tr>
<td>W4</td>
<td>0.32</td>
<td>1.56</td>
<td>5.39</td>
<td>0.59</td>
</tr>
<tr>
<td>W5</td>
<td>0.491</td>
<td>1.48</td>
<td>1.94</td>
<td>0.45</td>
</tr>
<tr>
<td>W6</td>
<td>0.354</td>
<td>1.2 (1.68)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>3.68</td>
<td>0.49</td>
</tr>
<tr>
<td>W7</td>
<td>0.311</td>
<td>0.95 (3.35)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>4.55</td>
<td>0.48</td>
</tr>
<tr>
<td>W8</td>
<td>0.314</td>
<td>1.4 (2.01)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>5.39</td>
<td>0.63</td>
</tr>
<tr>
<td>W9</td>
<td>0.401</td>
<td>1.6 (3.2)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>4.64</td>
<td>1.09</td>
</tr>
<tr>
<td>W10</td>
<td>0.298</td>
<td>1.1</td>
<td>3.53</td>
<td>0.3</td>
</tr>
<tr>
<td>W11</td>
<td>0.326</td>
<td>1.4 (1.74)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>3.54</td>
<td>0.39</td>
</tr>
<tr>
<td>W12</td>
<td>0.367</td>
<td>1.7 (2.95)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>4.22</td>
<td>0.81</td>
</tr>
<tr>
<td>W13</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>W14</td>
<td>0.299</td>
<td>1.2 (2.83)&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>2.17</td>
<td>0.23</td>
</tr>
</tbody>
</table>

(a) Represent an observed maximum inclusion size; however, this size was much bigger than the end of the upper tail of the size distribution observed in the particular weld.
ent weld metals are listed in Table 8. Generally, the inclusion core consists mainly of a mixture of oxides of titanium, manganese, silicon, and aluminum in different proportions, reflecting a very complex deoxidation product. Conditions in the molten pool approach equilibrium and, therefore, the stronger deoxidants such as titanium and aluminum occur in higher proportions in the inclusions than in the weld as a whole. Additionally, phases rich either in manganese and sulfur; silicon; or zirconium, carbon, and nitrogen, which indicates the presence of manganese sulfides, silica, or zirconium carbonitrides were also observed.

Figure 10B and C shows some of the spectra obtained from the analysis of the inclusions by EDX-microprobe analysis. Most of the carbon in the spectrum is due to the carbon film that supports the inclusions. The copper and zinc in the spectra are due to the sample holder used.

Analysis by EDX-microprobe analysis also confirmed the existence of several phases within inclusion agglomerates. Figure 10B and C show the spectra obtained from the different areas of the inclusion agglomerate shown in Fig. 10A. Region A corresponds to an oxide rich in titanium and manganese with a small proportion of aluminum and silicon; region B seems to correspond to a manganese sulfide; and region C is mainly a titanium oxide.

A sequence of inclusion formation in Al-Ti-Si-Mn deoxidized steel weld metals has been proposed by some researchers and outlined as follows (Ref. 7). In general, the inclusions consist of an oxide core, which is formed during the primary deoxidation stage. The chemical composition of the deoxidation products can vary within wide limits, depending on the relative activities of aluminum, titanium, silicon, manganese, and oxygen in the weld metal. The surface of the oxides will be covered partially by MnS and TiN. Precipitation of these phases occurs after the completion of the weld metal deoxidation, probably during solidification, where the reactions are favored by solute enrichment in the interdendritic liquid.

Conclusions

Based on the results and analysis of the experimental characterization of high-strength weld metal conducted during this study, the following conclusions are provided.

Chemical Composition

- The carbon equivalent (CE_IW) of weld metal deposited with E70X–E80X, E90X, and E100X–E120X grade consumables ranges from 0.25 to 0.35, 0.31 to 0.54, and 0.47 to 0.73, respectively.
- The oxygen levels of weld metals deposited with SMAW, FCAW (gas shielded), and GMAW with 100% CO2 ranges from 450 to 650 ppm. On the other hand, welding with the GMA process shielded with Ar-CO2 mixtures resulted in an oxygen content range of 260 to 360 ppm in the weld metals. The oxygen level of weld metals deposited with self-shielded FCAW was 110 ppm. The nitrogen content in weld metals deposited with the GMA process contained nitrogen levels from 30 to 140 ppm.

Microstructure

- The as-deposited weld metals with a carbon equivalent between 0.26 and 0.39 consist mainly of a ferritic microstructure with a decreasing fraction of grain boundary ferrite and an increasing fraction of sideplate ferrite and acicular ferrite. In general, the reheated region of these welds has transformed to equiaxed polygonal ferrite. The reheated zones of weld metal with carbon content between 0.1 and 0.15% present a high fraction of second phase precipitates that could be pearlite and/or carbide aggregates.
- In weld metals with a carbon equivalent of 0.47 or higher, an increasing fraction of lower temperature transformation products including martensite was observed. Additionally, it was observed that weld metals with higher alloying additions do not readily retransform during reheating induced during multipass welding.

