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The EPOCH 4 provides the ultimate combination of unsurpassed ultrasonic performance, simplicity of operation, and scope of documentation capabilities. New key features include customizable narrowband filtering, a tunable square wave pulser, and a high PRF rate up to 1kHz. Its light weight of 5.4 lbs (2.4 Kg) including a high-power NiMH battery, new large high resolution Liquid Crystal Display (LCD) or Electroluminescent Display (ELD), and ease of transducer calibration are unmatched by any other portable flaw detector.

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• SPECIAL EMPHASIS: SAFETY AND HEALTH

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Sumitomo Wins $336 Million Rail Car Order

Sumitomo Corp. of America (SCOA), New York, N.Y., recently received a $336 million order for commuter rail cars for use in Illinois. The company, along with Nippon Sharyo, Ltd., will supply 250 new commuter rail cars to Metra, the northeast Illinois commuter rail system based in Chicago.

The order is the largest in Illinois history and one of the largest ever in the commuter railroad industry. Plans call for SCOA to deliver 250 new stainless steel Gallery Type bi-level commuter cars. The car shells will be designed and built by Nippon Sharyo with final assembly by Super Steel of Milwaukee, Wis. Metra is expected to exercise its option for 50 additional cars that would raise the contract total to approximately $398 million. Completion date for delivery is 2005. The order is part of a $2 billion improvement plan Metra's board of directors approved last November. Under Metra's "Build Illinois" provision, SCOA will provide a portion of the total contract value to manufacturers and suppliers from Illinois.

Nippon Sharyo, which has annual sales of more than $800 million, has manufactured railroad vehicles for more than 100 years. Since 1980, SCOA and Nippon Sharyo have supplied more than 450 rail passenger cars in the United States.

Campaign Launched to Recruit and Retain Union Pipefitters

The Mechanical Contractors Association of Chicago (MCA), which represents the pipefitting industry in Chicago, recently launched two new programs to recruit new members and keep union pipefitters at the leading edge of industry.

The efforts are part of MCA's new campaign "Union Pipefitters -- Taking on Tomorrow." The two new programs are the MSCA Service Bureau, a recruitment program designed to attract top-quality service technicians to the organization, and the Certified Safety Bureau, which will provide cutting-edge safety training and tracking.

To combat labor shortages found throughout the industry, the MSCA Service Bureau is planning a strong marketing program aimed at qualified technicians. The program will include a series of billboard and cable television ads designed to attract technicians to MCA's program. The organization serves about 400 union mechanical contracting firms through the Piping Education Council, whose members employ nearly 8000 Local Union 597 pipefitters.

"We want technicians to ask themselves if they are earning what they are worth in terms of pay and benefits," said MCA executive vice president Stephen Lamb. "MCA is taking the lead in an initiative to ensure that our members are staffed with the best and brightest employees available today." The Service Bureau will provide skills training, serve as a clearinghouse for service-related information and as a labor resource for MCA's service contractors.

The Certified Safety Bureau will increase the quality, availability and tracking of safety training to union mechanical contractors and their employees. Its backbone will be a computerized database of all approved industry safety training. The training will be provided through interactive computer instruction, classroom training and on the job site through contractor request.

Copper Development Association Names Kireta President and CEO

The board of directors of the Copper Development Association recently named Andrew G. Kireta, Sr., as the association's president and chief executive officer. He succeeds Robert M. Payne, who retired after ten years of service in that position.

The Copper Development Association is the information, technical and market development arm of the copper and brass industry in the United States. Kireta has been with the organization for 21 years, serving as vice president for tube, pipe and fittings since 1997.

Payne culminates a 40-year career in nonferrous metals that began with Revere Copper and Brass, Inc., at its Baltimore Div.

Michigan Avenue Partners to Acquire Alcoa's Longview Aluminum Smelter

Alcoa Inc., Pittsburgh, Pa., and Michigan Avenue Partners (MAP), Chicago, Ill., recently announced an agreement in which MAP will acquire the 204,000-metric-ton-per-year aluminum smelter in Longview, Wash.

Alcoa was required to sell a 25% interest in Longview as a condition for European Union approval of Alcoa's acquisition of Reynolds Metals Co.; instead it will give up 100% of Longview to MAP.

The purchase is contingent on financing, is subject to regulatory approvals and is expected to close by the end of the first quarter of this year.
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Midnight Regulations Issued at Record Pace

Regulatory activity, primarily in the form of final rules, during the period between the presidential election and the Inauguration has increased almost 20% since 1948. Regulations issued during this time period are referred to as "midnight regulations" because agency heads and other officials who are political appointees are like "Cinderellas" who turn back into ordinary citizens upon Inauguration. Once they return to private life, those officials will be without power and unable to effect regulation changes, so they work to push through as many rules as they can before the transition takes place.

President Carter used to hold the record, releasing more than 25,000 pages of midnight regulations between the election and Inauguration, but this was surpassed last month by the Clinton Administration, which almost reached the 30,000 page mark.

By far, the leading agency in releasing last-minute regulations in 2000 was the Environmental Protection Agency, which had hoped to issue as many as 88 new rules prior to the change in administrations.

Federal Contractor Rules Finalized

The federal government has issued the final version of its controversial contractor qualification rules. These rules (65 Fed. Reg. 80255) mandate that all federal contractors must have a "satisfactory record of integrity and business ethics" in order to become, or remain, eligible to receive a federal contract. Contractors without a satisfactory record are those who have not complied with labor, employment, environmental, antitrust and consumer protection laws.

The regulations have long been a top priority of organized labor, but are opposed by the business community. Undoubtedly, a legal challenge will be initiated to question the validity of these regulations.

Record Education Budget Approved

Congress passed a record $42 billion education budget as it adjourned in December of last year. This appropriation is an 18% increase over the previous fiscal year, the largest one-year increase in education funding in the history of the U.S. Department of Education.

Worker Injury, Illness Rates Decrease Again

Workplace injury and illness rates declined in 1999 for the seventh straight year, according to the U.S. Department of Labor. They have dropped almost 30% since 1992. Further, the decrease in injuries and illnesses, approximately 4%, is even more impressive in light of the fact that employment overall rose by 2%. Data for 2000 is not yet available.

Congress Fixes Tax Error

The Installment Tax Correction Act, passed late last year, fixed an unintended consequence of an earlier tax bill that restricted the use of the installment of accounting for small businesses. This restriction placed a burden on the sale and purchase of companies, particularly small businesses, by compelling the payment of taxes up front in many instances, rather than over a period of time.

Federal Research Misconduct Defined

The Office of Science and Technology Policy has issued a final policy on misconduct in connection with federal research. The policy is primarily aimed at private companies or universities that perform work pursuant to government contracts. It became effective immediately upon release.

"Research misconduct" is generally defined under the policy as "fabrication, falsification or plagiarism in proposing, performing or reviewing research or in reporting research results." It does not include, however, "honest error or differences of opinion."

OSHA Celebrates 30 Years

The U.S. Occupational Health and Safety Administration (OSHA) celebrated its 30th anniversary at the end of December 2000. Since its creation on December 29, 1970, OSHA has contributed toward the 50% decline in work-related fatalities and 40% decline in occupational injuries. Among its accomplishments, OSHA cites the establishment of hazard communication, bloodborne pathogen and cotton dust standards, as well as its efforts to reduce brown lung disease.

Significant Government Actions Ranked

The Washington, D.C., think tank, The Brookings Institution, has issued its ranking of the federal government's top 50 greatest achievements since 1944 based on the opinions of more than 400 historians. Number one on the list is rebuilding Europe after World War II, followed by strengthening the nations' highway system and reducing workplace discrimination.

Contact the AWS Washington Government Affairs Office at 1747 Pennsylvania Ave., N.W., Washington, DC 20006; telephone (202) 466-2976; FAX (202) 835-0243.
Making Good S.E.N.S.E.

In an effort to improve U.S. worker’s skills in a variety of fields, including welding, the U.S. Department of Education awarded a grant to the American Welding Society on July 2, 1993, to develop, organize and operate a business committee that would prepare a skills standard and curriculum leading to an individual becoming an “entry level welder.” To accomplish those goals, AWS formed the Education Grant Committee, a broad-based group of AWS members from the business community that included representatives from the welding equipment manufacturing, shipbuilding, aerospace, automotive and general fabrication industries; trade unions; and educators.

The total cost of the project was $1,072,466.85, with the Department of Education funding 49% and AWS the other 51%. In January 1995, AWS was awarded an extension of the grant to develop and prepare additional national skill standards and curriculum guidelines for more advanced training for welders.

Hence, the AWS S.E.N.S.E. — Schools Excelling through National Skill Standards Education — program was born. It consists of three voluntary national skill standards for training and qualification of welding personnel (Level I – Entry Level, Level II – Advanced Welder and Level III – Expert Welder) and their associated curriculum guides. The program emphasizes education that produces students who can demonstrate a level of competency in certain identified skills and who are, therefore, more employable.

Following are just a few of the developments pertaining to this widely accepted and popular program:

- As of December 2000, 458 schools participate in S.E.N.S.E.
- Kentucky, New Jersey and Ohio have adopted the standards on a statewide basis.
- Companies in the welding industry have contributed to the AWS standards and have adapted the curriculum for their own use.
- The AWS Education Department has produced a S.E.N.S.E. newsletter for the purpose of exchanging information between AWS and participating organizations.
- The AWS Education Department has also updated its list of all the S.E.N.S.E. schools. The list includes the most current contact information, including e-mail addresses. It will be available for download from the AWS Web site.

When S.E.N.S.E. was first developed, it was decided that each section would be revised and revamped every five years. So, it is now time to take the program to the next level.

A 20-member S.E.N.S.E. Ad Hoc Subcommittee from all facets of the welding industry has been appointed to review and update the current materials. When the committee members have completed the draft copy, they will post it on the AWS Web site (www.aws.org) so you can review it and give your input on the draft version at that time. You can send any comments or suggestions you have about the program to the AWS Education Department at (800) 443-9353 ext. 229.

After the committee develops a draft copy, AWS will submit the updated version to the American National Standards Institute for its approval. ANSI approval will lend additional validity to this already highly regarded program.

Your input is important. After all, we want to restore welding as a premier vocation that is financially and personally rewarding.

Robert J. Teuscher
AWS Past President (1999–2000) and Chairman, AWS Education Committee
The Ranger™ 250 gasoline engine-driven welder has always delivered 250 amps of pure DC output and 8,000 watts of continuous AC power.

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*See your local Lincoln Electric distributor for details. Customer must register to participate.
The Benefits of American National Standards

More than any other nation, the U.S. industrial and commercial system is based on voluntary consensus standards developed by volunteer committees of Standards Developer Organizations (SDOs) such as AWS, ASME and ASTM.

In the American system, individuals with a real interest in the subject produce standards from the ground up. In the United States, federal, state or local municipalities may adopt all or parts of a voluntary standard in regulations such as building codes and transit systems. In fact, under the National Technology Transfer and Advancement Act of 1995, federal agencies are directed to use American National Standards (ANS) to satisfy their regulatory requirements. Federal agencies develop their own standards only when suitable ANS don’t exist. Outside the United States, governments are involved in standards development to greater degrees.

To accomplish their goal, SDOs must attract consumers, academics and employees of manufacturers and government agencies who are stakeholders in a particular product or process. Stakeholders represent suppliers, consumers and general-interest groups. For example, in structural welding the supplier group includes structural fabricators and erectors and others providing tools or products to them. Consumers consist of owners of structural assemblies, engineering contractors, designers and consultants. General-interest people are academics, government employees (including those who may be regulators) and consultants who are neither suppliers nor consumers.

Standards developed by these groups reflect the goals of all stakeholders, and are scientifically and experience based, safe and affordable. Remember, all standards are safety standards.

The SDO serves as facilitator and policeman. The SDO consists of volunteers and staff members who provide the forum and the rules for the technical committees that actually develop the standard. The rules and procedures must meet those of the American National Standards Institute (ANSI). ANSI Procedures for the structural development of standards and coordination of American National Standards can be found on the ANSI Web page at www ANSI.org.

You may be asking yourself, “So what?” Well, like it or not, your professional life is affected by these committee-developed standards that decide the requirements for industrial products you produce or use. And, furthermore, they affect your personal life, too, such as whenever you purchase consumer products that conform to standards developed by Underwriters Laboratories, Inc.

So maybe you should be more active in the AWS Standards Development Program. AWS publishes more than 170 American National Standards, and these standards are also used internationally.

What are the benefits? You will meet and work with leaders of the welding industry. You will be able to advise your employer of changes that will be occurring in the industry. You will develop a network of technically competent people who can help you through problems on your job. You will learn to respect others with a contrary view and to compromise to produce a true consensus.

To apply for committee membership, call (800) 443-9353 ext. 325, or e-mail to sara@aws.org. You can also sign up on the AWS Web page at www.aws.org by clicking on Technical. Once there, you can comment on published standards or draft standards, learn about upcoming committee meetings and apply for membership on any Technical Committee.

We look forward to hearing from you.

Leonard P. Connor
Managing Director, AWS Technical Services
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Company ___________________________ City ___________________________ Province/Country ___________________________
Phone ___________________________ Fax ___________________________

B. Primary Show Interest

☒ AWS Welding Show
☒ PMA METALFORM Symposium

C. Are You A Member Of:

☒ AWS
☒ PMA
☒ Not a member/Unsure
☒ Other (specify) ___________________________

D. Primary Function (check one)

01 President, owner, partner, officer, corporate executive
02 Managing director, chief operating officer
03 Chief executive officer, chief administrative officer
04 Manager of public relations or marketing
05 Manager of educational services
06 Manager of technical or research program
07 Sales representative
08 Marketing/sales manager, director
09 Manager, editor, editor-in-chief, or assistant editor of technical publication
10 Engineer—welding
11 Engineer—design
12 Engineer—other
13 Architect designer
14 Metallurgist
15 Inspector, tester, inspector
16 Supervisor, foreman
17 Technician
18 Welder, welding or cutting operator
19 Consultant
20 Educator
21 Librarian
22 Student
23 Customer service
24 Other (specify) ___________________________

E. Purchasing Authority (check one)

☒ Recommend
☒ Specify
☒ Approve

F. Company’s Primary Business (check one)

Manufacturing:
29 Furniture & fixtures
30 Primary metal products
31 Fabricated metal products
32 Machinery except elect. (inc. gas welding)
33 Electrical & electronic equip., supplies, electrodes
34 Petroleum & coal industries
35 Transportation equip.—air, aerospace
36 Transportation equip.—automotive
37 Transportation equip.—boats, ships
38 Transportation equip.—railroad
39 Instrument & related equipment
40 Carried construction
41 Chemicals & allied products
42 Utilities
43 Welding distributors & retail trade
44 Misc. repair services (inc. welding shops)
45 Educational Services (univ., libraries, schools)
46 Engineering & architectural services (inc. assns.)
47 Misc. business services (inc. commercial labs)
48 Government (federal, state, local)
49 Other (specify) ___________________________

Non-Manufacturing:
50 Metal Service Centers & Offices
51 Other (specify) ___________________________

G. Type of Company (check one)

52 Contract manufacturer/job shop
53 End product manufacturer/OEM
54 Non-manufacturing
55 Distributor
56 Other (specify) ___________________________

H. Total Employees at this location (check one)

A ☒ 1 ~ 9
B ☒ 10 ~ 49
C ☒ 50 ~ 99
D ☒ 100 ~ 249
E ☒ 250 ~ 499
F ☒ 500 ~ 999
G ☒ 1000 +

I. Primary Product Manufactured at this Location

J. Company’s Activity Includes:

(check all that apply)

57 Stamping
58 Sheet metal fabricating
59 Spinning
60 Forming
61 Tool & die
62 Welding
63 Sawing/trimming
64 Roll forming
65 Coil forming
66 Perforating
67 Assembly
68 Machining
69 Deep drawing
70 Tube/Fitting
71 Advanced materials, intermetallics
72 Aluminum
73 Arc welding
74 Automation
75 Bending and shearing
76 Braiding and soldering
77 Ceramics
78 Computerization
79 Cutting
80 Ferrous metals
81 High energy beam processes
82 FOR
83 Nonferrous metals except aluminum
84 Pressure vessels and tanks
85 Fusing
86 Resistance welding
87 Robotic
88 Safety and health
89 Sheet metal
90 Structures
91 Thermal spray
92 Laser Welding
93 Software/systems
94 Other (specify) ___________________________
95 None of the above

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Site Is Doorway to Four Engineering Councils

Information from four New York, N.Y., based engineering councils — the Materials Properties Council, the Welding Research Council, the Pressure Vessel Research Council and the Bolting Technology Council — can be reached from the same Web site. From the home page, a mouse click links you to pages for each organization.

The Materials Properties Council, Inc. Although some of the material on the site is accessible to council members only, other information is for the general public. The site gives background on the organization, including its goals, history and a list of officers and supporting companies. A user's manual for OmegaPipe™, a software package that performs life assessments on steam piping systems, which can be downloaded as a PDF file, is also on the site.

Synopses of research projects, for example, Repair Welding of Nickel Superalloy Combustion Turbine Blades and Service Exposed Dissimilar Weld Evaluation, are also available.

Welding Research Council. You can read abstracts and purchase WRC bulletins on-line. The Web site also has information on upcoming conferences and committee meetings.

Pressure Vessel Research Council. Besides meeting schedules, workshop details and background about the organization, this area includes a description of council projects and participants, with contact information. A photo gallery of pressure vessel failures is also featured.

Bolting Technology Council. This site emphasizes the benefits of joining the organization, a list of the industries it serves and its areas of interest. It also includes a history of the council and contact information.

Help for Successfully Applying Robotics

Robotics Online is sponsored by the Robotic Industries Association (RIA), a trade group representing approximately 230 robotics suppliers, users, system integrators, research firms and consultants. This site offers page after page of information. In the Tips for Successfully Applying Robotics section, you first click on an application such as arc welding, material handling or dispensing. You are then presented with a wide selection of case studies, articles and technical papers. For instance, in a paper titled Why Automate Your Welding Operation?, Genesis Systems Group offers a checklist that includes the following questions that need to be answered before you purchase a system: "What is the number of units per unit of time? This will help determine how many arcs are required and what the utilization of equipment will be. Number of different assemblies you want to automate on a single cell? As more part numbers are added to a workcell, the tooling and control system may become more complex. Can the operators keep everything straight? What level of foolproof details are required? How often do you change over to run different parts? This can greatly affect the tooling design and cost. Some applications may have many dedicated fixtures, while others may have one fixture with details that are moved."

The site features a Buyers' Guide with product listings, company profiles (often with links to company sites) and an on-line request for bids form. You can also request a free copy of the Robotics Industry Directory. The Educational Resources section offers more technical papers, an on-line bookstore from which you can purchase books and links to organizations that do research on robotics. The site includes details on events, a map to help you navigate, opinion pieces and some information for RIA members only.

If you click onto the Community Forum section, you can post jobs or a résumé and read tips on how to interview successfully for a job. Its career area also includes an article titled How to Get the Best Jobs in Robotics and Factory Automation, by Jeff H. Chapman. You can also ask and get answers from an automation expert via e-mail, post messages and participate in a live chat or access transcripts of previous chats.

Site Highlights

Welding Wire

National Standard Co. The Web site for this wire manufacturer based in Niles, Mich., offers information on its welding products, bead wire, specialty wire and engineered product segments. The welding wire pages include product descriptions and capabilities. Material safety data sheets are available in PDF format for each wire listed. The pages for the engineered products division, which makes components and materials for the automotive airbag market, has links to related industry associations, publications and other industry sites.

The Web site includes the company's financial statements, both quarterly and annual reports. The News and Events section posts press releases about the company, its products and its involvement with the Save the Children® foundation.

The site offers answers to frequently asked questions, a company history and an on-line literature request form.
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USS Cole Returns to the United States for Repairs

Two months after the terrorist attack that killed 17 U.S. Navy sailors and injured 39 others, the USS Cole returned to Litton Ingalls Shipyard in Pascagoula, Miss., to undergo repairs. The badly damaged Aegis-class destroyer arrived aboard the Blue Marlin, a Norwegian heavy-lift ship. A shroud covered the gaping hole left by the explosion that occurred when suicide bombers ran into the ship as it was being refueled in Aden, Yemen, October 12, 2000.

The USS Cole was built at Ingalls and the ship was christened at the yard before delivery to the Navy in 1996. Many of the same workers who originally constructed the ship will make the repairs. "Ingalls and all of its employees who built USS Cole regret the tragic circumstances that brought the ship back to our shipyard," said Jerry St. Pe', chief operating officer of Litton Ship Systems and executive vice president of Litton Industries, "but we are committed to working with the Navy to return the ship to the fleet in the shortest time possible."

Mike Chapman, general ship superintendent at Ingalls, managed the construction team that built the Cole and will perform the same function for the repair team. In an interview December 16, 2000, on National Public Radio's Weekend Edition, Chapman described the Cole's arrival in Pascagoula.

"I was standing on the dock. I watched her come around the corner," Chapman said. "We had looked at a lot of photographs and read a lot of reports on her damage, what she had gone through, but to see it in person really hit. We were glad to see her, but we wished it had been under different circumstances. We wished she had been coming home sailing proud."

Chapman said repairs are expected to take about a year, approximately one-third the original construction time. "What we’re going to do is we’ll take out all the damaged decks and bulkheads and equipment, and we will replace all the equipment with newer, updated equipment," he said. "We’ll build her back and make her a better ship than she was the first time we put her together."

The first steps in the repair process are to place a watertight patch over the hole, float the destroyer off of the Blue Marlin and move it to dry land. The capability of placing the ship back on land was one reason why the Navy selected Ingalls to make the repairs. "Some aspects of the damage remain unknown and will present challenging engineering problems during the repair," the Navy said when announcing its selection of a repair facility. "The land-level facility at Ingalls provides greater flexibility to deal with major structural damage."

Once the ship is back on land, Ingalls' workers will remove the damaged sections, fabricate huge new ship sections in other areas of the shipyard, then install the new sections aboard ship. Ingalls performed similar repair work on the battle-damaged USS Stark in 1988. — Mary Ruth Johnsen, Features Editor.
Students Unveil Versatile Vehicle Designs

Three students from the Center for Creative Studies-College of Art and Design in Detroit, Mich., recently unveiled their concepts for the next generation of General Motors' Hummer brand. The designs were developed as part of the 12th annual scholarship program sponsored by the American Iron and Steel Institute (AISI).

The students, Rudolf Gonzalez, East Elmhurst, N.Y.; Marc Senger, Leesburg, Va.; and David Tang, Tenafly, N.J., were required to explore the design possibilities of an expanded Hummer range with the potential for higher manufacturing volume. The students designed with steel in mind, incorporating advancements in high-strength steel, hydroforming and tailor-welded blanks to reduce weight, while maintaining the visual cues that define the Hummer brand. They designed concepts for an expanded product range that included entry-level, mid-level and luxury vehicles, then executed the designs in 3/10 scale clay models.

Tang's entry-level concept implies performance, functionality and industrial strength, and interior room and spacing as unique elements of the design. The design offers lean mass efficiency by incorporating steel technology such as a roll bar made of hydroformed tubing.

"A well-proportioned body with robust detailing is definitely the selling point of this concept," Gonzalez said of his mid-level vehicle design. "Through the use of tailor-welded blanks in the doors and roof, I'm able to lightweight the vehicle without sacrificing structural rigidity."

Senger's concept for a luxury vehicle includes a turbine electric hybrid engine and aircraft-inspired circular styling cues. "My concept symbolizes a move to make driving hybrid vehicles fun..."

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Through function," he said. Senger's luxury-level vehicle utilizes hydroforming and rigid, galvanized sheet steel sections to reduce weight; exposed mechanical components for aesthetics and unpainted components that suggest ruggedness.

"The imagination of these students is not only promising, but also very refreshing," said Darryl Martin, senior director, automotive applications, AISI.

TWI Uses Laser Welding to 'Sew' Clothing

TWI recently conducted a feasibility study for Nigel Cabourn, a clothing manufacturer in Newcastle, England, to assess the potential for using a laser welding process to manufacture garments.

In the project, TWI was asked to weld together a shirt, which included putting in buttonholes, pleats in the seams and a collar. The shirt was produced using a low-power diode laser welding process called ClearWeld™, which uses an almost colorless infrared absorbing medium developed by GENTEX Corp.

"The results of the study were very encouraging and we now plan further research to test this new concept," Nick Sellars of Nigel Cabourn told Connect, a TWI publication. "It opens up a whole range of possibilities in garment design."

The study produced the following results:

- Seams were made with little marking of the fabric.
- Joints can be made through an upper layer, without visibly affecting that layer.
- Often, seam designs similar to those for stitched seams may be used.
- Only subtle differences exist between the appearance of welded and stitched seams.

Industry Notes

- The Alliance Pipeline commenced commercial service on December 1, 2000, two months behind schedule. The $2.9 billion pipeline system will transport approximately 1.325 trillion ft³ of natural gas per day from northeastern British Columbia to Chicago. The Alliance Pipeline was the first to use mechanized gas metal arc welding as a primary mainline construction technique in the United States as reported in the November 1999 issue of the Welding Journal. The 2300-mile-long line was originally scheduled to begin service October 2, but construction delays at the Aux Sable fractionalization plant and other problems caused the delay.
3M Has MORE Solutions for Respiratory Protection!

These are some of the many factors to consider when selecting respirators for welding, brazing, soldering and metal pouring. Workers who perform in difficult welding environments have to be comfortable and properly protected. 3M respirators provide better performance in welding environments and address a wide variety of welding requirements. Product offering includes:

- **Filtering Facepiece Respirators.** 3M has a selection of low-cost filtering facepiece respirators that provide great comfort and protection from metal fumes.
- **Half and Full Facepiece Respirators.** These respirators offer lightweight, easy-breathing comfort.
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Innovation
Laser System Cuts and Welds Large Components

The PEDILAS laser system’s modular design allows it to be configured to cut and weld. The equipment involves a gantry, or portal system, with 5-axis laser beam movement for integrated cutting or welding of large workpieces. The large work area can be used for processing only or be divided into two sections, one for processing and one for fixtureing the next workpiece. The laser resonator travels alongside the system with its own carriage and drive system. This allows the PEDILAS system to have the and-groove crane rail in the X-axis provides support for the cutting stations. Up to 12 cutting stations are provided, including two plasma stations for oxyfuel and plasma arc cutting, beveling, plate marking, drilling, or routing. It incorporates Yaskawa AC brushless motors with digital drive amplifiers, coupled directly to planetary gearboxes. The selected gearbox limits maximum backlash to five arc minutes for improved positioning and repeatability. The resolver used for positioning feedback is integral to the drive motor, eliminating drive errors or inaccuracies associated with mechanical couplings. A new helical rack travels up to 1500 in./min. The machine offers a choice of seven cutting widths ranging from 8 to 20 ft.

ESAB Cutting Systems
411 S. Ebenezer Rd., Florence, SC 29501-0545

Cutting Gantry Has Host of Features

The Avenger 1 gantry shape-cutting machine is equipped with a plasma bevel cutting head, a 200-A precision plasma station and four oxyfuel stations with flame control. The plasma bevel head combines process automation technology and control software capabilities. The machine features all-welded, stress-relieved, reinforced components with machined contact surfaces, wheels and roller bearings. A large, heavy tongue-high acceleration and deceleration common in laser processing without imposing the high G forces generated by this movement on the laser resonator itself. The working area beneath the Y-axis bridge is open and accessible from both ends.

Schuler Inc.
15300 Commerce Dr. N., S-104, Dearborn, MI 48120

Three-Scale Flowmeter Regulator Has Multiple Features

The H2051 triple-scale flowmeter regulator for gas metal arc and gas tungsten arc welding has an output of 0–50 standard ft³/h and features a shatter-resistant polycarbonate flow tube. Designed for attachment to welding gas cylinders or manifold systems, the H2051 flowmeter regulator provides measure-
ment of inlet pressure and shielding gas flow. The flow tube has measuring scales for argon/CO₂, helium or argon and utilizes a high-visibility red flow ball. The adjustment flow control valve ensures gas savings because it locks flow at desired settings. Maintenance is reduced with the O-ring valve, which eliminates gas leakage. The rubber ring is used around the threads of the flowmeter instead of soft packing material, which wears out.

Smith Equipment
2601 Lockheed Ave., Watertown, SD 57201-5636

User-Friendly Controller Designed for Flexibility

The EZ-Link™ series of controllers are easy-to-use, microprocessor-based controllers that provide flexibility for the operator. Welding and motion functions are coordinated in one package. The front panel layout includes an easy-to-read backlit LCD display. Custom-designed software permits a wide range of programmed sequence configurations. Applications include a controller for longitudinal welding with speed control that has travel start and stop delays that can be preset. Travel carriage, initiation of the weld sequence and weld length can be controlled, and an automatic home sequence can be programmed with the longitudinal controller. The controller for circumferential welding includes precision lathes, positioner and head-and-tailstock systems. This controller has features similar to the longitudinal version and automatically adjusts surface travel speed based on the part diameter input by the operator. A pass counter permits multipass welding with an optional limit switch arrangement.

Pandjiris
5151 Northrup Ave., St. Louis, MO 63110

Booms and Carts Come in A Rainbow of Colors

The company's line of heavy-duty booms and carts now come in 12 color options, including Organic Orange, Red Baron, Blue Streak II, Purple Wave and Yellow Submarine. The new colors are also available on wall and floor mount accessories. Standard colors — gray and yellow — are available at no charge. Booms provide horizontal and vertical reach and are manufactured from heavy-gauge steel that holds up to 200 lb. There is a locking device for added safety and 360 deg of rotation with proper ballast. The mounts improve wire feed and organize a safe work area. The carts make workstations more accessible by organizing and storing power sources, feeders, gas cylinders and water coolers. Integral to the carts is a 41-gal neoprene-lined...
tank for ballast or coolant with an optional water circulator pump, a capacity of up to 3000 lb and swivel-front steering and durable rubber tires with cast iron wheels.

**Bucket Makes Remote Welding Easier**

The company's construction bucket was designed for gas tungsten arc welding operators who work long distances from the power source. The construction bucket includes a 12.5-ft torch package (choice of 125-, 150- or 220-A air-cooled torch or flex torch, plus work clamp), a 38-ft extension (2-gauge wire) or 88-ft extension (#1/0 wire), PCA-2 power cable connector with rubber boot, Smith flowmeter regulator, welding accessory kit (back cap, collets, collet bodies, nozzles for 5/32- or 1/8-in. electrodes) and 10 tungsten electrodes (1/32- or 1/16-in., 2% thoriated). Packaged in a 6.5-gal bucket, the equipment allows operators to weld up to a 200-ft radius around the power source. It connects a 12.5-ft torch to either a 38- or 88-ft extension of heavy-gauge welding cable and gas hose. For safety, a rubber boot protects all connections.

**Welding Nozzle International**

1560 121th St. E., Palmetto, FL 34221

**Wire Offers Superior Beads and Pool Control**

The Outershield® 71 Elite gas-shielded, flux cored wire produces a bead in any position and has excellent out-of position pool control. Its fast-freeze slag characteristics make this electrode suitable for applications requiring high deposition rates in the flat, uphill and overhead positions. Additional features include easy slag removal, low spatter/fume levels and smooth arc. The wire is available in 0.045-, 0.052- and 1/8-in. diameters in packaging that includes 10- and 30-lb spools, a 60-lb coil and a 600-lb drum. Typical applications include ships, bridges, barges and offshore platforms, as well as general and structural fabrication. It can be used for fillet, lap-joint and butt-joint welds on single- and multiple-pass applications. The electrode was developed for all-position, semiautomatic welding of mild steel and low-alloy steels.

**Orbital Welding System Is State of the Art**

The company's orbital welding system provides weld data management features and labor-saving innovations in programming, fixturing and weld documentation. The system is powered by a 486 microprocessor, which enhances programming capabilities and can be easily upgraded with new software. Hundreds of welding programs can be stored, eliminating the need to re-enter information and improving the operator's ability to control diameter, root opening and other variables. New programs are easy to create using either a computerized programming interface or a feature that automatically generates programs based on user responses to system prompts. Data can be transferred to

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other computers, improving the ability to analyze and customize reports for documenting quality, cost of welds and more. The portable M100 power supply weighs 37 lb. Other features include Series 20 weld fixtures, which enable one-step fitup of short sanitary fittings for welding, a tube facing tool, for preparing the ends of tubing, fittings and ferrules without damage or contamination to the internal diameter of each component, and a root opening gauge, for maintaining the quality and precision of welds.

Swagelok Co.
31400 Aurora Rd., Solon, OH 44139-2764

Ergonomically Designed Torch Offers Precision

The Diamond Back torch was designed by the company’s engineers and operators for precision and hand comfort. The head of the torch features scalloped indentations on the right, left and top sides for finger-grip placement. For precision operators who hold the torch like a pencil, this shape increases control over torch movements while reducing hand fatigue. The back of the handle features a recess where operators can rest their thumb. The torch naturally pivots around this recess, making it easier to walk the cup around the pipe’s circumference. The handle also features tighter knurling to keep it from slipping out of the operator’s grip. The series includes air-cooled torches rated at 125, 150 and 200 A and water-cooled torches rated at 250 and 350 A, all at 100% duty cycle.

Miller Electric Mfg. Co.
1635 W. Spencer St., Appleton, WI 54912-1079

Clarification

The article "A Wise Method for Assessing Arc Welding Performance and Quality," by Dennis Harwig, published December 2000, page 35, contains a Fig. 5 that is a duplicate of Fig. 5. The correct Fig. 6 is printed below.
These days, respiratory protection systems are a valuable workplace productivity tool, not just an expense to ensure OSHA compliance.

BY KEN SCHEEL

For years, the aim of respiratory protection programs was simply to meet OSHA requirements for workers engaged in welding and other metal finishing applications. Today, however, welding supervisors look to such programs with a new eye, engaging plant managers and production foremen in discussions about how respiratory protection systems can increase worker productivity, comfort and morale, and actually lower manufacturing costs.

This new focus is particularly important for workers in metal-finishing operations who may be exposed to multiple airborne contaminants. Welding fumes that contain cadmium oxide, manganese, zinc oxide or lead can seriously affect a worker’s health, causing metal fume fever, lung and kidney damage, pulmonary edema and other conditions. Gases encountered during welding operations, such as ozone, can also damage workers’ health.

KEN SCHEEL is in the technical services department of the 3M Occupational Health and Environmental Safety Division (651) 733-1110. He is responsible for positive-pressure respirator systems.
Protection and Productivity Improve

Positive-pressure respirator (PPR) systems, or supplied air respirators with loose-fitting facepieces, hoods or helmets and powered air-purifying respirators, are increasingly being regarded as valuable workplace productivity tools, not just an expense incurred to assure OSHA compliance. In addition to protecting workers' eyes, head and face from airborne contaminants, this equipment can also guard against heat stress when combined with a cooling system. An improvement in employee comfort and, hence, morale can have the added benefit of improving product quality, too. As a result, many industries are reconsidering how best to implement their own respiratory protection programs.

“A well-designed respirator program and the appropriate PPR system enables workers to do more grinding, cutting and welding, and be more efficient in maintenance and repair operations,” said Tom Nelson, CIH, former corporate health and safety manager for DuPont and now an industrial hygiene consultant.

Wes Norton, a CIH, CSP with more than 20 years of industrial experience, agreed. “There are numerous industrial operations where positive-pressure respirators are beneficial. When you offer workers a choice between a half-facepiece, negative-pressure respirator and a positive-pressure system with a loose-fitting hood or helmet, they choose the supplied-air system because of the comfort benefits.”

Respirator programs that use positive-pressure systems with loose-fitting helmets and hoods are easier to administer, too, according to Jerry Guilliams, a Boeing Co. senior industrial hygienist and safety specialist, because the respirators do not require fit testing and users need not be clean-shaven. “Right there, you have eliminated two significant aspects of worker resistance,” he said.

While ease of administration is a plus, reducing workers' eye and face injuries — and sustaining productivity — is paramount. For example, U.S. Pipe and Foundry in Chattanooga, Tenn., reduced eye injuries by 75% after switching to positive-pressure respirator systems. U.S. Pipe has about 750 employees producing ductile iron fittings, hydrants and valves. Until a few years ago, the foundry’s most frequently reported safety problem was foreign matter in the eyes of workers in the grinding department.

Based on the plant's record of worker visits to its first aid room, injuries were significantly reduced after the switch was made. In January 1980, for example, there were 294 visits recorded. In January 2000, the number of visits dropped to 57.

U.S. Pipe's success in reducing eye injuries started several years ago when workers switched from air purifying, half-facepiece respirators to powered air-purifying respirators (PAPR) with a general-purpose helmet and liftable faceshield. In 1999, the Chattanooga plant switched to L-901 PAPR systems with full hardhat protection, a liftable, wide-view lens, and a flame-retardant shroud to protect workers' shoulders and chests from sparks and other particles. The lightweight headgear is popular with grinders because it can be worn by employees with beards, and because the PAPR unit directs a constant flow of filtered air over the worker's head and face. Because workers feel more comfortable, they take fewer breaks.

Eye Injuries Reduced at Ward Manufacturing

Ward Manufacturing, Blossburg, Pa., employs 1050 workers who produce malleable iron pipe fittings and pipe unions, cast-iron pipe fittings, grooved pipe couplings and a flexible corrugated stainless steel tubing for distributing natural and propane gas. Ward's chief respiratory challenge is silica dust as a by-product of its pipe fabrication operations.

“An engineering control system designed to capture silica dust didn't meet our expectations,” Craig Johnson, health and safety manager at Ward said. “The dust problem would occur after the fitting was poured. The pipe fitting cooled, sand broke free, fell to the vibrating table and then rose into the air.”