Nonmetallic Inclusions

- The volume fraction of nonmetallic inclusions in most deposited HSS weld metals ranged from 0.2 to 0.6%. In a few welds, however, the volume fraction of nonmetallic inclusions was as high as 0.8...
The inclusion density observed in the welds ranged from $1.2 \times 10^8$ to $5.4 \times 10^8$ particles per mm$^3$. The average and maximum inclusion diameter ranged from 0.3 to 0.6 $\mu$m, and from 0.9 to 1.7 $\mu$m, respectively, in the deposited weld metals.

- In welds deposited with SMAW, the particle size distribution was observed to be dependent on the flux basicity. A similar trend was observed in weld metal deposited with gas-shielded FCAW electrodes as compared with welds deposited with self-shielded FCAW electrodes.

- The average inclusion size does not drastically change with oxygen plus sulfur levels up to about 400 ppm. However, above 400 ppm, the average inclusion size increases with an increase in oxygen plus sulfur level in the weld metal.

- Inclusions of different shapes and textures including spherical and faceted, and agglomerations of particles were observed in the weld metals. Generally, the inclusion core consists mainly of a mixture of oxides of titanium, manganese, silicon, and aluminum in different proportions, reflecting a very complex deoxidation product. Additionally, phases rich either in manganese and sulfur, silicon, or zirconium, carbon, and nitrogen, which indicates the presence of manganese sulfides, silica, or zirconium carbonitrides were also observed.
WELDING RESEARCH

References


Preparation of Manuscripts for Submission to the Welding Journal Research Supplement

All authors should address themselves to the following questions when writing papers for submission to the Welding Research Supplement:

1) **Abstract.** A concise summary of the major elements of the presentation, not exceeding 200 words, to help the reader decide if the information is for him or her.

2) **Introduction.** A short statement giving relevant background, purpose, and scope to help orient the reader. Do not duplicate the abstract.

3) **Experimental Procedure, Materials, Equipment.**

4) **Results, Discussion.** The facts or data obtained and their evaluation.

5) **Conclusion.** An evaluation and interpretation of your results. Most often, this is what the readers remember.

6) **Acknowledgment, References and Appendix.** Keep in mind that proper use of terms, abbreviations, and symbols are important considerations in processing a manuscript for publication. For welding terminology, the Welding Journal adheres to AWS A3.0:2001, Standard Welding Terms and Definitions.

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A comprehensive characterization procedure is described for the collection and analysis of ER70S-6 welding fume.

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

ABSTRACT. A procedure has been developed to characterize welding fume generated from arc welding processes that includes the measurement of fume generation rate (FGR), fume particle size, and mass distribution, and the morphology, chemistry, and composition of the fume. Fume was collected using both a state-of-the-art collection chamber and an electrical low-pressure impactor (ELPI), the former designed to optimize fume collection and the latter allowing fume to be segregated into 12 size ranges from 0.03 to 10 μm. Detailed characterization of fume particles was conducted using a combination of x-ray diffraction (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM), x-ray energy dispersive spectroscopy (XEDS), and x-ray photoelectron spectroscopy (XPS). These techniques, when used collectively, provide extensive information on welding fume particle structure, composition, and morphology. Using the ELPI, composition and morphology can be studied as a function of particle size. In this paper, the collection and analysis procedure is described in detail, and an example analysis of the ER70S-6 welding wire is provided. Welding fume characterization methods were performed on fume generated by gas metal arc welding (GMAW) of the ER70S-6 welding wire with 100% CO₂ and 75%Ar-25%CO₂ shielding gases. The combined techniques provide a comprehensive understanding of the fume generated by arc welding consumables.

Introduction

Fume generated by arc welding processes is an unfortunate byproduct and general nuisance to the welding industry. The principal concern with welding fume is associated with health risks resulting from fume inhalation. Additionally, government regulations continue to decrease the exposure limits to the various elements that are contained in the fume (Ref. 1). Several studies have examined welding fume generated from a variety of processes and consumables in an attempt to better understand the different aspects of fume behavior. These include fume generation studies (Refs. 1–6) as well as several characterization studies (Refs. 7–10), which used a variety of characterization techniques such as XRD, SEM, and TEM.

These and some other advanced techniques have been combined in this study to obtain a more comprehensive insight on composition and morphology of welding fume relative to both the bulk fume as well as individual fume particle chemistry and morphology. The use of an aerosol cascade impactor to separate fume into different size ranges allows fume to be studied as a function of particle size. This is a particularly important part of this approach since fume inhalation is affected by its size and aerosol characteristics.