Employees wore filtering facepiece respirators to protect them from dust because concentrations were below OSHA's permissible exposure limit. Although employees also wore safety glasses, there was still a rash of eye injuries due to circulating airborne silica dust. The dust also settled on employees' hair and eyebrows, so when they showered at the end of the day, silica dust would wash into their eyes.

To help reduce eye injuries and increase worker comfort, Ward switched to a supplied air system with loose-fitting headgear. “Since we switched to these respirator systems in April 1997, we've had no eye injuries. None. We're able to provide our workers with Grade D breathing air and at the same time provide a cooling effect. This system has a unit to cool the filtered air before it flows over the head and face. In summer, if it's 90°F outside with high humidity, it is easily more than 100°F in the

Definitions to Know

Atmosphere-supplying respirator: A respirator that supplies the user with breathing air from a source independent of the ambient atmosphere, including supplied-air respirators (SARs) and self-contained breathing apparatus (SCBA) units.

Helmet: A rigid respiratory inlet covering that also provides head protection against impact and penetration.

Hood: A respiratory inlet covering that covers the head and neck, and may also cover portions of the shoulders and torso.

Loose-fitting facepiece: A respiratory inlet covering designed to form a partial seal with the face.

Negative-pressure respirator (tight-fitting): A respirator in which the air pressure inside the facepiece is negative during inhalation, compared with the ambient air outside the respirator.

Positive-pressure respirator: A respirator in which the pressure inside the respiratory inlet covering normally exceeds the ambient air pressure outside the respirator. This includes continuous flow and pressure demand SARs and powered air-purifying respirators.

Powered air-purifying respirator (PAPR): An air-purifying respirator that uses a blower to force ambient air through air-purifying elements to the respiratory inlet covering.

Supplied-air respirator: An atmosphere-supplying respirator for which the independent source of breathing air is not designed to be carried by the user. This includes continuous flow and pressure demand systems. Also known as airline respirators.

Tight-fitting facepiece: A respiratory inlet covering that forms a complete seal with the face.

sort area. By switching to a supplied air system, we've given our workers the benefit of cool filtered air flowing down their faces and across their breathing zone."

**Safety and Health Benefits**

Positive-pressure respirator systems can have a broad impact on worker protection because they address a variety of workplace issues.

Respiratory protection: Positive-pressure respirators protect workers against particulates, welding sparks, fumes, gas and vapors. These systems are especially useful in welding and grinding work, general maintenance, the utility industry and in industrial paint shops. Health benefits also include the assigned protection factors (APFs) for these systems, which define how much protection a respirator offers against airborne contaminants. The typical negative-pressure, half facemask has an APF of 10 (i.e., protective against concentrations up to 10 times a substance's permissible exposure limit). Positive-pressure APFs generally range from 25 to 1000.

Eye, head and face protection: Most positive-pressure respirator systems can be equipped with helmets, hoods or loose-fitting facepieces to protect eyes, head and face. For example, one employer's 10-year study found eye injuries in grinding and chipping operations were reduced 90% when employees wore helmets that covered the whole head and eliminated the need for separate goggles and face shields.

**OSHA compliance:** Selecting the appropriate PPR system and accessories can significantly reduce the compliance burden. For example, supplied-air, loose-fitting hoods and helmets do not require fit testing. Furthermore, employees don't have to shave beards and mustaches because PPR systems employing helmets or hoods don't require a tight face seal, as do respirators with either half, or full, facepieces.

**Productivity Benefits**

Positive-pressure systems cost employers about $700 per worker to outfit an employee in a belt-mounted powered air system with a bumpcap and welding lens. While that initial outlay may seem high, the costs of productivity downtime, poor finished quality, absenteeism and employee turnover can be even more costly.

Workers in foundries or workers exposed to industrial ovens often take a 10-min break for every 30 min of work because of the intense heat. However, a cooling unit that is part of the respirator system can cool the breathing air by as much as 50°F, enabling workers to stay on the job longer. This provides obvious productivity benefits for employers and gives employees on piecework a reason to embrace respiratory protection. A cooling system, which workers regulate individually, can also be used to provide warm air for cold-weather work.

"The ability to individually control the climate is an important benefit," Norton said. "When employees can control the temperature to their own comfort zone, they are more likely to view their working conditions favorably."

**Employee Involvement**

The key to Boeing's successful respiratory protection program was having employees test the supplied-air systems and then compare them with negative-pressure, full-face and half-mask respirators, Guilliams said. Even in work areas with ventilation systems that reduce contaminant concentrations below the permissible exposure limit (PEL), employees in the paint shop, chemical processing and maintenance departments chose the supplied-air respirator systems with eye and head protection accessories and an air-cooling unit.

"Involving employees in the selection and providing them with flexible, comfortable equipment has been a huge boost to morale and job satisfaction," Guilliams said. "We have made a strong business case for respirators based on protection, productivity, comfort and morale benefits. With the tight labor market and the need for highly skilled workers, it is more important than ever for our people to be comfortable and happy."
CONFINED SPACE MONITORS: Tough Choices for Tight Spots

Reliable operation and proper features in a gas monitor are a must if you're working in a confined space

BY DAVID D. WAGNER

Confined space — just the sound of it appears challenging to those of us who are even slightly claustrophobic. Read the Occupational Safety and Health Administration's (OSHA) definition in 29 CFR 1910.146 of a permit-required confined space, "...an area with limited or restricted means of entry and exit; not designed for continuous human occupancy; potential to contain a hazardous atmosphere," and it becomes apparent these areas are somewhat less-than-desirable places to spend the workday. Unfortunately for many, entry and work in confined spaces is a fact of everyday work life.

Confined spaces exist in almost every industry and in every workplace. In oil refineries and chemical plants, in power stations and paper mills, in water treatment plants and sewer systems, in telecommunications and electric vaults, in hospitals and on farms, on ships, in aircraft and railroad cars confined spaces are too numerous to count. If you are an electrician, plumber, pipe fitter, welder, boiler maker, carpenter, farmer, astronaut or emergency service worker, chances are that at some point your daily duties will require you to enter a confined space and be challenged by the hazards that await there.

Know the Hazards

Some of the hazards in confined spaces are easily recognized. It can be relatively easy to see the potential for falls or entrapment from cave-ins or falling equipment. However, it is the unseen atmospheric hazards that present the greatest danger in a confined space. The lack of breathable oxygen, the potential for explosion due to dangerous levels of combustible gases or the presence of deadly poisonous gas vapors such as carbon monoxide cannot be seen. Therefore, you must rely on the readings of a portable gas-monitoring instrument to alert you of potential danger.

So, before you drop down that manhole or crawl into that tank car, here are some considerations concerning the gas monitor you choose and the procedures you follow to ensure your safety.

Choosing the Right Sensor

Make sure the sensors in the instrument you are using are appropriate for the confined space. Many people consider a confined space monitor to be synonymous with a four-gas instrument containing oxygen, combustible gas, carbon monoxide and hydrogen sulfide sensors. While it is true most confined spaces do...
potentially contain some hazard related to one of these gases, it is not true for all. If you are entering a space that may potentially contain chlorine, an instrument with carbon monoxide and hydrogen sulfide sensors installed will be of little use. Many instruments offer you the ability to change the sensors to match the particular hazard you will encounter. These instruments will provide greater flexibility and value in a wide variety of applications.

The gas-monitoring instrument must be durable and able to withstand harsh conditions. Although a portable gas detector is certainly a sophisticated piece of electronic equipment, it is still a tool. As such, it is subjected to the rigors of the environment it is used in, just like any other tool. It is dropped, dunked or caught up in other equipment, and all the while it must still provide a potentially life-saving service. Be certain the instrument you choose is constructed in a manner that will not let its, or your, survival in a tough environment be left to chance.

Confined space pre-entry tests require remote sampling of the atmosphere from outside the space. Therefore, the instrument you choose must have the capability of using a remote sample pump. Whether the sampling pump is integral to the instrument, or is detachable, is strictly left to your preference. In either case the pump must have the capability of drawing an adequate sample flow over the distance required to cover the entire space. The pump also should be able to detect and clearly inform you if the sample line is blocked, thereby preventing gas flow to the instrument and its sensors.

Be certain that the sample tube material you are using with the pump is of high quality and is compatible with the vapors that you might expect to encounter. Some highly reactive gases like chlorine, nitrogen dioxide or hydrogen chloride may be absorbed into the walls of the tubing and scrubbed from the sample stream. Never use sample tubing made of materials containing silicon rubber compounds. The silicone vapors may off-gas from the tubing and poison catalytic head type combustible gas sensors, leaving the instrument unable to detect explosive gases. Sample tubing made of urethane or FEP (Teflon®) is generally suitable for most applications.

**Precautions When Welding in Confined Spaces**

While confined space operations are inherently hazardous, extra precautions are required whenever welding or cutting is performed in such spaces. Welders can come into contact with any number of different atmospheric hazards, including fluorides, zinc, lead, mercury, beryllium, cadmium and toxic cleaning compounds, whose dangers can become exacerbated inside confined spaces. OSHA welding work guidelines describe a confined space as a relatively small or restricted space, such as a tank, boiler, pressure vessel or small compartment of a ship.

OSHA standard 1910.252, outlines general requirements for welding, cutting and brazing, and also directly addresses operations in confined spaces. Another OSHA standard, 1915.51, deals with ventilation and protection for welding, cutting and heating, primarily for shipboard work.

Before cutting or welding, spaces must be checked for atmospheric hazards using gas detection instruments. Cutting and welding are prohibited in confined spaces with explosive atmospheres (mixture of flammable gases, vapors, liquids or dusts with air), or in spaces that previously contained those materials and that have not been cleaned or properly prepared.

After taking gas detection instrument readings, the space must be adequately ventilated with mechanical ventilators to prevent accumulation of toxic materials or possible oxygen deficiency. NEVER use oxygen to ventilate a space.

The minimum ventilation rate is 2000 ft³ (57 m³) per minute per welder, except where local exhaust hoods and booths are present, or when airline respirators are used. Vent all hollow spaces, cavities or containers, and take care to observe partitions or other barriers that might obstruct cross ventilation.

After ventilation, again take atmospheric readings with gas detection instruments. When the space is ready for entry, the welder must be fitted with any respiratory protection required (National Institute for Occupational Safety and Health (NIOSH) standard 42 CFR Part 84), safety belts and lifeline, along with other required personal protective equipment. A standby attendant, trained in preplanned rescue procedures, must be posted outside of the space. The standby attendant must maintain visual and verbal communication with the welder at all times.

Some operations require work in confined spaces that are immediately hazardous to life. In such instances, workers must wear a full-facepiece, pressure-demand, self-contained breathing apparatus or a combination full-facepiece, pressure-demand supplied-air respirator with an auxiliary, self-contained air supply.

Other precautions include the following:

- **Accidental contact.** When arc welding is to be suspended for any substantial period of time, such as during lunch, shift change or overnight, all electrodes must be removed from the holders and the holders carefully located so that accidental contact cannot occur. Machines also must be disconnected from their power sources.

- **Torch valve.** Whenever the torch is not used for a substantial period of time, such as lunchtime, shift change or overnight, the torch valves must be closed and the gas supply positively shut off at some point outside of the confined space. This action eliminates the possibility of gas escaping through leaks or improperly closed valves. Also, where practical, the torch and hose also should be removed from the confined space.

- **Secure cylinders and machinery.** Gas cylinders and welding equipment must be left outside of the confined space. Before operations are started, heavy portable equipment mounted on wheels must be securely blocked to prevent accidental movement.
Check the Power

The gas monitor should be able to operate from a variety of power sources. Rechargeable batteries are generally most suitable for portable monitoring instruments because the combustible gas sensors used in the detectors consume large amounts of battery power. Extended confined space operations often require instrument run times beyond the capacity of the rechargeable batteries. The ability to replace the rechargeable battery pack with disposable alkaline or lithium battery cells will certainly come in handy in these situations. In addition, make sure that the instrument is capable of running the required amount of time when the sample pump is being used. Some sample pumps use the instrument's battery for power and will reduce the-run time of the instrument much more than you might expect.

Know the detection limits of the instrument. There are clear differences in the measuring ranges of sensors in various instruments. As a rule of thumb, the monitor should be capable of measuring concentrations approaching the immediately dangerous to life and health (IDLH) level of the target gas. All catalytic combustible gas sensors require a minimum background oxygen concentration present to respond accurately. Be aware of what that level is and make sure the instrument you choose can be used with a dilution apparatus. By doing so, you will ensure the accuracy of the combustible detector when sampling from inert or oxygen-deficient atmospheres.

Calibrate Often

Beware of claims that instruments do not need to be tested or calibrated on a regular basis. Know one thing for sure: the only way to ensure a gas monitor will respond to gas is to test and verify its operation with known concentrations of the target gases prior to each use. For example, someone using the instrument before you might have damaged one of the sensors resulting in no difference in the response of a catalytic or electrochemical gas sensor used in a clean atmosphere from one that has failed catastrophically. Regular calibration and functional testing will guarantee the instrument and its sensors are working properly. Whether or not it is done is up to you. If calibration and testing are too difficult and cumbersome for you to do on your own, docking systems or service programs are available to automatically perform these tasks on your instruments and document the results.

Keep Monitoring

Whether to monitor continuously or not is an often asked question. Usually, confined space atmospheres are tested before entry to complete the required permits, and then the gas monitor is put back on the truck until the next test. Unfortunately, the work done while in the confined space may create an unseen hazard. Chemical reactions with solvents during cleaning processes in tanks or vapors produced during maintenance operations, such as welding, can build up dangerous gases in a confined space while you work. Continuous monitoring (Fig. 1) of the space's atmosphere during the entire entry will ensure there is no potential danger. An instrument capable of activating a remote alarm will also alert your partner watching from outside of hazardous conditions.

So many choices, so little room for error. Do yourself a favor. Make sure you take time to know and understand the hazards of confined space operations and assure yourself you have the right equipment. It could save your life.
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Design Analysis for Welding of Heavy W Shapes

An investigation evaluated the effects of welding parameters and joint geometry on the magnitude and distribution of residual stresses on thick-section butt joints.

BY C. TSAI, D. KIM, J. JAEGER, Y. SHIM, Z. FENG AND J. PAPRITAN

Cracking and fracture problems have been associated with groove weld splicing of thick plates and rolled shapes (Ref. 1). Problems were reported in 1981 at the Orange County Convention Center in Orlando, Fla. (Ref. 2), and at the American Airlines hangar constructed at Dallas/Fort Worth International Airport in 1988 (Ref. 3). Segregation and slow cooling at the midthickness region of the flange and web intersection causes a reduction in base metal toughness. In addition to reduced toughness, high residual stress (Ref. 4) from nonlinear thermal cycles created by the welding process and geometric irregularities at the weld access holes increase the potential for cracking.

Field experience has shown the welding sequence can have a controlling effect on cracking of heavy, wide flange butt joint connections. When the sequence is such that flanges are welded prior to the web, cracks can initiate from web access holes and propagate through the web material. If the weld sequence is such that the web is welded first, followed by the flanges, cracks again initiate at the web access holes; however, the cracks then tend to propagate through the flange material.

As a recent field case, W36 x 359 rolled shapes from A572 Grade 50 steel were built up into heavy sections to reinforce the guide wall structural system in the Bonneville Navigation Lock (Ref. 5). Because these thick members would be subjected to tensile loads, there was concern for cracking. To provide design guidelines for welding these heavy W shapes, this study performed a finite element model (FEM) analysis to calculate the thermo-mechanical responses of the weldment to various welding processes and procedures. These thermomechanical responses included transient temperature and strain (or stress) variations of the weldment during heating and cooling periods, and residual stress distribution in the weldment after cooling down to room temperature. Experimental measurements of transient temperature and strain changes during welding and residual stresses in the joint members were conducted to check the validity of the numerical results. These studies resulted in recommendations for improved design and fabrication of thick-shape welded connections.

The finite element studies modeled a W36 x 359 shape, however the experimental investigations utilized W36 x 300 shapes. Although the experimental and test results were based on the W36 x 300 shapes, the structural dimensions of these two materials are similar, as shown in Fig. 1. The thermomechanical responses of these shapes to the welding heat source are also similar. Therefore, comparisons between the finite element analysis and the experimental investigations were based on the proximity of these two shapes.

Investigation Variables and Welding Processes and Parameters

The variables in this investigation included welding process and parameters, welding sequence, weld access hole geometry and weld joint geometry.

Several welding processes were studied for welding the flanges. They included flux cored arc welding (FCAW), submerged arc welding (SAW) and electrogas welding (EGW). The webs were modeled with the FCAW process only. The associated welding parameters included welding current, voltage and travel speed. Typical values of these parameters were assumed for the FEM analysis, as shown in Table 1.

Flanges: The current, voltage and travel speed for the FCAW process for the root pass and second pass were 190 A, 27 V with a travel speed of 6.7 in./min (170.2 mm/min). The remaining...
Table 1 — Welding Parameters Used in FEM Analysis

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Flange</th>
<th>Web</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCAW</td>
<td>SAW</td>
<td>EGW</td>
</tr>
<tr>
<td>Current (amps)</td>
<td>190-250</td>
<td>350</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>27-30</td>
<td>30</td>
</tr>
<tr>
<td>Travel speed (in./min)</td>
<td>6.7-11.8</td>
<td>20</td>
</tr>
<tr>
<td>Number of passes</td>
<td>37-26</td>
<td>23</td>
</tr>
<tr>
<td>Filler metal dia. (in.)</td>
<td>0.05</td>
<td>6/64</td>
</tr>
</tbody>
</table>

(a) Root and second pass, (b) remaining passes (c) single-V groove, (d) double-V groove.

passes were deposited with welding parameters of 250 A, 30 V and 11.8 in./min (300 mm/min). The current, voltage and travel speed for the SAW process were 350 A, 30 V and 20 in./min (508 mm/min). The welding parameters for the EGW process were 850 A, 43 V and 1 in./min. Water-cooled copper shoes were used to keep the molten metal in the groove during welding.

Webs. The webs were welded by the FCAW process with welding parameters of 200 A, 27 V and 6.7 in./min.

Weld Joint Geometry

In this study, the wide flange shapes were joined by a complete penetration groove weld butt joint. Trade Arbed (Ref. 6) and American Institute of Steel Construction (AISC) (Ref. 7) recommend using single-V-groove welds to join the flanges and a double-V-groove weld for the web. Oregon Iron Works (OIW), a fabricator for the Bonneville Navigation Lock project, proposed this recommended joint design (Ref. 5).

The weld joint edge preparation and fit-up details for the flange are presented in Fig. 2. Figure 2D illustrates an alternate double-V-groove weld that was also investigated in this study for possible use in welding the flanges with FCAW. The weld joint edge preparation and fit-up for the web are shown in Fig. 3.