Jenkins et al. have provided a summary of techniques that can be used for fume analysis (Ref. 11). Their synopsis showed that reporting molar concentration of elements on the fume is more adequate than reporting atomic percentage and makes it easier to compare results from different techniques as SEM-XEDS, TEM-XEDS, and XPS. X-ray photoelectron spectroscopy is a surface analytical technique that allows the measurement of fume-born particle surface composition and has been used in previous fume studies (Refs. 8, 9, 11–13). Since this technique is surface sensitive, it is ideal for analyzing the exterior layers of fume particles, which are most likely first to interact in the body after ingestion or inhalation. XRD analysis, which has become a fairly standard practice to analyze bulk fume, is a good technique for determining crystallographic structure of fume particles. This technique is normally used to analyze bulk fume samples and is very effective for determining the major metallic species and compounds that are present. On the other hand, electron microscopy allows individual particle characterization.

This paper outlines a procedure (Fig. 1) for collection and analysis of bulk welding fume samples and analyzing compositions of individual size ranges provided by an electrical low-pressure impactor (ELPI) made by Dekati Ltd. of Finland. Using this procedure, the fume produced by the GMAW process using ER70S-6 welding wire is analyzed, and the results of the various analytical techniques are presented. Fume from this consumable in size ranges including the ultrahine (0.03–0.1 μm), fine (0.1–2.5 μm), and coarse (2.5–10 μm) particle sizes were collected and analyzed with the analytical techniques described previously.

Fume Collection Procedures

Welding Procedures

The welding wire used for this study was ER70S-6 and base material was A-36 steel. The compositions of welding wire, base material, and weld deposits produced with two different shielding gases are shown in Table 1. The short circuit transfer mode was used for welding with both gases, and nominal welding parameters were developed that represented a mid-range heat input (according to the manufacturer’s recommended operating range) level for this filler metal. The welding power supply was a Miller constant current square wave machine that outputs 300 A/32 V at 60% duty cycle. Welding parameters are presented in Table 2. Test welds for fume generation rates were performed on 8-in. (20.3-cm) square A36
plates in circular paths around the base plates. Plate motion was achieved via a rotary positioning system within the fume enclosure during these tests. The GMAW gun was inserted through the back of the enclosure and contact tip to work distance was adjusted by a vertically mounted linear positioning system. Welds for ELPI collections were performed on 4-×-12-in. (100-×-300-mm) plates with a stationary torch position and base metal motion via linear positioner. Process variables (current, voltage, weld time) were obtained using a data acquisition system manufactured by Weld QC, Inc.

**Fume Chamber**

The American Welding Society Specification F1.2-1999, Laboratory Method for Measuring Fume Generation Rates (FGR) and Total Fume Emission of Welding and Allied Processes, describes the construction and use of a fume collection enclosure (Ref. 14). This chamber design, shown in Fig. 2A, was modified from the AWS designation to incorporate smaller filter pore sizes ensuring collection of the smaller particle size ranges by using a 0.3-μm pore size filter instead of the recommended 4-μm filter. The conventional air pump was replaced by a high-volume air sampler system with a built-in flow adjuster assembly built specifically for air sampling systems by the Staplex Co. of Brooklyn, N.Y. The filters, also made by Staplex, are 8-×-10-in. (200-×-250-mm) glass fiber filters with a 0.3-μm pore size and collection efficiency of 99.98%. The flow rate may be varied and monitored from 0 to 70 ft³/min (2000 L/min), double that of the maximum specified by AWS; pressure drop across the filter was measured via a digital manometer with computer data acquisition capabilities.

For FGR measurements, the air pump flow rates on the fume hood are initially set to approximately 25 ft³/min (700 L/min). Flow rate decreases as fume particulate starts to obstruct the filter pores. As indicated in Fig. 3, Region I corresponds to airflow through the clean filter, Region II is where the collection occurs and the pressure drop increases as particles congest the filter pores, and Region III shows that filter saturation has been reached and no additional fume may be deposited onto the filter. Tests are normally stopped before saturation is reached to allow all fumes to clear the chamber and be deposited on the filter paper. A regression fit for the pressure drop across the filter showed an increase proportional to t², the collection time, as shown in the inset of Fig. 3. Filters were tested for comparison to the flow rate and pressure drop recommended by the AWS test. The initial results indicated that the smaller filter pores have better particle retention due to the increase in pressure drop for flow rates that correspond to the AWS-type test. The fume generation rates (FGRs) were measured in triplicate for ER70S-6 with both shielding gases as displayed in Fig. 4 along with some FGRs from other consumables tested with this method as a comparison. Standard deviation of the measurements is shown with error bars. Particles collected from welds produced with the two different shielding gases have quite similar composition since the welding wire is the same, though previous studies have shown differences in FGR values for different shielding gases (Refs. 5, 15, 16).

**Results**

The initial results indicated that the smaller filter pores have better particle retention due to the increase in pressure drop for flow rates that correspond to the AWS-type test. The fume generation rates (FGRs) were measured in triplicate for ER70S-6 with both shielding gases as displayed in Fig. 4 along with some FGRs from other consumables tested with this method as a comparison. Standard deviation of the measurements is shown with error bars. Particles collected from welds produced with the two different shielding gases have quite similar composition since the welding wire is the same, though previous studies have shown differences in FGR values for different shielding gases (Refs. 5, 15, 16).

**Electrical Low-Pressure Impactor**

Aerosol collection techniques including scanning mobility particle sizing (SMPS) (Ref. 6) and low-pressure cascade impaction (Ref. 9) have been used in the past to collect welding fume and report size distribution information. Collection in the present study was performed with an ELPI, which was designed for real-time monitoring of aerosol particle size distributions. Using 12 detection channels, the ELPI has the ability to distinguish a size distribution range of 0.03 to 10 μm by sensing electrical currents of charged particles. The operating principle is based on charging, particle inertia, and electrical forces.
detection (Ref. 17). Fume is gathered at a location near the source of fume generation then drawn toward the ELPI through Tygon® tubing with vacuum. The fume passes through a corona charger after entering the ELPI, which produces a field of ions and places a positive charge on the incoming fume particles. Once charged, the particles enter the impactor column where they are separated by inertial classification according to aerodynamic diameter as they pass through the different stages. As the fume passes through the jet plate of each successive stage, particles larger than a certain dimension are unable to make the sharp turn required to reach the following stage, causing them to impact on the collection substrate directly below the preceding stage as illustrated in Fig. 2B. Each stage has a particular cutoff diameter that determines the particle size that should not pass through to the following stage. This diameter is defined as the aerodynamic diameter of particles collected on that stage with an efficiency of 50% (see Fig. 2). Aluminum foil substrates were used for collection since they provide a highly conductive surface for electron microscopy. For determining mass and size distributions, these substrates were coated with a thin layer of Si grease before collection was performed so that particle “bounce” was eliminated, thereby enhancing particle sticking on the substrate. Fume was drawn through the system by means of low vacuum pressure created by an external vacuum pump.

After particles impact with each collection stage, their charge was detected by current-sensing electrometers. This current data is used to develop the number distributions as seen in Fig. 5. These distributions are an average of three measurements collected with the ELPI with error bars indicating one standard deviation (valid for percentage scale only) of the three measurements. The distributions for the ER70S-6 electrode show little variation with changes in shielding gas for the coarse particle size range (>2.5 \( \mu m \)). Distributions begin to diverge in the lower end of the fine particle range as the 75/25 is skewed toward larger particle sizes in this range. The 100% CO₂ gas has an increase in particle concentration in the low detection range of the ELPI (30 nanometers). Statistical analysis may be performed on these distributions to find geometric mean diameter and geometric standard deviation. The results of these calculations are summarized in Table 3 for the size and mass distributions.

A possible reason for variations in particle size distribution among the different shielding gases is a difference in oxidation potential between particles in the different gas types leading to slight composition changes after particle nucleation (Ref. 18). Particle density changes with oxidation potential, e.g., the Ar gas hinders particle oxidation resulting in higher concentrations of Fe-rich particles as opposed to

<table>
<thead>
<tr>
<th>Shielding Gas</th>
<th>Geometric mean diameter (( \mu m ))</th>
<th>Calculated (^{(a)}) geometric mean diameter (( \mu m ))</th>
<th>Geometric standard deviation (( \mu m ))</th>
<th>67% range (( \mu m ))</th>
<th>95% range (( \mu m ))</th>
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</thead>
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<tr>
<td>Number Distribution Statistics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% CO₂</td>
<td>0.049</td>
<td>2.06</td>
<td>0.024–0.103</td>
<td>0.012–0.206</td>
<td></td>
</tr>
<tr>
<td>75% Ar-25% CO₂</td>
<td>0.058</td>
<td>2.10</td>
<td>0.027–0.121</td>
<td>0.014–0.243</td>
<td></td>
</tr>
<tr>
<td>Mass Distribution Statistics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% CO₂</td>
<td>0.386</td>
<td>2.99</td>
<td>0.129–1.156</td>
<td>0.064–2.313</td>
<td></td>
</tr>
<tr>
<td>75% Ar-25% CO₂</td>
<td>0.338</td>
<td>2.71</td>
<td>0.125–0.916</td>
<td>0.062–1.833</td>
<td></td>
</tr>
</tbody>
</table>