Assuming E71T-1, 0.05-in.-diameter (1.2-mm) electrodes for the FCAW process, it was estimated the double-V-groove web weld required 8 passes to complete. The double-V-groove flange weld required 26 passes while the single-V-groove flange weld required 37 passes for FCAW. For the SAW process with 3/8-in.-diameter electrodes, a total of 23 passes were used for the single-V flange groove. The other side of the joint was backgouged and rewelded with 6 passes. The EGW process used square butt
joints without any joint preparation. The flange was welded uphill by a single pass with a 0.12-in. (3.2-mm) diameter flux-cored electrode.

Weld Access Hole and Welding Sequence

The weld access hole diameter is an important parameter because it can act as a stress concentrator that promotes cracking. The geometry for the web access holes is shown in Fig. 4 as recommended by Trade Arbed (Ref. 6), AISC (Ref. 7) and OIW (Ref. 5) for the respective welding processes.

Because welding sequence can have a significant effect on welding stresses, three different welding sequences were analyzed with FEM.

Finite Element Analysis

Temperature-dependent material properties of A572 Grade 50 were used in the thermal-mechanical finite element analysis, including thermal conductivity, specific heat, thermal expansion coefficient, Young's modulus, yield stress and strain hardening (Ref. 8).

A total of 13 cases were analyzed (Table 2). The thermal and stress analyses were both modeled as a two-dimensional problem in the plane of the web. Eight-mode quadratic interpolation elements were used for both thermal and stress analyses. The web was treated as unit thickness and the flange treated as unit width in the heat transfer analysis. On the other hand, the flange elements were given a width of 16.75 in. (425.5 mm) with a thickness of 1.125 in. (28.6 mm) used for the web elements for the stress analysis.

Since one of the parameters of interest pertained to effects from varying the diameter of the weld access hole, two finite element mesh designs were used for those cases in which the flanges were welded with the FCAW or EGW process, while only one mesh was used for the SAW process.

Assuming a condition of symmetry, a quarter of the joint was modeled. The finite element mesh for the 1/8-in. (3.8-mm) diameter weld access hole contained 374 elements (Cases 4–6) while the 1/8-in. (28.6-mm) diameter weld access hole contained 368 elements (Cases 1–3, 7) for the FCAW process. Only the elongated weld access hole was modeled for the SAW process, which contained 384 elements (Cases 8–10). Two models — the semicircle and elongated weld access holes — were considered for the EGW process. They contained 207 elements and 234 elements, respectively (Cases 10–13).

Table 2 — FEM Modeling Case

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Flange Welding</th>
<th>Access hole type</th>
<th>Joint geometry</th>
<th>Welding sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Single V</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>FCAW</td>
<td>1/8 in. dia.</td>
<td>Double V</td>
<td>D</td>
</tr>
<tr>
<td>8</td>
<td>SAW</td>
<td>Elongated</td>
<td>Single V</td>
<td>A</td>
</tr>
<tr>
<td>9</td>
<td>SAW</td>
<td>Elongated</td>
<td>Single V</td>
<td>B</td>
</tr>
<tr>
<td>10</td>
<td>SAW</td>
<td>Elongated</td>
<td>Square butt</td>
<td>A</td>
</tr>
<tr>
<td>11</td>
<td>SAW</td>
<td>Elongated</td>
<td>Square butt</td>
<td>B</td>
</tr>
<tr>
<td>12</td>
<td>SAW</td>
<td>Elongated</td>
<td>Square butt</td>
<td>A</td>
</tr>
</tbody>
</table>

Lumped Heat Input

The heat inputs from welding passes were lumped for cases in which the flanges were modeled with the FCAW or SAW process to make efficient use of CPU time. The background for lumped heat input modeling is discussed in detail elsewhere (Ref. 9).

The flange weld geometry was modeled as a series of stair-stepped elements. The 37 passes required to complete the full penetration single-V-groove flange weld using FCAW were lumped into 8 passes — Fig. 5. The root and first passes were combined as the first lumped pass. The heat input was then followed sequentially by lumping the remaining passes. Similarly, the 26 passes required to complete the double-V-groove flange weld with FCAW process was modeled as 8 lumped passes being deposited. As the stepping was being performed, only those elements associated with the passes currently being deposited and those that had been previously deposited were considered active at the weld joint. Ten minutes were allowed between each pass. The actual stair step modeling of these lumped passes in the finite element analysis is discussed in detail elsewhere (Ref. 5).

For the SAW process, 23 passes of the single-V-groove flange weld were lumped into a total of 10 heat input passes. The outer groove weld passes were lumped into 6 passes. Backgouging on the other side of the joint was considered as 1 lumped heat pass, but constraints from the root pass previously deposited on the joint were removed from the finite element model to simulate the gauging condition. Weld passes in the gouged groove on the other side of the joint was lumped into 3 heat inputs.

With the EGW process, the flange was welded as a single, up-
hull weld pass. Thus, lumping of the welding heat input was not required in the finite element analysis. In addition, no lumped heat input was used in modeling the web weld since it just needed 8 passes to complete.

**Ramp Heat Input Function**

To represent the transient condition of the welding process the thermal energy input was as a trapezoidal ramp function (Fig. 6) for each lumped pass. The ramp heat input and flux used for each process is given in Table 3. Details of the ramp heat input are discussed elsewhere (Ref. 9).

An arc efficiency of 0.85 was assumed for the FCAW process, with 0.95 for the SAW and EGW processes. Preheat and interpass temperature were chosen as 300°F (149°C) for both FCAW and EGW processes, and the ambient temperature was 70°F (21°C). No preheating was modeled for the SAW process, while a 300°F interpass temperature was assumed.

**Welding Sequence**

Since welding sequence can have a significant effect on welding stresses, three different welding sequences were modeled. The first sequence assumed the flanges were completely welded prior to welding the web. Since the flanges were welded first in this sequence, an edge constraint is developed at the flanges, which restricts shrinkage of the subsequent web weld. Consequently, for this welding sequence, denoted as Sequence A, the web weld was modeled with boundary conditions fixing the translation of the edges of the flange along its thickness in the global X direction.

The second fabrication sequence modeled applies to a condition where the web is completely welded first followed by flange welding. This assembly sequence develops a translational constraint in the global X direction along the spliced edge of the web during the flange welding. This second welding sequence is referred to as Sequence B.

Sequence B models a single-V-groove full penetration flange weld with the root opening located at the inside face of the flange. Sequence C is the same single-V-groove weld; however, the root opening is located at the outside face of the flange.

The third procedure modeled is a staggered flange and web welding sequence. In this model, one face of one flange is welded followed by welding one side of the web and then one face of the other flange. This sequence is then repeated to complete the full penetration butt joint. This sequence is referred to as Sequence D.

![Heat flux, q](image)

**Stress Analysis**

The temperature history obtained from thermal analyses of the various welding processes, sequences and joint geometries were used as thermal loading input for the stress analysis.

Since cracking has been seen initiating at the web and flange access hole interface, which then propagates through either the flange or web plate, residual stresses in the direction of member axis (Sx) along the access hole periphery are of interest.

Figure 7 shows the residual stress plots along the access hole for the FCAW process (Cases 1–3, 7). Tensile stress is plotted as a positive stress value. The access hole diameter is 1½ in. For Sequence A, the maximum tensile residual stress approaches yield stress (50 ksi) near the lower tangent point of the access hole (point C). This result agrees well with cracking problems experienced in the field during fabrication. The tendency in the field for the “flange, then web” welding sequence has been for cracks to initiate from the weld access hole and propagate through the web base metal.

For Sequence B, maximum residual tensile stress is 33 ksi and located at the upper transition tangent of the weld access hole (point B). This also is the area where cracking has been prone to occur in the field when the web is welded prior to the flange. For this welding sequence, the crack tends to initiate near point B and propagate through the flange base material. In addition to high tensile residual stress, the transient thermal stress also reaches yield point in tension at the top of the access hole near the weld (point A) and at the upper tangent point (point B) of the access hole. This high transient thermal stress occurs after the initial lumped weld pass (actual weld passes 1 and 2). However, this high tensile transient stress reduces from its initial values by the time the final cap passes are completed. The additional passes deposited to complete the joint tend to produce a more uniform temperature distribution with time near point A and, consequently, lower the final residual stress.

The maximum tensile residual stress of 50 ksi occurs near point B for Sequence C. For the alternating flange and web welding sequence (Sequence D), the maximum residual stress also occurs along the outer edge of the access hole along edge A to B but with a smaller stress value (40 ksi).

To investigate the effect of weld access hole diameter on residual stress, the finite element model was revised from a 1½-in.-diameter hole to 1¼ in. No other modifications were made to the thermal or stress analysis. Thermal and residual stress plots were developed along the 1¼-in.-diameter weld access hole similar to the 1½-in.-diameter model. The residual stress plots for the 1¼-in.-diameter weld access holes for Sequences A and B are shown on Fig. 8. Similar results, but with much smaller maximum tensile stress values, can be seen as compared with the 1½-in. access hole case.

Blodgett (Ref. 10) suggested large weld access holes could be beneficial in lowering residual stress. The numerical results indicate that lower maximum tensile residual stress does exist for the larger 1¼-in.-diameter access hole geometry.

The SAW and EGW processes were simulated for Cases A and B. Figures 9–11 show the residual stress distributions along the access hole periphery of each simulated joint.

Two types of access hole geometries were simulated for the EGW process. This was to study the effect of interface angle between the flange and web plates. Figures 10 and 11 show the residual stress distribution along the access hole periphery of each simulated case. The elongated hole geometry with a tangent interface resulted in lower residual stress than the normal interface access holes in both Sequences A and B.
Experimental Investigation

The actual testing was performed on W36 x 300 shapes, whereas the finite element analysis utilized W36 x 359 shapes. Five W36 x 300, A52, Grade 50 welded joint coupons were experimentally tested. The difference is the larger W36 x 359 shapes required more welding passes being modeled in the numerical model. However, all other variations, such as joint and access hole geometry and welding parameters, were minimal. Therefore, the thermomechanical responses of the numerical results for the W36 x 359 shape will be similar to those experimentally obtained for the W36 x 300 shape.

The effects on final residual stress and transient thermal strains from the various welding processes, welding sequences, and access hole geometry were evaluated by using blind hole drilling technique and high-temperature strain gauges, respectively. A specially designed data acquisition system was used to monitor the temperature and strain variations at specific locations during testing. The strain gauge locations were predetermined from the finite element analysis results where stresses and strains were predicted to be high. These locations were close to the access hole. Since the temperature around the access hole during welding was relatively high (up to 300°F), the effects of temperature change during welding on the strain gauge readings were considered and compensated.

All strain gauges were ¼ in. (9.5 mm) from the edges of the access holes for thermal strain measurements. Transient thermal strain data for the first web pass of Case 11 is shown in Fig. 12.

After the weldments returned to ambient temperature, residual stress measurements were made on the surface. A ¼-in.-diameter, high-speed drill bit was used to drill the hole. The residual stresses were calculated according to ASTM Standard E837-85 (Ref. 11). Two locations were selected on 4 of 5 specimens. All strain gauges were ¼-in. from the edges of the access holes or weld interface, as shown in Fig. 13. The local surface residual strain was gradually relieved by drilling, and reached a steady state at a depth that was about three quarters of the final hole depth. Representative experimental surface residual stress values obtained are tabulated in Table 4.

Numerical and Experimental Data Comparison

Transient thermal strains calculated by finite element analysis for various cases are presented elsewhere (Ref. 5). As a comparison between the numerical results and experimental measurements, Fig. 14 shows the transient strain components plotted correspond to the point as shown for Case 10.

The initial variance between numerical and experimental strain data ($t < 350$ s) shows a tendency for numerical results to overpredict experimental data. This is associated with the two-dimensional modeling of the moving electrode. However, the
Table 4 — Residual Stress Measurement Results

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Case 10</th>
<th>Case 11</th>
<th>Case 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S, (ksi)</td>
<td>30.8</td>
<td>-13.5</td>
<td>27.4</td>
</tr>
<tr>
<td>S, (ksi)</td>
<td>44.9</td>
<td>-76.0</td>
<td>57.4</td>
</tr>
<tr>
<td>Location E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S, (ksi)</td>
<td>46.0</td>
<td>-20.3</td>
<td>36.6</td>
</tr>
<tr>
<td>S, (ksi)</td>
<td>32.7</td>
<td>-47.7</td>
<td>72.3</td>
</tr>
</tbody>
</table>

"Of the three processes investigated, the FCAW process is recommended for splicing thick rolled shapes."

Conclusions

Residual stress normal to the weld joint near the access hole interface was calculated by the use of a thermal-mechanical finite element model for several conditions. Table 6 summarizes the numerical results.

The numerical model results in Table 6 indicate that for the FCAW process, the tensile residual stress at the crack initiation location (point B) is minimized by using a flange-web welding sequence (Sequence A) when a 1½-in.-deep access hole is used. In addition, the residual tensile stress can be further reduced by increasing the depth of the access hole to a 1½-in. depth. The EGW process with the same "flange, then web" welding sequence also produces lower residual stress at the access hole interface (point B). In addition, the tensile residual stress at point B was reduced by elongating the weld access hole from the semicircle to the elongated type access hole geometry. The SAW process appears to be the least desirable welding process for joining thick rolled shapes from a tensile residual stress consideration at point B.

Numerical results indicate a single-V-groove joint with the root opening at the outer surface of the flange (Sequence C) and a 1½-in.-diameter access hole produces high tensile residual stress at point B due to weld shrinkage. However, as the hole is elongated and made deeper to 1½ in., tensile residual stress is reduced to a compressive residual stress. Weld access holes that provide longer openings and larger widths in the web are more desirable from a residual stress vantage point. The longer opening reduces the joint constraint. In addition, by elongating the access hole, the termination point is pushed further away from the tensile residual stress field near the weld into a compressive residual stress region of the flange. This compressive residual stress is transverse to the tensile residual stress in the web. Their combination results in larger shear stress, and hence, a greater apparent ductility of the flange at the termination of the hole.

The angle of termination of the access hole from the web into the flange also has some effect on residual stress. Holes that terminate at a right angle with the flange have higher residual stress than a tangent transition termination.

The alternating welding sequence (Sequence D) with double-V-groove joints on the flanges did not show desirable results in terms of tensile residual stress at point B.

The cooling rate in the HAZ and its size were determined for the FCAW and EGW processes from experimental measurements. The FCAW process has a cooling rate of 372°F/s (207°C/s) while EGW is 19.4°F/s (10.7°C).
The use of single-V-groove joints, with the root opening at the inner face of the flange, and a double-V-groove weld for the web is desirable. This joint design results in minimal tensile residual stress at the flange-web interface of the access hole.

Future Work

The EGW process is a very promising method for splicing thick rolled shapes. This process tends to produce weldments with lower tensile residual stress. The use of single-V-groove joints, with the root opening at the inner face of the flange, and a double-V-groove weld for the web is desirable. This joint design results in minimal tensile residual stress at the flange-web interface of the access hole.

A "flange, then web" welding sequence (Sequence A) produces a minimal amount of tensile residual stress at the flange-web interface of the access hole and is the most desirable sequence.

The longer access hole opening produces less tensile residual stress at the flange web interface of the access hole. The interface with a tangent transition between web and flange is also desirable.

Table 6 — Residual Stress (Sx) from Numerical Analysis Near the Weld Access Hole

<table>
<thead>
<tr>
<th>Process</th>
<th>Sequence A</th>
<th>Sequence B</th>
<th>Sequence C</th>
<th>Sequence D</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCAW</td>
<td></td>
<td></td>
<td>1/8</td>
<td>1/8</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td></td>
<td></td>
<td>1/8</td>
<td>1/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGW</td>
<td></td>
<td></td>
<td>1/8</td>
<td>1/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

at 1500°F (816°C). Their respective HAZ size is approximately 0.13 in. (3.3 mm) from the weld interface for FCAW and 0.45 in. (11.4 mm) for EGW. This comparison indicates significant difference in the heat input characteristics of these two welding processes. Low fracture toughness is anticipated for EGW weldments.

Acknowledgments

The authors wish to acknowledge the support of the U.S. Army Corps of Engineers, both the Portland District Office and the Waterways Experiment Station Information Technology Laboratory. This project was performed under the Corps' contract DACW39-89-L-0006.

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The authors wish to thank Jim Snyder of Bethlehem Steel Corp., who provided the rolled shapes used in these experiments, and Tom Campbell of J. T. Edwards for cutting and delivering the material. Our thanks also extend to Ken Runyon, John Bosworth and Bruce Hornlourger of Beasley Co. for their support in preparing the FCAW joints.

The authors wish to acknowledge Cort Reiser for welding test coupons and many coworkers and associates in the Department of Welding Engineering at The Ohio State University who made contributions throughout the course of this investigation.

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Because the potential exists for head and eye injuries at nearly every job site, proper use of personal protective equipment such as safety spectacles and hard hats is a must.

BY INGEMAR H. OLSSON

Virtually every worker required to wear a hard hat — the most familiar symbol of personal protective equipment (PPE) — now wears one, yet studies indicate about 30% of those users aren’t in compliance with OSHA standards.

The news isn’t as good for eye protection. According to the Industrial Safety Equipment Association (ISEA) and Compliance magazine, 68% of all employees who should use protective eyewear, don’t. That’s why an estimated 400,000 eye injuries occur on the job every year, according to the National Society to Prevent Blindness.

We all know the Occupational Safety and Health Administration (OSHA) has very strict rules regarding head and eye protection. For instance, 29 CFR 1910.133 mandates we use eye protection whenever we’re exposed to flying objects, infrared (IR) and ultraviolet (UV) radiation, glare, liquids, molten metals and other dangers. Have I covered your job site? It’s hard to think of any project where we don’t face a danger from head and eye injuries.

Of course, we can’t simply assume OSHA regulations will solve all our problems; we have to assume responsibility for protecting ourselves. That means wearing hard hats, welding helmets and safety spectacles on the job.

Hard hats and protective eyewear are readily available. The cost varies depending on style, use, requirement and quantity. Traditional safety spectacles used on a job site to protect against the sun’s glare and any flying objects can be purchased for only $5 or $10. A basic all-around hard hat costs about $10.

INGEMAR H. OLSSON is National Sales Manager, Professional Trades, Construction and Welding Channels, Dalloz Safety, Reading, Pa., (610) 371-6161.
Let's review some important basics for proper head and eye protection.

**Head Protection**

- Always wear appropriate head protection. The latest revision to the ANSI Z89 regulation groups hard hats into Type 1, which protects against falling objects, and Type 2, which protects against both falling objects and side impact. Hard hats are further defined as classes G, E and C. Class G head protectors reduce the danger of contact exposure to low-voltage conductors, as well as to the impact and penetration requirements of either a Type 1 or Type 2. Class E hard hats reduce the danger of contact exposure to high-voltage conductors. Class C hard hats provide no protection against contact with electrical conductors.

- Make sure it fits well. Hard hats should not fall off when the head is bent down or the person wearing it looks at his or her feet. If falling is a potential hazard in your work environment, your biggest danger is that your hard hat will not stay on when you fall. Wear one with increased side impact protection and a chinstrap to secure it.

- Obey “Hard Hat Area” signs. These are posted to protect you wherever there is danger from falling and flying objects and possible side impacts.