(a) The geometric mean diameter of the mass distribution was calculated from the geometric mean diameter of the number distribution with the Hatch-Choate equation (Ref. 20).
Fe-oxide, which has a lower density. The slight decrease in density causes the distribution to shift to higher aerodynamic diameters. The definition of aerodynamic diameter, a principle the ELPI uses to separate particles, is that a diameter of a unit density sphere (1 g/cm³) will have the same aerodynamic properties as a particle of interest (Refs. 17, 19). Therefore, a dense Fe-rich particle with the same diameter as an Fe-oxide particle will settle on a higher stage of the impactor causing the distribution shift toward higher aerodynamic diameters. In addition to the effect of the shielding gas on the particles’ density and, consequently, on the size distribution, the difference in the oxidation potential of the gas will have important influence on fume particle formation.

Mass distributions were obtained by weighing the collection substrate of each stage prior to and after the collection with a precision analytical balance accurate to 10⁻⁵ g. The mass distributions that were measured may be plotted as shown in Fig. 6 vs. the particle diameter. This allows for a comparison between the number of particles and the particle mass of each size. Error is indicated for an average of three measurements, again showing one standard deviation of error (valid for percentage scale only). The mass distributions peak at approximately 0.25 μm aerodynamic diameter. Discrepancies between the size and mass distributions can be explained by the fact that particles on the smaller stages, while much larger in number than the center stages, have a much smaller mass. Individual particles on the top stages have the highest mass but are the fewest in number. The mass distribution for 100% CO₂ shielding gas is shifted to slightly higher particle sizes.

The Hatch-Choate equation (Ref. 20) was used to convert the geometric mean diameter of the number distribution to that of the mass distribution to evaluate the performance of the ELPI functioning as an electrometer. The calculated (with Hatch-Choate equation) geometric mean mass diameter is included in Table 3. Relative error (%) between the measured and calculated mean mass diameters for the 100% CO₂ and 75% Ar-25% CO₂ shielding gases were approximately 21 and 18%, respectively. These values indicate the correlation between the ELPI’s ability to measure number distribution (electronically) vs. the mass distribution obtained by weighing ELPI stages. Note that some error may arise from the conversion itself since Hatch-Choate assumes “perfect” log-normal distributions.

**Analytical Characterization**

Characterizing individual and bulk welding fume particles is highly important to understand the fumes’ formation phenomenon and the possible impact of fume on the health of those working in metal joining areas. Fumes are an undesirable byproduct of the various arc welding processes and have motivated many studies over the past 50 years as speculation has increased of medical problems arising from overexposure to fume during welding. It is important to consider each of these size ranges independently from one another since they are generally formed by different mechanisms. The following techniques are ideal for analyzing different characteristics of fume such as structure, morphology, and composition.

**X-Ray Diffraction**

X-ray diffraction experiments were performed on fume collected on the bulk fume filters from the fume hood to obtain information on the phases present in welding fume. This technique is a good starting point for identifying the crystalline phases in fume particles.
point for the analysis techniques to follow because it provides basic phase identification. In addition, much of the previous analysis work on welding fume has included XRD of bulk fume samples, which makes a nice point of reference with respect to comparisons of structure and phase information found in previous studies.

Fume from the FGR tests was transferred onto off-axis zero background Si-crystal sample slides after a thin coating of petroleum jelly was applied to the slide to allow the fume to adhere. Data were collected using a Scintag XDS-2000 diffractometer equipped with a Cu x-ray tube and an energy-dispersive i-Ge detector. The goniometer was a vertical \( \theta \)-\( \theta \) arrangement in a standard Bragg-Brentano geometry. Data analysis was performed using MDI Jade software (version 6.1) and Bruker/Socabim EVA (version 7.0). The phases were identified by comparison with the ICDD/ICSD 2002 PDF database.

Figure 7 shows the diffraction patterns of fume obtained from 100% CO\(_2\) and 75% Ar/25% CO\(_2\) shielding gases with heat inputs of 18.4 and 16.8 kJ/in. (0.72 and 0.66 kJ/mm), respectively. Two phases identified in fume from both gas types were Fe\(_3\)O\(_4\) (magnetite) and Fe. An additional phase, FeO (wustite), was found in the fume from 100% CO\(_2\) shielding gas. Oxidation potential is higher in this case as opposed to the 100% CO\(_2\) shielding gas. These samples were collected with the bulk fume collection hood, thus the phases represent the entire size range of welding fume particulate generated for both conditions.

Since the oxidation potential of the 75% Ar/25% CO\(_2\) gas is lower, more metallic Fe is seen in that case as opposed to the 100% CO\(_2\) shielding gas. These samples were collected with the bulk fume collection hood, thus the phases represent the entire size range of welding fume particulate generated for both conditions.

### Scanning Electron Microscopy

Scanning electron microscopy and x-ray energy dispersive spectrometry are ideal for examining particle morphology and measuring bulk and individual particle compositions, respectively. The SEM is the most efficient method to determine both the composition and morphology of the large- and medium-size particles from the individual stages collected in the ELPI since little sample preparation is required and many analyses can be completed in a relatively short time. Average composition of fume particles on each stage can also be determined by analyzing the small piles of fume that form on the aluminum substrate during fume collection in the ELPI (see Fig. 2C). These piles consist of many particles and, thus, this type of analysis represents an average of many fume particles. In addition, individual fume particles may be analyzed and the composition of particles of different sizes compared. A limitation of the SEM is that equipment does not allow the composition of particles below approximately 0.3 \( \mu \)m in diameter to be easily analyzed since the electron beam interacts with a volume of at least this size, depending on the accelerating voltage.

Bulk composition of fume particles from Stages 2, 4, 8, and 10 of the ELPI were analyzed representing average fume particle sizes of 0.06, 0.16, 0.96, and 2.4 microns, respectively. Only fume particles collected on aluminum collection plates in

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**Table 5** — Chemical Composition of Fume Particles Shown in Fig. 9 as Measured with SEM–XEDS (Composition Is Reported in Atomic-Percent)

<table>
<thead>
<tr>
<th>Element XEDS Spot Analysis (at.-%)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si K</td>
<td>1.4</td>
<td>1.5</td>
<td>17.5</td>
<td>23.7</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.5</td>
<td>0.5</td>
<td>9.4</td>
<td>13.1</td>
</tr>
<tr>
<td>Fe K</td>
<td>97.3</td>
<td>97.3</td>
<td>73.1</td>
<td>62.9</td>
</tr>
<tr>
<td>Cu K</td>
<td>0.7</td>
<td>0.6</td>
<td>0.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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**Fig. 7** — XRD spectrum of bulk fume produced from ER70S-6 fume with the following: A — 75% Ar-25% CO\(_2\) shielding gas; B — 100% CO\(_2\) shielding gas.

**Fig. 8** — Distribution of bulk fume composition vs. particle diameter for both shielding gases as measured with SEM-XEDS on ELPI stages. Note that oxygen was present on each stage but was not quantified.
the ELPI were analyzed. Figure 2C is an example of an aluminum collection plate mounted on an aluminum SEM analysis post. The center region of a given fume pile (roughly 100 μm in diameter) represents the region where the average compositions of the fume particles for each stage were determined. A summary of the average compositions in both weight-percent and atomic-percent for the four stages analyzed are provided in Table 4 and Fig. 8. The data show that Mn is present in uniform concentrations on each stage. The amount of Fe for any given stage appears to be dependent on the amount of O present on that stage since an Fe increase is generally accompanied by a decrease in O and vice versa. Fe also increases in concentration with increasing particle size. Cu (from the wire coating) concentration appears to increase and Si decreases as particle size increases in 100% CO₂ shielding gas. Cu decreases with particle size for the 75% Ar-25% CO₂ mixture. Na and S were present in trace amounts in the bulk composition analysis. Chemical analysis was performed on individual particles using an electron beam spot (rather than rastering) on a given particle of interest. Monte Carlo simulations performed with Casino (Ref. 21) showed the interaction volume of the beam with the particle generates x-rays from the entire volume of the particle thus providing an average composition. The chemical analyses were performed for approximately 15 particles on each stage of the ELPI including spherical, agglomerated, and irregular particle morphologies. An example of several spot XEDS analysis locations and corresponding compositions are shown in Fig. 9 and Table 5, respectively. Note that XEDS measurement locations 3 and 4 are an average of several of the surrounding particles since particle size is less than electron beam interaction volume. The compositions measured from individual particle analyses generally coin-

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Average Compositions of Fume Particles</th>
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<tbody>
<tr>
<td>Stage 1</td>
<td>Weight-Percent</td>
</tr>
<tr>
<td>Mn</td>
<td>0.07</td>
</tr>
<tr>
<td>Fe</td>
<td>0.84</td>
</tr>
<tr>
<td>Cu</td>
<td>0.09</td>
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</tbody>
</table>

Fig. 9 — Secondary electron SEM micrographs of fume generated from ER70S-6 wire with the following: A — 100% CO₂; B — 75% Ar-25% CO₂.

Fig. 10 — XPS peak intensities as a function of etching for two shielding gases.