- Never wear a hard hat backward. When wearing a welding helmet with a safety cap, many welders often turn the suspension around and wear the shell backward. While regulations do not specifically address this issue, if a hard hat was not tested in this “as worn” position, it does not meet the ANSI Z89 standard. Contact the hard hat manufacturer to determine which uses are acceptable for a particular hard hat or head protector.

- Don’t drill holes in the shell of a hard hat. Doing so may nullify its Class E or G rating, and/or lessen its impact resistance.

- Don’t use adhesives or paint on a hard hat. They could attack or damage the shell, reducing the level of protection.

- Hard hats generally do not have a service life. That’s because hard hats are used in and subjected to a variety of conditions. Obviously, a hard hat worn every day will need to be replaced far more quickly than a cap used by a manager on a once-a-week trip to a hard hat area.

- Take advantage of appropriate accessories. In addition to welding equipment, some manufacturers offer various attachments for hard hats, including hearing protection, i.e., earmuffs, as well as visors and faceshields. Liners are available for cold weather wear.

- Headgear for visors need to be adjusted for a personalized fit. Ratchet-type headgear suspensions are available and can be easily adjusted simply by turning the ratchet knob. Other types use a pin-lock design style, which can also be easily adjusted to accommodate different head sizes. Visors should be securely attached to headgear following the manufacturer’s instructions. Do not guess or have a “looks okay” attitude. For any faceshield to work and protect as it was intended, the visor must be attached correctly.

- Maintain head protection. Clean hard hats with mild soap or detergent and warm water. Never use solvents. Inspect the suspension frequently and discard it at the first sign of deterioration or fraying.

**Eye Protection**

- Don’t use regular prescription glasses as safety spectacles. If you wear prescription glasses, you should obtain safety spectacles that incorporate your prescription, or use protective eyewear that comfortably fits over prescription eyewear. Always wear safety spectacles underneath welding helmets, visors and faceshields, which are considered secondary, not primary, protection.

- Go for the best. Safety spectacles of inferior optical quality can distort or blur vision and depth perception, causing headaches, nausea and fatigue, as well as accidents. Make certain any protective eyewear with plastic lenses meets high mass and high-velocity impact and penetration criteria in accordance with the ANSI Z87.1 standard. Eyewear meeting these criteria are marked with “Z87.”

- Always use a shaded lens when welding, brazing, cutting with a torch, etc. Welding lenses and visors are manufactured in shades to protect against radiation hazards and are rated from 1 through 14 — the higher the shade’s number, the darker the lens and the greater its ability to absorb IR radiation. Welding, cutting and brazing operations produce three types of radiation. Visually, one can see the brightness, while IR is felt as heat. Invisible UV radiation is also present. A shade 3 lens will transmit about 14% of visible light and 9% of IR. By contrast, a shade 10 lens transmits only 0.01% of visible light and 0.001% of IR.

  For example, if you do light cutting or brazing, use a shade 3 or 5 lens. Arc welding requires a minimum of shade 10. The identification marking for any shade is stamped on the lens.

  With electrical contracting, electrical arcs and flash are among the hazards that may be encountered, often without warning. Special UV- and IR-absorbing lenses are available to protect against this, as well as intermittent electrical arc. Again, match the eye protection with the severity of the radiation.

- Do not use nonabsorptive, tinted lenses for welding. Many lenses offered by Dalloz Safety and other manufacturers are not absorptive lenses dedicated for welding. For example, Willson® TCG™ dark gray lenses absorb 86% of IR radiation, but are not absorptive welding lenses. They are mainly used outdoors for electrical work where color recognition of wiring is essential.

  When electrical contacting, electrical arcs and flash are among the hazards that may be encountered, often without warning. Special UV- and IR-absorbing lenses are available to protect against this, as well as intermittent electrical arc. Again, match the eye protection with the severity of the radiation.
• Consult the standards. Both ANSI Z87.1-1989 and OSHA 29 CFR 1910.133 contain selection charts on shaded lenses for welding, cutting and related applications. Consult these standards for specifics. The CSA Z94.3-92, Industrial Eye and Face Protectors, standard lists shaded numbers and their maximum transmittance values for UV, IR and visible light transmission. The Canadian standard also requires that sideshields used to protect against UV, IR and visible radiation have a shade number equal to, or greater than, the front lens filters, but not greater than a shade 5 rating.

• Lasers require special lenses. Shaded lenses for welding cannot be used when working with lasers because of their monochromatic light, which requires specialized protective eyewear. Take all proper precautions with protective eyewear for lasers since nearly 70% of accidents involve eye injuries.

• Take advantage of special lens options to make your job easier and safer. Consider a fog-resistant lens coating for workplaces with high humidity, or an indoor-outdoor lens if you frequently move from a warehouse to an outside stocking area and vice versa. An indoor-outdoor lens is designed to protect against both sunlight and harsh overhead lights. Make sure safety spectacles provide sufficient protection against ultraviolet and infrared radiation.

• Be certain tinted lenses do not affect color. This is especially important if you are working with electrical wiring or encountering traffic signals.

• Use secondary protection as needed. When a job involves severe impact or other hazards, for example from grinding or sanding, use a face shield or visor as a secondary safety device. OSHA requires that when welding helmets are used, safety spectacles must still be worn as the primary eye protection. The same is true for visors and faceshields. That’s because a welding helmet could accidentally flip up, thus exposing unprotected eyes to high glare, high UV and high IR radiation.

• Keep safety spectacles and other protective eyewear clean and in good condition. Use only mild soap or detergent. Do not use any solvents. To avoid scratching, do not use paper towels or nontreated paper to dry plastic lenses. Use a diluted household bleach (one part 5% household bleach to ten parts water) to disinfect protective eyewear. Most safety spectacles and goggles have replaceable lenses, so change them whenever they are scratched or pitted. Frames should be discarded when cut, broken, faded or visibly worn. If goggles or faceshields are subjected to a chemical splash, they should be discarded. Unseen stress cracks can be a real threat if the visor or lenses are later used for impact protection.

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Welding Safety and Health

Effective training is the key to any safety program. Welders (this includes brazers and solderers) and cutters must be trained in the proper use of equipment and processes, and they must know all the safety rules pertaining to their jobs and the consequences of not following them.

For any training program to be effective, management must support it and give direction in its implementation. Only with this commitment to safety and health will the results be positive.

Understand the Hazards

Users of equipment must read and understand the manufacturer’s instructions on safe operation. Material safety data sheets (MSDS) are provided by manufacturers of consumables, and they must be made available to employees by the employer. They must be read because the MSDS identify hazardous materials that may be present in the product and permissible exposure limits. Certain specifications require precautionary labels, and these should be read and followed.

Employers are required to train their employees with respect to hazardous materials used in the workplace. Individuals must also be trained to recognize hazards to safe operation. For instance, defective or worn electrical insulation must be recognized and not tolerated in welding and cutting. The same can be said for worn or defective hoses in oxyfuel operations.

Persons who must perform their job in potentially hazardous locations, such as a confined space or poorly ventilated area, must be thoroughly informed of the hazards involved and be given the proper equipment and assistance to perform under those conditions.

Radiant Energy Protection

Individuals in areas adjacent to welding and cutting must be protected from radiant energy, sparks and spatter by flame-resistant screens and shields, suitable eye and face protection and protective clothing. Protective screens should provide for air circulation both above and below them. If arc welding or cutting is performed constantly next to painted walls, the walls should have a covering that has low reflectivity to ultraviolet radiation. Paints with titanium dioxide or zinc oxide have low reflectivity, but pigments with a base of powdered or flaked metals are not recommended. Color pigments can be present if they do not increase reflectivity.

Public demonstrators of welding and cutting are responsible for the safety of the observers. Appropriate eye protection must be available, as well as proper ventilation of fumes. Cables and hoses must be directed away from the public area, and fire extinguishers must be readily available.

Fire Concerns

Open flames, electric arcs, sparks, hot metal and spatter all present a potential fire hazard. Sparks can travel great distances from their source and lodge in cracks or other small openings. Combustibles in the work area present a particular hazard. Perform work away from combustibles or shield it with appropriate noncombustible barriers. Common combustible materials encountered are wood, paper, plastics, cloth materials, chemicals, flammable liquids and gases, dry grass and brush. It is recommended that floors be free of combustible materials at least for a 35-ft radius around the work area.

The best protection would be to have specially designated areas free of fire hazards for welding and cutting. If that is not possible, cover cracks, windows, doorways and other openings with flame-resistant material. Enclosing the work area with flame-resistant screens is a desirable option.

Carefully store fuel for engine-driven equipment, and follow manufacturers’ instructions, since vapors can be explosive under certain conditions. Take particular care to prevent gas leakage from acetylene, propane and other fuel gas cylinders and apparatus. Check them on a regular basis.

If a metal wall, ceiling or partition is adjacent to a welding or cutting operation, any combustibles on the other side must be removed since metal readily conducts heat. If removal is not possible, a fire watcher should be stationed with the combustibles, and a fire extinguisher available. A thorough inspection for signs of fire should be conducted up to 30 minutes after completion of the operation.

Burns can be serious. Always take precautions to protect your eyes, face and body from ultraviolet and infrared radiation, sparks and spatter. Those in the work area other than the operator should also be protected.

Explosion Precautions

When flammable gases, vapors and dust mix with oxygen in certain proportions, the danger of explosion exists. Heat and sparks from welding and cutting can be the source of ignition; therefore, these operations should not be performed in atmospheres that contain a combustible mix.

Hollow containers must be vented before applying heat, and never apply heat to containers that have held an unknown material, a combustible substance or a substance that may form flammable vapors. Never apply heat to a container that is covered by an unknown, toxic or flammable substance.

Before starting the operation, clean the container thoroughly or fill it with an inert gas. Always wear appropriate eye protection when the risk of explosion is present.

Welding Safety and Health

Eye and Face Protection

Anyone viewing the arc must have a welding helmet or face shield with the appropriate filter plates for the process being viewed. Safety spectacles, goggles or other suitable eye protection must also be worn during welding and cutting. These devices must have side shields when there is danger of injurious rays or flying particles such as from grinding or chipping. Since the arc is covered by flux in the submerged arc welding process, an arc welding helmet is not necessary, but tinted safety glasses should be worn since occasional flashes of the arc might show through the flux.

Safety goggles with the appropriate filter plates and side shields must also be worn with oxyfuel gas welding and cutting. Torch brazing and soldering requires safety spectacles with the appropriate filter. Resistance, induction and infrared welding require operators to wear safety spectacles, goggles and face shields to protect themselves from spatter.

Fumes and Gases

Factors that influence fume generation are welding current, arc voltage, transfer mode, welding process and shielding gas.

Generally, fumes increase with an increase in welding current, although there are some covered, flux cored and solid electrodes in which the fume increase is nonproportional. Also, an increase in voltage generally increases fume generation. Arc voltage is directly related to arc length.

Arc turbulence encountered with gas metal arc welding in the short circuiting mode contributes to a relatively high fume generation during this transfer. The higher current needed with spray transfer has an effect on fume generation.

The use of CO₂ as a shielding gas will generate more fumes than argon-rich mixtures. When using an inert gas such as helium, more fumes are generated when compared to argon.

In studies that considered the ratio of weight of fumes generated to weight of weld metal deposited, covered electrodes and self-shielded flux cored electrodes produced the most fumes. Gas-shielded flux cored electrodes generated somewhat less fumes and solid wires, the least. Fumes from the submerged arc process are captured in the flux and slag coverage and are not released to the atmosphere.

Minimize Fume Exposure

Keep your head to one side of the fume plume and not directly in it. If possible, position the work so the fume rises to one side. Use a helmet that curves under the chin and toward the chest. Close-fitting helmets and respirators are beneficial.

A proper ventilation system is necessary. The ventilation can be localized at the point of welding or it can be a general filtering of the shop air through natural convection or by mechanical means. The system must ensure that concentrations of hazardous airborne contaminants are below levels allowed by the Occupational Safety and Health Administration (OSHA) or other pertinent authorities.

There are materials sometimes present in consumables, base metals or coatings that have very low permissible exposure limits if released into the atmosphere as fumes during welding, brazing or cutting operations. The table below shows some of those compounds and the base or filler metals that may release them.

The Occupational Health and Safety Administration has established permissible exposure limits (PEL) of airborne contaminants. To ensure levels are within allowable limits, air samples must be taken at the breathing zones of the personnel involved. Information on how to obtain an accurate sample in the breathing zone is contained in ANSI/AWS F1.1, Methods for Sampling Airborne Particulates Generated by Welding and Allied Processes. The amount and composition of welding fume can be determined with the testing outlined in this document.

Employers must make available and ensure the employee understands the information contained in material safety data sheets provided by manufacturers of welding consumables. These sheets provide information on materials in electrodes, rods and fluxes that are hazardous or harmful to health.

The Occupational Health and Safety Administration has

### Possible Toxic Materials Evolved during Welding or Thermal Cutting

<table>
<thead>
<tr>
<th>Base or Filler Metal</th>
<th>Evolved Metals or Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon and low-alloy steels</td>
<td>Chromium, manganese, vanadium</td>
</tr>
<tr>
<td>Stainless steels</td>
<td>Chromium, manganese, nickel</td>
</tr>
<tr>
<td>Manganese steels and hardfacing materials</td>
<td>Chromium, cobalt, manganese, nickel, vanadium</td>
</tr>
<tr>
<td>High-copper alloys</td>
<td>Beryllium, chromium, copper, lead, nickel</td>
</tr>
<tr>
<td>Coated or plated steel or copper</td>
<td>Cadmium*, chromium, copper, lead nickel, silver</td>
</tr>
</tbody>
</table>

*When cadmium is a constituent in a filler metal, a warning label must be affixed to the container or cart.

### Electrical Safety

Bare or poorly insulated conductors are a main source of electrical shock in welding. Precautions must be taken against contacting bare elements in the welding or primary circuit, especially when the welder is required to be in a cramped kneeling, lying or sitting position. Welding in damp conditions is an electrical hazard. Welders should not stand in water when welding, and dry gloves and clothing should be worn at all times.

At a minimum, rubber-soled shoes should be worn for protection while standing on potentially conductive surfaces. It is better if the surface is insulated with a rubber mat. Remove rings and jewelry before welding as a precaution against electric shock.

Equipment should be installed, operated and maintained according to the manufacturer's recommendations and electrical codes. The workpiece welded and the frame of electrically powered machines must be connected to a good electrical ground. Chains, wire ropes, cranes, hoists and elevators must not be used as grounding connections or to carry welding current. Do not allow the metal parts of electrodes, electrode holders or torches to touch bare skin or wet clothing. Electrode holders should not be cooled by immersion in water, and do not drape or coil welding cables around the body.
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NACE Northern Area Western Conference. February 26-28, Hilton Hotel, Anchorage, Alaska. Sponsored by NACE International, the Corrosion Society. Contact: Dan Powell, Co-chairman, (403) 235-6400, e-mail: dan.powell@corrpro.ca.

International Laser Safety Conference. March 5-8, Catamaran Resort Hotel, San Diego, Calif. Sponsored by the Laser Institute of America. Contact: LIA, 13501 Ingenuity Dr., Ste. 128, Orlando, FL 32826.


• Max International. May 6-10, IX Center, Cleveland, Ohio. Co-hosted by the American Welding Society and The Precision Metalforming Association, this collocated event is comprised of the AWS International Welding and Fabricating Exposition and Annual Conference and METALFORM ExpoSium, Contact: AWS Convention and Exhibitions Dept., 550 NW LeJeune Rd., Miami, FL 33126, (800) 443-9353 ext. 256 or (305) 443-9353 ext. 256, FAX: (305) 442-7451.

♦ Tenth International JOM-Jubilee-Conference on the Joining of Materials, JOM-10. May 11-14, Helsingor, Denmark, Co-sponsored by the Institute for the Joining of Materials and AWS. Contact: Institute for the Joining of Materials, Klintohøj Venge 21, DK-3460 Birkerød, Denmark. 45 45 82 80 85, FAX: 45 45 94 08 55 or e-mail: jom_aww@post10.tele.dk.

Twin Cities 2001 Advanced Productivity Exposition. May 15-17, Minneapolis Convention Center, Minneapolis, Minn. Sponsored by the Society of Manufacturing Engineers (SME), America Machine Tool Distributors' Association (AMTDA) and the Association for Manufacturing Technology (AMT). Contact: SME Customer Service, (800) 733-4763 or (313) 271-1500 ext. 1600 or visit the SME Web site at www.sme.org.

International Robots and Vision Show. June 5-7, Rosemont Convention Center, Chicago. Sponsored by the Robotic Industries Association (RIA) and Automated Imaging Association (AIA). Contact: RIA/AIA, 900 Victors Way, PO.

Note: A diamond (♦) denotes an AWS-sponsored event.


15th International Joining, Cutting and Surfacing Fair “Schweissen & Schneiden.” Sept. 12–18, Essen, Germany. Contact: Claus-Peter Regiani or Christina Kursawe, 49(0)201-7224-227 or -529, FAX: 49(0)201-7244-435, e-mail regiani@messe-essen.de or kursawe@messe-essen.de, www.messe-essen.de.

First Middle East Nondestructive Testing Conference and Exhibition. September 24–26, Gulf International Convention Centre, Bahrain. Cosponsored by the American Society for Nondestructive Testing and the Bahrain Society of Engineers. Contact: The Conference Secretariat, Bahrain Society of Engineers, P.O. Box 835, Maama, Bahrain, 973-727 100, FAX: 973-729 819, e-mail: Mohandis@batelco.com.bh.

International Conference on Advances in Materials and Processing Technologies. September 18–21, Leganés, Madrid, Spain. Contact: AMPT ’01 Congress Secretariat, Fundación Universidad Carlos III, Congregación, Avda. de la Universidad, 30, 28911 Leganés, Madrid, Spain, 34 91 624 91 42, FAX: 34 91 624 91 47, e-mail: congrega@fund.uc3m.es.

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Educational Opportunities


Respiratory Protection and Fit Testing. February 27–28, Salt Lake City, Utah. Sponsored by the Rocky Mountain Center for Occupational and Environmental Health, University of Utah. Contact: Registration Coordinator, the Rocky Mountain Center for Occupational and Environmental Health, University of Utah, 75 South 2000 E., Salt Lake City, UT 84112, (801) 581-5710, FAX: (901) 585-5275.

Rocky Mountain Comprehensive Review of Industrial Hygiene. March 5–9, Salt Lake City, Utah. Sponsored by the Rocky Mountain Comprehensive Review of Industrial Hygiene.
Boiler and Pressure Vessel Inspectors Training Courses and Seminars. 2001 schedule, National Board of Boiler and Pressure Vessel Inspectors Training and Conference Center, Columbus, Ohio. Conducted by The National Board of Boiler and Pressure Vessel Inspectors. For courses and times, contact: Richard McGuire, Manager of Training, (614) 888-8320, e-mail: rmcguire@nationalboard.org; www.nationalboard.org.