Fig. 11 — Spherical particle from ER70S-6 (100% CO₂) fume. TEM micrographs: A — Normal; B — high-resolution; C — SAD pattern on [111] zone axis of particle identifying (Mn,Fe)₃O₄.
X-Ray Photoelectron Spectroscopy

X-ray photoelectron spectroscopy (XPS) is a surface-sensitive chemical analysis technique that is used to obtain information on the oxidation state for the elements in welding fume. Normal sampling depth is on the order of several angstroms (Ref. 22). Previous studies have incorporated surface-sensitive techniques into welding fume studies (Refs. 8, 9, 11–13, 23) because particle interaction with human tissues most likely occurs with the surface of particles, thus surface chemistry is possibly the most important aspect when considering chemistry.

XPS uses “soft” x-ray radiation to bombard a sample (Ref. 24). Unlike XRD, where the x-ray is diffracted by the crystal lattice, in XPS the x-ray is absorbed and a photoelectron is ejected. By subtracting the energy of the impinging x-ray (which is known) and the energy of the electron (which is measured), the binding energy of the electron can be determined. Based on this information, the composition and valence states of various elements can be determined. Most instruments are equipped with a “sputtering” gun that bombards the surface with argon atoms, thereby removing layers from the surface re-revealing the composition of the underlying material. This depth profiling feature of XPS allows both the surface and underly-ing compositions of fume particles to be examined and the valence states of various metallic elements to be determined.

The XPS system used for this study was a Kratos Ultra Axis XPS and UPS system with depth profiling capabilities using Ar+ ion etching. XPS analysis for both shielding gas types was performed using fume collected on Stage 3 of the ELPI that has an average particle diameter of 0.095 microns. XPS shows that the outer surface of the fume particles is highly oxidized and is consistent with the Fe3O4 and FeO compounds found in XRD. Etching of the fume results in a reduction of the oxygen concentration and an increase in the presence of metallic species. The peak intensity measured for each peak in counts per second (CPS) were normalized to the total intensity and plotted as shown in Fig. 10. Both metallic Fe and Mn peaks were present after etching addition to oxides containing both Fe and Mn. The degree of surface oxidation was greater with 100% CO2 shielding gas relative to the 75% Ar-25% CO2 shielding gas. Copper was also detected in low levels, but only after etching of the particles. Based on combined XRD and XPS data, the valence state of iron and manganese appears to be (Fe,Mn)+2 and (Fe,Mn)+3 in fumes from both shielding gases.

Transmission Electron Microscopy

Transmission electron microscopy (TEM) provides the highest spatial resolution available for determining both the morphology and composition of individual fume particles less than approximately 300 nanometers in diameter. This technique is commonly used to analyze several types of aerosols since it can image nanoscale particles better than other methods providing insight into morphology, crystalllographic and electronic structures, and chemical composition of the ultratrine particle sizes (Ref. 22). Scanning transmission electron microscopy has been used in the past to characterize welding fume morphology and composition (Refs. 9, 10).

The TEM analyses were performed with a JEOL HRTEM JEM 3010 coupled with chemical micro- and nano-analysis by XEDS system equipped with a Si(Li) detector. A double-tilt beryllium sample holder was used for crystallographic analysis and low background chemical analysis. TEM analysis was performed at 300 kV using a wide range of magnifications, from 10,000 to 1,000,000 ×. Several techniques, including bright field, dark field, selected area diffraction, nano-beam diffraction, and XEDS microanalysis were also performed. Microanalysis probes of 5-25 mm diameters were used along with 400-s spectra collection times to provide adequate counting statistics. Images and electron diffraction patterns were recorded on TEM film as well as digitally using a 1024 × 1024 pixel CCD camera.

Samples were directly collected at 3 in. above the arc by pasting carbon-coated gold TEM grids through the fume plume. Additional samples were collected in Stages 1–4 of the ELPI as a comparison. As revealed by the SEM analysis, the ELPI stages contained a mixture of individual fume particles and agglomerates. Both direct collections above the welding arc and in the ELPI revealed the presence of individual and agglomerated particles, which agrees with previous findings that fume particle agglomeration occurs within the vicinity of the arc. This is of little surprise since particles begin to collide with one another almost immediately after they nucleate into a vapor. While some additional agglomeration may occur within the ELPI, it does not appear to be significant.