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### Educational Opportunities

**AWS Schedule — CWI/CWE Prep Courses and Exams**

Exam application must be submitted six weeks before exam date. For exam information and application, contact the AWS Certification Dept., (800) 443-9353 ext. 273. For exam prep course information, contact the AWS Education Dept., (800) 443-9353 ext. 229. Dates are subject to change.

<table>
<thead>
<tr>
<th>Cities</th>
<th>Exam Prep Courses</th>
<th>CWI/CWE Exams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage, Alaska</td>
<td>EXAM ONLY</td>
<td>March 24</td>
</tr>
<tr>
<td>Atlanta, Ga.</td>
<td>Feb. 26–March 2</td>
<td>March 3</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bangor, Maine</td>
<td>April 2–6</td>
<td>April 7</td>
</tr>
<tr>
<td>Birmingham, Ala.</td>
<td>EXAM ONLY</td>
<td>May 26</td>
</tr>
<tr>
<td>Buffalo, N.Y.</td>
<td>EXAM ONLY</td>
<td>Feb. 17</td>
</tr>
<tr>
<td>Charlotte, N.C.</td>
<td>Feb. 12–16</td>
<td>Feb. 17</td>
</tr>
<tr>
<td>Cincinnati, Ohio</td>
<td>May 14–18</td>
<td>May 19</td>
</tr>
<tr>
<td>Chicago, Ill.</td>
<td>April 30–May 4</td>
<td>May 5</td>
</tr>
<tr>
<td>Cleveland, Ohio</td>
<td>May 11–May 15</td>
<td>May 12</td>
</tr>
<tr>
<td>Columbus, Ohio</td>
<td>EXAM ONLY</td>
<td>March 3</td>
</tr>
<tr>
<td>Corpus Christi, Tex.</td>
<td>EXAM ONLY</td>
<td>May 5</td>
</tr>
<tr>
<td>Denver, Colo.</td>
<td>Feb. 26–March 2</td>
<td>March 3</td>
</tr>
<tr>
<td>Detroit, Mich.</td>
<td>EXAM ONLY</td>
<td>April 21</td>
</tr>
<tr>
<td>Gulfport, Miss.</td>
<td>Feb. 19–23</td>
<td>Feb. 24</td>
</tr>
<tr>
<td>Houston, Tex.</td>
<td>March 5–9</td>
<td>March 10</td>
</tr>
<tr>
<td>(API 1104 Clinic &amp; CWI also offered)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indianapolis, Ind.</td>
<td>Aug. 6–10</td>
<td>Aug. 11</td>
</tr>
<tr>
<td>Jacksonville, Fla.</td>
<td>EXAM ONLY</td>
<td>April 28</td>
</tr>
<tr>
<td>Knoxville, Tenn.</td>
<td>March 12–16</td>
<td>March 17</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Las Vegas, Nev.</td>
<td>April 23–27</td>
<td>April 28</td>
</tr>
<tr>
<td>Long Beach, Calif.</td>
<td>May 21–25</td>
<td>May 26</td>
</tr>
</tbody>
</table>

### Cities

- Miami, Fla. EXAM ONLY March 15
- Mobile, Ala. EXAM ONLY Feb. 17
- Nashville, Tenn. May 21–25 May 26
- New Orleans, La. April 30–May 4 May 5
- Newark, N.J. March 12–16 March 17
- Oklahoma City, Okla. Feb. 5–9 Feb. 10
- Pensacola, Fla. EXAM ONLY April 21 April 22
- Phoenix, Ariz. March 19–23 March 24
- Pittsburgh, Pa. May 14–18 May 19
- San Francisco, Calif. May 14–18 May 19
- Seattle, Wash. EXAM ONLY April 28
- Spokane, Wash. May 14–18 May 19
- Springfield, Mo. March 19–23 March 24
- St. Louis, Mo. May 21–25 May 26
- Tulsa, Okla. EXAM ONLY March 10
- York, Pa. EXAM ONLY April 28

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Circle No. 29 on Reader Info-Card
By Susan Campbell

AWS and Trinity Industries Join to Provide Web Learning Applications

The American Welding Society (AWS) and Trinity Industries, Inc., announced they have finalized an exclusive relationship to convert AWS branded educational materials into interactive Web-based learning applications. The chosen technology provider for this collaboration is Vellis Knowledge, Inc., a leader in industrial e-learning.

Vellis brings industrial manufacturing companies cost-saving answers for a broad range of business problems. Through technology integration, Vellis offers a solution to a strategic problem of all industrial manufacturing clients: the widening skills gap between what companies need in technical skills and the current knowledge base of the work force.

Timothy R. Wallace, Trinity's chairman, president and chief executive officer, said, "Having a trained and certified manufacturing work force continues to be a high priority for industrial companies. I am enthusiastic about taking the best of Trinity's manufacturing expertise, partnering with the American Welding Society and merging their branded educational products with the best of the Internet through the Vellis Learning Management System."

According to Dr. Frank G. DeLaurier, executive director of AWS, "We are excited about the possibility of accomplishing part of our educational mission through our collaboration with Trinity Industries and Vellis's learning systems. The delivery of our many educational products in a Web-based learning environment will ensure that industry can take advantage of the latest technical information AWS has to offer."

Douglas Brenner, chief executive officer for Vellis Knowledge, Inc., said, "This relationship with Trinity and the American Welding Society is the perfect fit for Vellis, as we focus on integration of technology, courseware-content and services to improve learning outcomes for industrial workers. This is much more than just a lower cost training solution."

The first of ten modules, "Weld and Base Metal Discontinuities," will be available early this year. The completion of the series is expected in the late spring.

About Trinity Industries

Trinity Industries, Inc., headquartered in Dallas, Tex., is one of the nation's leading diversified industrial companies. Trinity operates through six principal business segments: the Railroad Group, the Inland Barge Group, the Parts and Services Group, the Highway Construction Products Group, the Concrete and Aggregate Group and the Industrial Group. Trinity's Web site may be accessed at www.trin.net or for specific growth information, visit www.TrinityGrowth.com.

About Vellis

Vellis Knowledge, Inc., provides complete skills, knowledge and training solutions to corporations around the world. Vellis specializes in industrial applications and is considered a world leader in the creation of learning resource materials for skilled workers in manufacturing and related industries. Through an award-winning team approach, Vellis creates high-level strategic solutions that are customized to the specific business challenges of individual corporations. These unique turnkey solutions combine software, content and specialized services. Headquartered in Chicago, Ill., Vellis also operates network offices in Michigan, Texas and Brisbane, Australia. Visit the company's Web site at www.Vellis.com.

About AWS

The American Welding Society, founded in 1919, is the largest organization in the world dedicated to advancing the science, technology and application of materials joining. Headquartered in Miami, Fla., AWS serves approximately 50,000 members in the United States and around the world. AWS is dedicated to providing leadership and services and works to serve and coordinate the joining industry in matters of codes, standards, materials, education, certification and research. AWS can be found at www.aws.org on the Web.
Pittsburgh Students Visit Sheet Metal Workers’ Apprentice Training Facility

Students from the South Vo-Tech High School, Pittsburgh, Pa., welding program visited the Local #12 Sheet Metal Workers Apprenticeship Training School facility to learn about the various welding techniques they utilize. Instructor George Kirk accompanied the students on the field trip.

CAN WE TALK?

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

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Volunteers Sought for the D9 Committee on Welding, Brazing and Soldering of Sheet Metal

The American Welding Society (AWS) D9 Committee on Welding, Brazing and Soldering of Sheet Metal is looking to add members to the Committee.

The Committee recently published AWS D9.1:2000, Sheet Metal Welding Code. The Committee is set to begin the next revision of the code. Individuals knowledgeable in the welding and braze welding of sheet metal in nonstructural applications are encouraged to apply. Contractors, welding instructors and welders involved in heating, ventilating and air conditioning, food processing equipment, cabinetry, electrical panels or other nonstructural applications are particularly sought.

If you are interested in participating in this work, please submit your application on the AWS Web site at www.aws.org or contact the D9 Committee Secretary, John Gayler, at (800) 443-9353 ext. 472 or via e-mail at gayler@aws.org.

Ordering AWS Publications

AWS publications are now being distributed by Global Engineering Documents. To order publications, call Global at (800) 854-7179. Publications can also be ordered from the e-store on the AWS Web site at www.aws.org.
SAFETY AND HEALTH

TOPICS

• Thermal Spraying
Fact Sheet No. 20

Introduction

Thermal spraying processes use modification of arc, plasma and oxyfuel energy sources to produce the resulting heat, atmosphere and particle velocity needed to properly coat an object (a substrate) with the desired thickness and properties of a surfacing material. The high temperatures, velocity and projectile distance of the spraying processes create a unique set of safety hazards for the operator and those nearby.

Definitions/Process Descriptions

According to ANSI/AWS A5.0, Standard Welding Terms and Definitions, thermal spraying (TSP) is a group of processes that deposit molten metallic or nonmetallic surfacing materials onto a prepared substrate. All thermal spraying processes introduce a feedstock (usually a powder or wire) into a heating device (combustion or electrical). There, the material is heated, blended to the heat plume and sprayed onto a prepared substrate. The molten particles strike the surface, flatten and form thin platelets that conform and adhere to the substrate and to one another. As they cool, particles build up a lamellar structure to form the desired coating. Combustion processes include low-velocity oxyfuel (LVOF) and high-velocity oxyfuel (HVOF) systems. Electrical processes are arc (two-wire), plasma arc (powder) and plasma induction (powder) systems. Typical operating conditions for the various processes are shown in Table 1 below.

Potential Hazards and Hazardous Effects

• Dust - Finely divided airborne solid particulate should be treated as an explosive and inhalation hazard. Adequate ventilation and wet collection of overspray should be provided to minimize these hazards.
• Fumes, Vapors and Gases - Ventilate and use safe practices according to ANSI Z49.1, the MSDSs and AWS Safety and Health Fact Sheet No. 1. In addition, most spray and abrasive blasting operations require the use of an approved respirator that complies with requirements of ANSI Z88.2. Also, precautions should be exercised to avoid the presence of chlorinated hydrocarbon solvent vapor in the area of the arc or plasma spray. Hazardous plasagene gas can be produced when hydrocarbon vapors are exposed to ultraviolet radiation from these processes.
• Noise - The loud noise (high dBA ranges) of these processes must be addressed. Ear muffs and noise control procedures should be provided to conform to the standard limits of OSHA 29 CFR 1910.95.
• Radiation - Intense ultraviolet (UV) and infrared (IR) radiation occur with these processes. They require total protection of the eyes and all exposed skin to avoid eye damage and burns. Eye shades of No. 3-6 for combustion and 9-12 for electrical processes are recommended (see AWS Safety and Health Fact Sheet No. 2).
• Electric Shock - The higher process voltages used in arc, plasma arc and plasma induction spraying increase the risk of electric shock. Take precautionary measures according to ANSI Z49.1 and AWS Safety and Health Fact Sheet No. 5.
• Fire - Use care when operating spray guns to avoid injury to personnel or causing a fire (see AWS Safety and Health Fact Sheet No. 6).
• Mechanical Hazards - The substrate surface preparation, spraying, finishing and post-treatment operations involved with thermal spraying processes present a variety of mechanical hazards specific to thermal spraying. Consult the equipment manufacturer’s manuals and material supplier’s MSDSs for their recommended safe practices.
• Compressed Gases - Compressed gases require safe handling and use as specified in ANSI Z49.1.

Information Sources


Table 1 — Typical Operating Conditions for the Various Processes

<table>
<thead>
<tr>
<th></th>
<th>LVOF</th>
<th>HVOF</th>
<th>Arc</th>
<th>Plasma Arc</th>
<th>Plasma Induction (Atmosphere)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>to 5000°F</td>
<td>to 6000°F</td>
<td>4000-15,000°F</td>
<td>4000-15,000°F</td>
<td>to 30,000°F</td>
</tr>
<tr>
<td>Velocity</td>
<td>200-700 ft/s</td>
<td>2500-4000 ft/s</td>
<td>800-1100 ft/s (&lt;Mach 1)</td>
<td>800-1800 ft/s (&lt;Mach 2)</td>
<td>800-1800 ft/s (&lt;Mach 2)</td>
</tr>
<tr>
<td>dBA (Sound Level)</td>
<td>110</td>
<td>150</td>
<td>115</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Spray Distance</td>
<td>4-10 in.</td>
<td>6-18 in.</td>
<td>2½-6 in.</td>
<td>2½-6 in.</td>
<td>3-8 in.</td>
</tr>
</tbody>
</table>
**AWS Expo Named Top-Ranking Show**

The American Welding Society (AWS) International Welding and Fabricating Exhibition has been named one of the top trade shows by *Expo Magazine*. Based on information from exhibit surveys, the September issue of *Expo* found the AWS Expo attracts the highest percentage of first-time attendees. The AWS Expo was compared with a number of national and international trade shows, including Comdex and FABTECH, making the International Welding and Fabricating Exhibition one of the top-ranking annual shows.

Beginning in 2001, everything the AWS Expo has to offer will combine with the technology and programs of the Precision Metalforming Association's (PMA) METALFORM show to create MAX International Manufacturing Applications Exhibition.

The first MAX International will run May 6–10 at the I-X Center in Cleveland, Ohio. More than 800,000 sq ft of exhibit space, housing more than 1200 exhibitors will bring together the latest technology in welding, stamping, cutting and fabricating equipment. The combination of these world-renowned shows will give tens of thousands of attendees the greatest selection of equipment and materials ever offered in one place.

Exhibition space and event registration are still available. Companies interested in exhibiting their products and services should contact the AWS Convention and Exposition Department at (800) 443-9353 ext. 221. Up-to-date-event information, including special conference sessions and receptions, is available on the AWS Web site at www.aws.org.

**Santa Clarita Valley College Responds to Demands of High-Tech Industries**

The College of the Canyons, located in Valencia, Calif., has been supplying southern California industry with skilled certified welders since 1976. With the rapid expansion of high-technology business in the Santa Clarita valley and vicinity, there has been a growing demand for welders with automation skills. These positions offer greater pay and require computer skills.

Jack Compton, director of the college's welding program, began offering an orbital welding class in January 1999. With support from such companies as Arc Machines, PCI Energy Services and Dimetrics, the orbital welding program has been successfully training students for placement in high-technology manufacturing and construction fields. With the recent generous donation of state-of-the-art orbital welding equipment by Arc Machines, Inc., Pacoima, Calif., the welding technology program has been significantly enhanced. In addition, Unitek Miyachi Laser Systems Div., Monrovia, Calif., has provided the latest in low-power YAG laser welding equipment, as well as a variety of small-scale fiber-optic resistance welding equipment. With the new influx of laser, orbital and resistance welding equipment, we have expanded our curriculum to include fundamentals of resistance, laser beam and orbital gas tungsten arc welding," said Compton.

Students are currently being trained on an AMI Model 227 power supply, Models 15 and 79 welding heads for orbital welding. Laser welding training is being supported with a Unitek Miyachi Model LW 250 low-power YAG system. For resistance welding, training is accomplished on Miyachi Models 1P-217A, 1P-215A power supplies and Models HH-80 and HH-88 weld heads. This broad spectrum of welding process applications, along with hands-on welding experience enables students to seek careers in the aerospace, semiconductor, petrochemical, power generation, food and medical industries.

The College of the Canyons is the only community college in California equipped with this range of automated welding equipment. The partnership of local industry and the College of the Canyons presents a great opportunity for students who are seeking high-technology careers in automated welding.

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**SAFETY AND HEALTH**

**TOPICS**

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**Robotic Industries Association (RIA).** *Safety Requirements for Industrial Robots and Robot Systems,* RIA R15.06. Robotic Industries Association, P.O. Box 3724, 900 Victors Way, Ann Arbor, MI 48106.


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**The Safety and Health Fact Sheets, 2nd ed., cover all aspects of safety and health applicable to welding and cutting. The Fact Sheets include 20 pages on subjects such as fumes and gases, radiation, noise and electrical hazards. Compiled in 1998. Price for AWS members is $27; nonmembers, $36. Copies of Safety and Health Fact Sheets can be ordered by calling Global Engineering Documents at (800) 857-7179 or through the AWS Web site at www.aws.org.**
Nominations for District Director

The term of office for District Directors in the following Districts will terminate on May 31, 2002. As District Nominating Committees will be appointed this spring, it is time to think of position nominations. For further information, use your current District Director's contact information given below.

♦ District 3
Claudia B. Bottenfield
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♦ District 18
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♦ District 21
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Chief Consultant
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San Diego, CA 92126
(858) 693-1657
FAX: (858) 693-4352
Email: bscs@pacbell.net

♦ AWS Publications

♦ Standard Methods for Mechanical Testing of Welds

The American Welding Society has completed the new edition of Standard Methods for Mechanical Testing of Welds (AWS B4.0M:2000). Developed under the guidance of industry experts, this standard covers the common methods for the mechanical testing of welds, including bend, tension, fracture and other tests.

Standard Methods for Mechanical Testing of Welds contains detailed figures to assist users in accurately testing welds. For each testing method, information is provided on other applicable standards, such as ANSI and ASTM, testing requirements and sample preparation, as well as all the necessary test reporting requirements.

The new edition of Standard Methods for Mechanical Testing of Welds is 104 pages and lists for $68. $51 for AWS members.

Ordering Information

Standard Methods for Mechanical Testing of Welds, as well as all other AWS publications, can be ordered by calling Global Engineering Documents at (800) 854-7179, or by visiting the e-store on the AWS Website at www.aws.org.
TEAM Industries, Inc., is a nationally recognized supplier of shop fabricated piping, ASME Code pressure vessels, noncode tanks and modular piping equipment skids. Established in 1987 by a small group of private investors and 17 employees, the company has grown to more than 200 employees serving an international customer base. The company's fabrication services are used in many markets, including processing, petrochemical and refining, waste water, fertilizer, mining, industrial process, hazardous waste, power and cogeneration.

The company's growth can be attributed to its focus on meeting customer needs through on-time delivery of high-quality products. In addition to TEAM's integrated engineering, compatible with today's 3-D design programs, and daily tracking of the progress of each piping assembly through the company's shop, TEAM's custom computer system can provide timely cost accumulation and cost projections to its customers.

The company's 100,000-sq-ft production facilities are equipped with both custom and state-of-the-art equipment. Multiple work bays permit segregation of carbon and stainless steel piping fabrication (spools) with additional areas available for plate and tank fabrication, modular assembly, surface preparation and painting, hydrostatic testing, nondestructive examination and applications requiring special cleaning and testing. TEAM has an annual average output of 25,000 piping spools and the capability of fabricating tanks and vessels ranging in size from 2- to 18-ft diameters. The company's uplifting capacity is 40 tons and it has fabricated vessels up to 60 ft in length.

TEAM's highly skilled union craftsmen (United Association of Plumbers and Steamfitters, Local #400) provide confidence in the accuracy and integrity of the company's welded components. The company's highly skilled welders are experienced in a variety of alloys including low temperature, stainless, chrome moly, nickel, Hastelloy, titanium and duplex.