Detailed TEM analysis was conducted on fume particles that were captured on TEM grids held just above the welding arc, using procedures described previously. Fume from ER70S-6 welds made with both 100% CO2 and 75% Ar/25% CO2 were analyzed, but no significant, or systematic, difference between the fume generated using these shielding gases could be determined. Two general types of particles were analyzed. The first type was individual spherical particles in the range from 20 to 100 nm (0.02–0.1 μm). Most of these particles exhibited a core-shell structure with the core consisting of an Fe3O4 or (Fe,Mn)3O4 structure, surrounded by a Si-rich shell. The second type was an agglomerate morphology consisting of many very small spherical particles, typically in the range from 10 to 20 nm (0.01 to 0.02 μm). Many of these particles were of the (Fe,Mn)3O4 type, and also exhibited a core-shell structure with a Si-rich shell. Other particle types such as Fe- and FeO-rich particles detected using XRD analysis were not observed in the TEM analysis. Fe and FeO particles are likely much larger in size than those examined in TEM since they are formed from weld spatter, which cannot oxidize as heavily throughout the volume of the particles. A typical arrangement of TEM particle analysis micrographs are shown in Fig. 11 where A shows an agglomerate of nanoscale particles, B shows a high-resolution image of one of the particle shells, and C illustrates the resulting diffraction pattern of the pointed particle, which was identified as (Mn,Fe)O-type diffraction along the [111] zone axis.

Core-Shell Particle Structure

TEM revealed that the core-shell particle structure was common among the particles less than 100 nm in diameter. Contrary to this, the XPS analysis of similar particle
sizes did not reveal this trend since the Si 2p signal varied little as a function of particle etching depth (see Fig. 10). XPS is a surface-sensitive technique with a very limited spatial resolution. On the other hand, TEM is a technique that provides volumetric information of very small (thin) samples and has an outstanding spatial resolution. However, this outstanding spatial resolution may compromise the statistics of the results, especially if the analysis is performed by an inexperienced user and if it is not complemented with other techniques. In addition, the Ar-ion milling is not a very well-controlled process, especially on a heterogeneous surface such as the type tested. While using HRTEM it is possible to unequivocally identify a core-shell structure, it is a more complex matter using XPS especially in complex structures such as piles of sphere-like particles with a wide range of sizes, structures, and compositions. The information provided by HRTEM and XPS analyses is not expected to be identical but complementary; therefore, these techniques should be analyzed together and kept in context to avoid misinterpretation.

Conclusions

A combination of analytical techniques was used to examine welding fume generated from ER70S-6 wire with two different shielding gases (100% CO2 and 75% Ar-25% CO2). Fume was collected with an electronic low-pressure impactor (ELPI) that was used to find welding fume particle size and mass distribution in sizes ranging from 30 nm to 10 μm in size, and collect fume samples for further characterization studies. This instrument is very useful for the study of welding fume since it has the ability to separate particles into different size ranges and deposit them on substrates that may be evaluated individually by SEM, TEM, and XPS. Using this technique, the composition of welding fume was measured as a function of aerodynamic diameter. The results may be used to provide a comparison of respirable and irreproducible particles vs. their compositions.

Experimental results from XRD showed higher oxidation in the particles from fume generated with 100% CO2 shielding gas compared with the 75% Ar-25% CO2, which most likely results in a change in density of fume particles by shifting the ratio of oxygen and iron in the particles. The more heavily oxidized particles form smaller aerodynamic sizes on average than those with less oxidation, which is shown by the ELPI size distributions and statistical analysis of the 100% CO2 gas vs. the 75% Ar-25% CO2 mixture. TEM and XPS revealed higher oxygen content in particles from the 100% CO2 shielding gas, which confirms why the shift is occurring.

Electron microscopy techniques permitted micro- and nanoscale analyses of the morphology, chemical composition, and crystallographic structure of agglomerates of particles and isolated particles. In the case of TEM, the analyses made possible the identification of core-shell structures in some of the particles. This combination of characterization techniques has been employed to collect fume generated by GMAW, and to characterize the fume by size distribution, chemical composition, structure, and morphology, which requires the use of multiple imaging and analytical techniques since the size variation of welding fume particles is quite large.

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References

NOMINATIONS SOUGHT FOR PROF. KOICHI MASUBUCHI AWARD

March 3, 2008

Dear Colleague:

On behalf of the Masubuchi Award Committee, I seek your assistance in identifying and nominating outstanding candidates for the 2008 American Welding Society Prof. Koichi Masubuchi Award. This award, which is sponsored by the Dept. of Ocean Engineering at the Massachusetts Institute of Technology, was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures. It is one of the most prestigious awards provided by AWS and is presented each year to one person under the age of 40 who has made significant contributions to the advancement of materials joining through research and development.

The deadline for submitting nominations for the 2009 Masubuchi Award is November 3, 2008. The candidate must be 40 years old or younger, and may live anywhere in the world. The candidate need not be a member of AWS. The candidate must have a very strong history of accomplishments in research and development in the field of welding and joining. The nomination should be prepared by someone familiar with the background of the candidate, and include a résumé listing background, experience, publications, honors, awards, plus at least three letters of recommendation from researchers. Nomination should be submitted electronically to me at jnd1@lehigh.edu.

On behalf of the Award Committee, I thank you for your assistance in helping AWS continue to identify worthy candidates for this prestigious award.

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Lehigh University
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