The company's quality control system carries two ASME Code stamps ("PP" and "U"). Most QC personnel are Certified Welding Inspectors (or CWIs). The company has 14 employees currently holding certification as AWS CWI (or CAWI) in executive management, engineering, project management, quality control and welding and fitting positions. The company also has one ASNT Certified NDT Level III person on staff.

TEAM is a strong supporter of the welding industry and regularly participates in the code development activities of AWS, ASME and PFI.

Submit Your Technical Committee Reports

Committee Chairmen — We want to recognize the efforts of your committee and inform our readers of its accomplishments. Send a brief profile of its activities and recent accomplishments, along with a member roster and contact numbers, and we will publish it in the Welding Journal's Society News section.

Send your submissions to

Susan Campbell, Associate Editor
American Welding Society
550 N.W. LeJeune Rd.
Miami, FL 33126
Telephone, (305) 443-9353 ext. 244, FAX, (305) 443-7404
E-mail: campbell@aws.org •

AWS MEMBERSHIP

Member Grades As of January 1, 2001

Sustaining Companies ................. 327
Supporting Companies ................. 153
Educational Institutions ............... 164
Total Corporate Members ............ 644

Individual Members ................. 43,545
Student Members .................. 4,876

Total Members .......... 48,421
Tenth International JOM Jubilee Conference

The Institute for the Joining of Materials (JOM) has announced the Tenth International JOM Jubilee Conference on the Joining of Materials, JOM-10, May 11-14, in Helsingor, Denmark.

The following are the main themes of JOM-10:

- Information technology, cases in its exploitation, as well as prediction of its value, for future and present welding fabrication.
- Robotization and automation in welding and associated processes.
- Brazing, soldering and associated processes in nonweld joining.

JOM welcomes the active support of AWS to the JOM-10 through speakers and participants. AWS cosponsored previous JOM conferences 7 through 9.

For further information on JOM-10, contact the Institute for the Joining of Materials, Klintehoj Vænge 21, DK-3460 Birkerød, Denmark; e-mail to jom.aws@post10.tele.dk; telephone +45 45 82 80 95; or FAX +45 94 08 55.

Visit AWS on the Web

The world of AWS is as close as a click of your mouse. While visiting the American Welding Society’s Web site, you can renew your membership, buy books and standards and even look for a new job. To see what’s on the Web site for you, just visit http://www.aws.org.

AWS Foundation on the Web

For further information on the AWS Foundation scholarship and student loan programs, visit the AWS Foundation on the Web at www.aws.org/foundation.

Sustaining Member Companies

Wolfe Engineering, Inc.
546 Division Street
Campbell, CA 95008
(408) 379-9580
www.wolfe-engr.com

Wolfe Engineering is an established leader in the design and fabrication of high-quality precision parts and subassemblies for the microelectronics and aerospace industries. Since 1992, the company has successfully partnered with major corporations by providing its own brand of customized manufacturing, engineering support and leading-edge technologies.

Wolfe offers a broad range of services, including the following:
- Turnkey parts manufacturing in accordance with client specifications.
- Customized engineering and fabrication for subassemblies and retrofits.
- Rush assembly and overnight service.
- Core competencies in high-purity clean room manufacturing.
- Testing, inspection, and quality assurance.

Wolfe Engineering was established in direct response to supplier’s needs for premium quality turnkey manufacturing while meeting deadlines. Technology companies soon recognized the cost benefits associated with outsourcing specialized fabrication projects, and Wolfe Engineering answered the call. The company’s unique portfolio of services allows customers to achieve significant reductions in overhead and lower operation costs. The company has more than 40,000 sq ft of manufacturing area and two clean rooms for high-purity assembly.

Merriam-Graves Corporation
933 Route I Bypass
Portsmouth, NH 03801-3553
(603) 433-0855
www.merriam-graves.com

Merriam-Graves Corp. is one of the largest independent industrial gas and welding supply distributors in the northeastern USA.

The company has 20 strategically located branches in six states, with more than 75 trucks delivering products to its clients. Supporting these locations is a 53,000-sq-ft pumping plant, equipped with computer-driven filling and mixing equipment, which ensures the accuracy of mixtures, purity of the product and guarantees customers the highest quality products. In addition, a 20,000-sq-ft materials distribution center provides next-day service to customers in the northeast.

Merriam-Graves also has a welding machine repair facility staffed by trained, authorized repair technicians. The company’s quality repair work and quick turnaround time keep downtime to a minimum. The company can also rent customers a unit until their welding machine’s repairs are complete.

The company’s personnel are trained in all of the latest improvements in the welding and cutting industry. Frequently, Merriam-Graves holds process and product training seminars for customers. These training seminars focus on a particular application and utilize the expertise of the company’s premium suppliers to provide attendees with the tools to improve their knowledge of welding and cutting.
New Jersey Section member Bob Bartley, right, presenting a speaker's gift to guest speaker Garth Stapon.

DISTRICT 1

Director: Geoffrey H. Putnam
Phone: (802) 439-5916

DISTRICT 2

Director: Alfred F. Fleury
Phone: (732) 868-0768

♦ LONG ISLAND
November 9
Speaker: Skip Swift, district representative.
Affiliation: Thermal Arc, Stooey Hardfacing and Welding Alloys.
Topic: Plasma arc welding: defining process applications for automation and low-amperage welding.

♦ NEW JERSEY
November 1
Speaker: Garth Stapon, marketing manager, metal fabrication.
Affiliation: Praxair, Danbury, Conn.
Topic: Welding with metal-cored wires.
Activity: Bob Von der Osten, a first-year welding student, was recognized by the Section for being Somerset County Vo-Tech Student of the Month and winning second place in the AWS New Jersey Section's Welding Competition.

♦ NEW YORK
November 20
Speaker: Daniel T. Campbell, attorney-at-law.
Affiliation: Nelson, Campbell and Szufitta.
Topic: Employment and labor laws.

DISTRICT 3

Director: Claudia Bottenfield
Phone: (717) 397-1312

♦ LEHIGH VALLEY
November 7
Speaker: Edward W. Rowlands, Jr., general foreman; David H. Cooley, vice president; and Mark Welkey.
Activity: The Section received a detailed plant tour with thorough explanations of condenser technology and fabrication.

DISTRICT 4

Director: Rny C. Lanier
Phone: (919) 321-4285

♦ SOUTHWEST VIRGINIA
November 15
Activity: Section members met to
plan the year's remaining events and activities.

**TRIANGLE**
December 27
**Activity:** The Section had AWS Night Out at the Raleigh Sports Arena to see the Carolina Hurricanes play the New York Rangers.

**DISTRICT 5**
Director: Boris A. Bernstein
Phone: (787) 883-8383

**FLORIDA WEST COAST**
November 8
Speaker: Curt Wilsoncroft, specialist.
Affiliation: Tweco Arcair, Lancaster, Ohio.
**Topic:** Arc gouging.
**Activity:** James Fasting was presented with the District Educator of the Year Award. Welding student Dien Tran accepted the second of five sponsorship checks from the Section to help him in his trials for the World Skills Competition.

**SOUTH CAROLINA**
November 16
**Activity:** Section members and guests enjoy a social meeting featuring a frogmore stew dinner prepared by Odel Haselden and Jon Guerry.

**HOUSTON VALLEY**
November 14
**Activity:** A planning meeting was held to discuss positive ways to increase interest and attendance at Section meetings.

**NORTHEAST MISSISSIPPI**
December 8
**Activity:** The Section held its Annual Ladies' Night and Holiday Party at Ruben's Catfish House in Columbus, Miss. Entertainment for the event was provided by ventriloquist Michael Gray and his sidekick, Scotty.

**DAYTON**
November 14
Speaker: Steve Roth, president.
Affiliation: Southern Ohio Forge and Anvil (SOFA).

**DISTRICT 6**
Director: Gerald R. Cramer
Phone: (518) 385-0570

**DISTRICT 7**
Director: Robert J. Tabernik
Phone: (614) 488-7913

**DISTRICT 8**
Director: Harrell E. Bennett
Phone: (423) 478-3624

**DISTRICT 9**
Director: John Bruskotter
Phone: (504) 367-0603

**MOBILE**
November 16
Speaker: Diane Irby.
Affiliation: Irby Specialty Services.
Florida West Coast District Educator of the Year Award winner James Fasting, left, with Section Chairman Darrell Jar- dine.

Northwestern Pennsylvania Section Chairman Israel Shabtai thanking guest speaker Jeff Kehs for his presentation.

Attending the New Orleans' Sections November meeting are, from left, First Vice Chairman John Pajak, Greg St. Cyr and his son, David, guest speaker Bill St. Cyr, Chairman Marie Lygate and Membership Chairman Shelton Ritter.

Cleveland Section Chairman Bob Farasey, center, presenting a speaker's gift to Richard Avery, left, while Section member Bob Sott looks on.

District 10 Director Vic Matthews, right, with Mahoning Valley Section First Vice Chairman Chuck Moore after presenting him with both District and Section Meritorious Awards.

**DISTRICT 10**

Director: Victor Y. Matthews
Phone: (216) 383-2638

**NORTHEASTERN PENNSYLVANIA**

**October 10**
Speaker: Jeff Kehs.
Affiliation: Hypertherm.
Topic: Simple solutions to complex problems in plasma arc cutting.

**CLEVELAND**

**October 17**
Speaker: Richard E. Avery, consultant.
Affiliation: Nickel Development Institute.
Topic: Fabricating high-nickel alloys for corrosive environments.

**DISTRICT 11**

Director: Scott C. Chapple
Phone: (913) 241-7242

**MAHONING VALLEY**

**November 16**
Speakers: Richard Kral, production manager, and Bruce Sikora, sales engineer.
Affiliation: The Holland Co., Chicago, Ill.
Topic: Electric-flash crane rail welding.
Activity: Section Chairman Kenny Jones was presented with the District Meritorious Award. First Vice Chairman Chuck Moore received District and Section Meritorious Awards. District 10 Director Vic Matthews presented the awards.
Northern Plains Section members pose for a photograph during their November maintenance meeting.

**DISTRICT 12**

Director: Michael D. Kersey  
Phone: (262) 650-9364

**UPPER PENINSULA**

**Activity:** The Section toured the Giddings & Lewis Foundry in Menominee, Mich. The tour included manual and automated sand mold making, pouring of ductile and grey iron, shakedown and metallurgical testing.

**FOX VALLEY**

**November 9**  
**Speaker:** Bob Christiansen, sales representative.

**DISTRICT 13**

Director: J. L. Hunter  
(309) 888-8956

**CHICAGO**

**September 30**  
**Activity:** The Section had an exotic animal safari adventure at the Brookfield Zoo. The special after-hours event included a dolphin presentation, an exotic animal tour by motor safari, a reception in the Habitat Africa Exhibit and a continental buffet dinner in the Zoo’s restaurant at the Living Coast.

**DISTRICT 14**

Director: Hil Bax  
Phone: (314) 644-3500, ext. 105

**LEXINGTON**

**November 16**  
**Speaker:** Frank McKinley, AWS  
Affiliation: KY Service Co.  
Topic: Hardfacing.

**Activity:** McKinley presented awards to members. The CWI of the Year Award was presented to Billy Wilson, an instructor at Kentucky Tech at Somerset. Tim Pinson, an instructor at Harrison Vo Tech, received the Educator of the Year Award.

**DISTRICT 15**

Director: J. D. Heikkinen  
Phone: (218) 741-9693

**NORTHERN PLAINS**

**November 30**  
**Speakers:** Rory Knudson and Matt Mischke.  
**Affiliation:** Praxair, Fargo, N.D.  
**Topic:** General discussion on maintenance of welding power sources, feeders and engine-driven welding machines.

**Activity:** Section Secretary/Treasurer Lee Larson presented Mike Lipin of Standard Indiana the Section’s Sponsorship Awards. Section Chairman Dave Lynnes met with the nonmembers attending the meeting and discussed the benefits of AWS membership.

**ARROWHEAD**

**November 16**  
**Speaker:** Randy Karpik, owner.
Central Arkansas CD

Chairman Dennis Pickering, left, presenting David Fulbright with 100 AWS dollars for winning the drawing.

Affiliation: Fast Inc., Eveleth, Minn. 
Topic: Theory, operation and manufacture of snowmobiles and snowmobile suspensions. 
Activity: The Section toured the assembly plant of Fast Inc., the makers of the "Blade" snowmobile.

**DISTRICT 16**

Director: C. F. Burg 
Phone: (515) 294-5428

**SOUTHEAST NEBRASKA**

OCTOBER 17
Speaker: Erv Woodard. 
Affiliation: DBI, Inc. 
Topic: Nondestructive examination. 
Activity: The Section toured the Lincoln Steel Company plant. Lincoln Steel is a structural steel fabrication shop.

NOVEMBER 21
Activity: Exmark Mfg. Co. held a tour for Section Members. Exmark is a manufacturer of commercial walk behind and riding lawn mowers.

**MID-PLAINS**

NOVEMBER 16
Speaker: Helio Couto. 
Affiliation: Aspen Dairy, Miller, Nebraska. 
Activity: The Section toured the Aspen Dairy, which is a 4500-animal herd dairy operation. All animals are inside and 3500 cows are milked three times a day. Average milk production per cow is 80 lb per day. Calving is an everyday occurrence at the dairy. There are 1500 cows that are pregnant at any given time. On average, 25 calves are born each day.

Central Arkansas Section members at the November meeting hosted by the Sheet Metal Workers Local Union #36L. Gary Jones, far left, is business manager for the Union, and Doug Smith, second from right, is an apprentice. Section Chairman Dennis Pickering is at far right.

**DISTRICT 17**

**CENTRAL ARKANSAS**

SEPTEMBER 20
Speaker: Dennis Pickering, AWS Central Arkansas Section chairman. 
Affiliation: Hot Springs Rehab Center. 
Topic: Shielded metal arc welding. 
Activity: The meeting was hosted by the Sheet Metal Workers Local Union #36L at its apprentice training school.

**DISTRICT 18**

**HOUSTON**

NOVEMBER 15
Speaker: Joe Hale, metallurgy manager. 
Affiliation: Sermatech Gas Path. 
Topic: Superalloy repairs on gas-turbine blades and other components. 
Activity: George Kampschaefer was presented with the District 18 Director's Award by District 18 Director Jim Appledorn.
**DISTRICT 19**

**Director:** Phil Zammit  
**Phone:** (509) 468-2310 ext. 120

- **SPOKANE**  
  **October 11**  
  **Speaker:** Gene Monaco  
  **Affiliation:** Monaco Enterprises Racing  
  **Topic:** NASCAR operation and race car fabrication safety specs on roll cages  
  **Activity:** District 19 Director Phil Zammit attended the meeting.

**DISTRICT 21**

**Director:** F. R. Schneider  
**Phone:** (619) 693-1657

- **SAN DIEGO**  
  **November 8**  
  **Activity:** The Section toured the Hi-Tech Welding Services plant. Hi-Tech President Wyatt Swaim gave an overview of the history of Hi-Tech Welding and shared his knowledge of electron beam welding. General Manager John Monsees explained how to weld titanium and titanium metallurgy. Sjon Delmore, director of marketing, shared Hi-Tech's products with members. District 21 Director Bob Schneider and his wife, Evelyn, attended the meeting.

**DISTRICT 22**

**Director:** Mark Bell  
**Phone:** (209) 367-1398

- **INTERNATIONAL SECTION**

  **SAUDI ARABIA**  
  **October 11**  
  **Speakers:** Khaled M. Ali, Section chairman, and Ted Valentini, marketing manager  
  **Affiliation:** AWS and ITW Group, respectively  
  **Topic:** Overcoming issues with welding high strength pipes.

**Announce Your Section's Activities**

Stimulate attendance at your Section's meetings and training programs with free listings in the Section Meeting Calendar column of Society News.

Useful information includes your Section name; activity date, time and location; speaker's name, title, affiliation and subject; and notices of golf outings, seminars, contests and other special Section activities.

If some of your meeting plans are sketchy, send the name and phone number of a person to contact for more information.

Send your new calendar to Susan Campbell, Associate Editor, Welding Journal Dept., AWS, 550 N.W. LeJeune Rd., Miami, FL 33126; FAX: (305) 443-7404.
SECTION EVENTS CALENDAR

NEW JERSEY
FEBRUARY 20
Thermal Dynamics.
Topic: Simple automation for plasma arc cutting machines.

FEBRUARY 20
Thermal Dynamics.
Topic: Simple automation for plasma arc cutting machines.

MILWAUKEE
FEBRUARY 15
Topic: Welding and joining failure analysis.
MARCH 15
APRIL 19
Activity: ABB Flexible Automation plant tour.
MAY 17
Activity: Past Chairmen's and Spouse's Night.

LAKESHORE
FEBRUARY 8
Activity: Maritime Museum tour and Spouse's Night.
MARCH 14
Activity: Student Day Event.
APRIL 12
Activity: MG Industries plant tour.
MAY 18
Activity: District Conference.

YORK-CENTRAL PENNSYLVANIA
FEBRUARY 1
Speaker: Jerry Mathison.
Affiliation: ESAB.
Activity: Past Chairmen’s Night.

MARCH
Activity: Ladies’ Night and an evening on the dinner train.
Date: To be announced.
APRIL 5
Activity: Joint meeting with ASNT.
Speaker: William DeFelice.
Topic: Cryogenics.

ALASKA
FEBRUARY 15
Topic: Welding and joining failure analysis.
For further information on meetings, e-mail awsalaska@altavista.com.
MARCH 16
Topic: To be announced.
Location: Anchorage.
MAY 19
Activity: AWS Alaska Section Picnic.
Location: Palmer, Alaska.

COLORADO
February 8
Activity: ABB Flexible Automation plant tour.
MAY 10
Speaker: Jack Harkness.
Topic: How to write a WQTR.
Activity: Student Recognition and Award Night.
JUNE 14
Activity: Executive Board Meeting.
AUGUST 9
Activity: Executive Board Meeting.

STUDENT ACTIVITIES
DISTRICT 3
Director: Claudia Rottenfield
Phone: (717) 397-1312

LEHIGH CAREER AND TECHNICAL SCHOOL
NOVEMBER 7
Activity: The Student Chapter toured the Alstom Power Inc. plant in Easton, Pa.

Student Chapter members Rody Schaffer, left, and Ryan Bohn examining fabrication details at Alstom Power Inc. in Easton, Pa.

Student Chapters, Send Us Your News
Student Chapters are encouraged to send reports of their meetings, activities and events, along with photographs, for publication in the Welding Journal's Student Activities department.
Send your meeting/event reports to Susan Campbell, Assoc. Editor, Welding Journal, 550 N.W. LeJeune Rd., Miami, FL 33126.
Reports can also be faxed to (305) 443-4704 or e-mailed to campbell@aws.org.

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2000–2001 Member-Get-A-Member Campaign

Listed below are the people participating in the 2000–2001 Member-Get-A-Member Campaign. For campaign rules and a prize list, please see page 69 of this Welding Journal.

If you have any questions regarding your member proposer points, please call the Membership Department at (800) 443-9353 ext. 480.

Winner's Circle
(AWS Members sponsoring 20 or more new Individual Members per year, since June 1, 1999)

J. Compton, San Fernando Valley*  
E. H. Ezell, Mobile*  
B. A. Mikeska, Houston*  
J. Merzthal, Peru*  
W. L. Shreve, Fox Valley*  
R. Wray, Nebraska*  
G. Woemer, Johnstown/Altoona*

*Denotes the number of times an Individual Member has achieved Winner’s Circle status. Status will be awarded at the close of each membership campaign year.

President’s Guild
(AWS Members sponsoring 20 or more new Individual Members between June 1, 2000, and May 31, 2001.)

J. Compton, San Fernando Valley — 45  
J. Merzthal, Peru — 21  
G. Woemer, Johnstown/Altoona — 20

President’s Roundtable
(AWS Members sponsoring 11–19 new Individual Members between June 1, 2000, and May 31, 2001.)

P. Baldwin, Peoria — 15  
G. Taylor, Pascagoula — 14  
A. A. Alabdullah, Saudi Arabia — 13  
A. O. Smith III, Tulsa — 13  
E. H. Ezell, Mobile — 12  
L. J. Smith, Houston — 12

President’s Club
(AWS members sponsoring 6–10 new Individual Members between June 1, 2000, and May 31, 2001.)

W. R. Beck, Rochester — 9  
C. Alonzo, Jr., San Antonio — 7  
R. Buse, Mobile — 6

President’s Honor Roll
(AWS members sponsoring 1–5 new Individual Members between June 1, 2000, and May 31, 2001. Only those sponsoring 2 or more AWS Individual Members are listed.)

J. T. Blank, Northern Michigan — 5  
C. M. Murray, Cleveland — 5

G. P. Neal, Fort Smith — 5  
D. J. Nelson, Puget Sound — 5  
R. L. Pascle, Detroit B&D — 5  
W. L. Shreve, Fox Valley — 5  
C.-I. Tsai, Taiwan — 5  
H. E. Cable, Sr., Pittsburgh — 4  
J. C. Cooley, Birmingham — 4  
W. Galvory Jr., Long Beach/Orange City — 4  
D. L. Hatfield, Tulsa — 4  
J. D. Sanders, Houston — 4  
L. Schweinegruber, Pittsburgh — 4  
J. H. Smith, Jr., Mobile — 4  
M. R. Teton, Utah — 4  
J. N. Carney, Western Michigan — 3  
R. Grays, Kern — 3  
C. R. Hein, Central Arkansas — 3  
S. D. Keskut, India — 3  
J. Koster, Western Michigan — 3  
B. L. Marin, Detroit — 3  
J. A. Rosado, Puget Sound — 3  
R. D. Rux, Wyoming — 3  
M. A. Sandvig, Northwest — 3  
B. Samovat, India — 3  
M. Tan, L.A./Inland Empire — 3  
P. G. Walker, Oazark — 3  
R. Wright, Southern Colorado — 3  
J. E. Campbell, Milwauk ee — 2  
D. S. Dodds, Pittsburgh — 2  
T. A. Flynn, Atlanta — 2  
M. Gartman, Northeast Mississippi — 2  
R. Ghansari, Canada — 2  
S. P. Hoff, Sangamon Valley — 2  
J. W. Jaeger, Southern Colorado — 2  
R. S. Judy, Portland — 2  
J. Knapp, Tulsa — 2  
M. A. Latif, Houston — 2  
J. R. Leavitt, Southwest Idaho — 2  
J. A. Livesay, Nashville — 2  
D. G. Luna, L.A./Inland Empire — 2  
S. M. McCasland, Syracuse — 2  
H. W. McKeae, New York — 2  
M. P. Mott, Florida West Coast — 2  
C. N. Porrco, Cleveland — 2  
S. M. Qureshi, International — 2  
A. Reyn, North Texas — 2  
K. L. Rigsby, New York — 2  
H. A. Rodriguez, Puerto Rico — 2  
W. Shieh, Northeast Mississippi — 2  
P. Soto, New Jersey — 2  
J. Stewart, Sangamon Valley — 2  
G. S. Teague, Eastern Carolinas — 2  
J. Thompson, Greater Huntsville — 2  
M. G. Weckes, Sabine — 2  
R. B. Wiser, Richmond — 2  
D. A. Wright, Kansas City — 2  
R. Zabel, Southeast Nebraska — 2

Student Sponsors
(AWS members sponsoring 3 or more new AWS Individual Members between June 1, 2000, and May 31, 2001.)

T. M. Buchanan, Mid-Ohio Valley — 29  
P. J. Betts, Mobile — 24  
T. C. Morrow, Arizona — 22  
J. Jones, North Texas — 21  
D. Serrano, Puerto Rico — 21  
J. J. Daugherty, Louisville — 20  
G. Woemer, Johnstown/Altoona — 20  
M. R. Anderson, Indiana — 18  
R. J. DePue, Ocean-Bradford — 18  
K. R. Moore, Corpus Christi — 18  
H. Jackson, L.A./Inland Empire — 16  
K. A. Ellis, Maryland — 15  
K. A. Dietrich, Wheeling — 14  
S. P. Sivits, Maine — 14  
R. Zabel, Southeast Nebraska — 14  
J. H. Smith, Jr., Mobile — 13  
T. Strickland, Arizona — 13  
H. R. Madron, Maryland — 12  
P. G. Childers, Oklahoma City — 10  
D. L. Hatfield, Tulsa — 10  
L. J. Heath, Maryland — 10  
W. H. Kielhorn, East Texas — 9  
A. K. Mattox, Lexington — 9  
C. Alonzo, Jr., San Antonio — 8  
S. D. Gore, Charlotte — 8  
H. W. Pelster, SF Nebraska — 8  
M. E. Tit, L.A./Inland Empire — 7  
J. T. Blank, Northern Michigan — 6  
W. Galvory Jr., Long Beach/Orange City — 6  
R. Schneider, Wyoming — 6  
J. J. Swoyer, Lehigh Valley — 6  
P. Baldwin, Peoria — 5  
J. N. Carney, Western Michigan — 5  
A. E. Classens, Charlotte — 5  
E. L. Harris, Pascagoula — 5  
D. J. Nelson, Puget Sound — 5  
J. Pummer, Long Beach/Orange City — 5  
T. Shirk, Tidewater — 5  
P. G. Walker, Oazark — 5  
S. R. Zwilling, Louisville — 5  
M. J. Bannister, Mobile — 4  
J. R. Carter, Sr., Carolina — 4  
R. S. Judy, Portland — 4  
C. J. Ray, Indiana — 4  
K. L. Rigsby, New York — 4  
J. D. Sanders, Houston — 4  
T. R. Alberts, SW Virginia — 3  
G. Callender, San Fernando Valley — 3  
R. Grays, Kern — 3  
T. F. McClelland, Colorado — 3  
P. O’Leary, Eastern Idaho/Montana — 3  
R. D. Rux, Wyoming — 3  
K. E. Samuelson, Albuquerque — 3  
E. J. Warren, Colorado — 3  
C. B. Wesley, Northwestern Pa. — 3
Standards for Public Review

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require all standards be open to public review for comment during the approval process. This column also advises of ANSI approval of documents. The following standards are submitted for public review. A copy may be obtained by sending the amount shown to AWS Technical Dept., 550 N.W. LeJeune Rd., Miami, FL 33126, or by calling (305) 443-9353, ext. 451.


ISO Draft Standards for Public Review

Copies of the following Draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 11 West 42nd Street, New York, NY 10036; telephone (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body.

In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis at AWS, 550 N.W. LeJeune Rd., Miami, FL 33126; telephone (305) 443-9353 ext. 466; e-mail: adavis@aws.org. Otherwise contact your national standards body.


TECHNICAL COMMITTEE MEETINGS

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should contact the staff secretary of the committee as listed below at AWS, 550 N.W. LeJeune Rd., Miami, FL 33126, telephone (305) 443-9353.

February 6-7, 2001, G1B Subcommittee on Vibration Welding. Fort Lauderdale, Fla. Standards preparation meeting. Staff contact: J. L. Gayler.


GUIDE TO AWS SERVICES

550 N.W. LeJeune Rd., Miami, FL 33126
Phone (800) 443-9353; Telex 51-9245; (888) WELDING
Fax (305) 443-7559; Internet: www.aws.org
Phone extensions appear in parentheses.

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482 Wolf Run Road
Cuba, NY 14727

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Assistant Executive Director
Debbie G. Gadavall (222)

Director of Quality Management Systems
Linda K. Williams (236)

Corporate Director of Finance/Comptroller
Frank K. Tarsha (252)

Information Services
Corporate Director
Joe Gill (258)

Human Resources
Director
Lisa Hernandez (266)

International Institute of Welding
Information
(294)

Provides liaison activities involving other professional societies and standards organizations, nationally and internationally.

GovernmenF Liaison Services
Hugh K. Webster
Webster, Chamberlin & I conn
Washington, D.C.
(202) 366-2976
Fax (202) 835-0243

Identifies sources of funding for welding education and research & development. Monitors legislative and regulatory issues important to the industry.

Welding Equipment Manufacturers Committee
Associate Executive Director
Richard L. Alley (217)

Industry Action Committee
Associate Executive Director
Charles F. Fassinger (297)

communications
Corporate Director Communications
Nannettc M. Zapata (308)

Corporate Director of Administrative Services
Jim Linkford (214)

Corporate Director of Marketing
Debrah C. Weer (279)

Promotes Society programs and activities to AWS members, the welding community and the general public.

Convention & Expositions
Exhibiting Management (221, 256)

Managing Director
Tom Davis (251)

National Sales Manager
Gene Pesant (458)

Organizes the week-long annual AWS International Welding and Fabricating Exposition and Convention. Regulates space assignments, registration materials and other Expo activities.

Publication Services
Division Information (348)

Managing Director
Jeff Weber (246)

WELDING JOURNAL
Publisher
Andrew Callison (249)

National Sales Director
Rob Saltstein (245)

Welding Handbook
Editor
Annette Gilchrist (305)

Publishes AWS's monthly magazine, the Welding Journal, which provides information on the state of the welding industry, its technology and Society activities. Publishes the Welding Handbook and books on general welding subjects.

Certification Programs/Business Development
Director of Int'l Business Development
Walter Herrera (475)

For customized certification and educational programs in industry and government.

Education
Director
James R. Cunningham (219)

Information on education products, projects and programs. CWI, SCAI and other seminars designed for assistance in Certification. Responsible for the S.E.N.S.E. Beginning welder program and dissemination of certification information on the Web.

Conferences
Director
Garrett I. Rodriguez (278)

Responsible for national and local conferences/exhibitions and seminars on industry topics ranging from the basics to the leading edge of technology.

Certification Operations
Information and application materials on certifying welders, welding inspectors and educators.

Managing Director
Wendy S. Reeve (215)

Awards & Fellows
Managing Director
Wendy S. Reeve (215)

Coordinates awards and AWS Fellow nominees.

TELEWELD
Fax: (305) 443-5951

For information about AWS technical publications, contact the Technical Services personnel listed below.

Technical Services
Department Information (340)

Managing Director
Foland P. Connor (299)

Qualification, Inspection, Food Processing Equipment

Andrew R. Davis (466) International Standards Program Manager, Welding in Marine Construction

Stephen P. Hedin (306) Safety and Health Manager, Symbols & Definitions

Engineers
Hartley H. Campbell III (300) Structural
Bakshi Gupta (301) Filler Metals
Christopher B. Baker (304) Brazing, Soldering, Testing, Railroads, Computation, Instrumentation
Tim Potter (400) Robotic Joining of Metals and Alloys, Piping and Tubing, Friction Welding
John L. Glyde (472) Metal Fabrication Methods, Welding, Resistance, Automotive Aerospace

For issue of Welding Journal, contact the Technical Services personnel listed below.
AWS publishes more than 160 volumes of material, including standards that are used throughout the industry. With regard to technical inquiries, oral opinions on AWS standards may be rendered. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

It is the intent of the American Welding Society to build the Society to the highest quality standards possible. We welcome any suggestions you may have. Please contact any of the staff listed on the previous page or AWS President L. William Myers, 482 Wolf Run Road, Cuba, NY 14727.

AWS FOUNDATION, INC.
550 N.W. LeJeune Rd.
Miami, Fl. 33126
(305) 445-6628
(800) 443-9353, ext. 293
Or e-mail: bobw@aws.org
Chairman, Board of Trustees
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Director of Development
Robert B. Witherell

The AWS Foundation 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.

• 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 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, and 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 must have served at least one year as a Director, other than Executive Director and Secretary.

Interested parties are to send a letter stating which particular office they are seeking, including a statement of qualifications, their willingness and ability to serve if nominated and elected and 20 copies of their biographical sketch.

This material should be sent to Robert J. Teuscher, Chairman, National Nominating Committee, American Welding Society, 550 N.W. LeJeune Rd., Miami, Fl. 33126.

The next meeting of the National Nominating Committee is currently scheduled for May 6, 2001, in Cleveland, Ohio. The terms of office for candidates nominated at this meeting will commence June 1, 2002.

• Honorary-Meritorious Awards

The Honorary-Meritorious Awards Committee has the duty to make recommendations regarding nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial and the George E. Willis Awards. These awards are presented in conjunction with the AWS Exhibition and Convention held each spring. The descriptions of these awards follow, and the submission deadline for consideration is July 1 prior to the year of presentation. All candidate material should be sent to the attention of John J. McLaughlin, Secretary, Honorary-Meritorious Awards Committee, 550 N.W. LeJeune Road, Miami, Fl. 33126.

National Meritorious Certificate Award: This award is given in recognition of the candidate’s council, 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 Company to honor the late William Irrgang. It is awarded each year to the individual who has done the most to enhance the American Welding Society’s goal of advancing the science and technology of welding over the past five-year period.

George E. Willis Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Company 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 candidate’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 award’s luncheon or at another time as appropriate in conjunction with the AWS President’s travel itinerary, and, if appropriate, a one-year membership to AWS.

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.
CALL FOR PAPERS

Eleventh International Conference on Computer Technology in Welding

September 19 and 20, 2001 — Columbus, Ohio

This is the eleventh in a series of computer conferences designed to provide the welding industry with the latest information regarding the use of computers for welding. This conference, jointly sponsored by the American Welding Society, The Welding Institute and the National Institute of Standards and Technology, will be held September 19 and 20, 2001, in Columbus, Ohio. Authors from around the world are strongly encouraged to submit an abstract, as attendance from an international audience will be encouraged.

Authors should submit the Author Form (on reverse side), together with an abstract of no more than 500 words to American Welding Society, Conference Department, 550 NW LeJeune Road, Miami, FL 33126, by January 31, 2001. The abstract should be sufficiently descriptive to give a clear idea of the content of the proposed paper. Authors will be notified of acceptance by March 5, 2001. Complete manuscripts will be required from selected speakers by May 1, 2001.

Authors are not limited to any specific topics, except that papers should be appropriate for the conference subject. Contributions are encouraged in the following areas:

• Modeling of Welds and Welding Processes
• Off-Line Planning/Weld Simulation/Visualization
• Computerized Data Acquisition and Sensing Systems
• Real-Time Welding Information and Control Systems
• Weld Process Automation
• Network and Web-Based Implementations
• Case Histories/Experiences with Commercial Software (by users)
• Welding Documentation (e.g., PQR)
• Databases, Database Applications and Knowledge Bases
• Standards

To ensure your paper's consideration for the conference, your abstract must be postmarked no later than January 31, 2001.
Author Application Form

Eleventh International Conference on Computer Technology in Welding
September 19–20, 2001 — Columbus, Ohio

Date Mailed ___________

Author’s Name: ______________________________

Please check how you are addressed: Mr. ________ Ms. ________ Dr. ________ Other ________

Title or Position: ____________________________

Organization: _______________________________

Mailing Address: ________________________________

City: __________ State: __________ Zip Code: __________ Country: __________

Telephone: __________________ Fax: __________

For joint authorship, give names. (If more than two coauthors, please use separate sheet.)

Name: __________________________________________ Name: __________________________

Organization: ____________________________ Organization: __________________________

Address: ____________________________ Address: ____________________________

PROPOSED TITLE (10 words or less):

ABSTRACT:

• Typed, double-spaced, 250–500 words, attached to this form.
• Be sure to give information to provide a clear idea of content of the proposed paper.
• If completed manuscript is available now, in addition to abstract, attach copy to this form.
• Application form and abstract must be postmarked no later than January 31, 2001.

MANUSCRIPT DEADLINE:

• All manuscripts must be submitted no later than May 1, 2001.
• Guidelines for submission of manuscripts will be provided to authors selected for the program.

PRESENTATION AND PUBLICATION OF PAPERS:

Has material in this paper been previously published or presented at any meeting?

Yes ________ No ________ When? __________ Where? __________

Return to AWS postmarked no later than January 31, 2001, to the following address:

Conferences
American Welding Society
550 N.W. LeJeune Road
Miami, Florida 33126
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Over the next 12 months, you will have to know how to compete more intensely than ever before to keep your plant running or your shop open and to make a decent profit. What new equipment and technologies should you buy to increase your productivity? How do you better utilize your existing plant and equipment to be more productive and cost competitive? How will you find out what is going on in your industry? Where will you learn how other people are solving challenges similar to yours, and how can you make your own plans for the future?

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May 6-10, 2001
I-X Center
Cleveland, OH

MAX INTERNATIONAL The Driving Force at the core of the manufacturing industry
Boiler and Pressure Vessel Safety Video Released

Case For Safety II, a video from the National Board of Boiler and Pressure Vessel Inspectors, makes the case for vigilance anywhere boilers and pressure vessels can be found. Featuring actual television footage of recent incidents, the video focuses on the personal and economic consequences of boiler and pressure vessel accidents. Included are reports on a pressure tank explosion at an Indiana steel mill that killed three people and injured nine, a catastrophic boiler explosion at a Michigan auto plant that resulted in six dead and fourteen injured, and a boiler explosion at a South Carolina high school. The video cautions against indifference to equipment that can be found in nearly every building and home in North America today. The tape is available for $15 plus shipping and handling.

The National Board of Boiler and Pressure Vessel Inspectors
1055 Crupper Ave., Columbus, OH 43229-1183

White Paper Explains Advantages of Stud Welding

Solutions in Metal Fastening: The Advantages of Stud Welding presents the steps of drawn arc and capacitor discharge (CD) stud welding methods and provides comparative information against other metal fastening processes. It demonstrates how stud welding helps companies increase metal fastening productivity and save costs, while maintaining high product quality. The paper describes the techniques of drawn arc stud welding, short arc stud welding, gas arc stud welding, contact CD stud welding and gap CD stud welding. Comparison charts show how stud welding performs against brazing/soldering, boring/drilling/tapping, clinch fastening and resistance welding, conventional bolting and manual welding.

Image Industries
382 Balm Ct., Wood Dale, IL 60191

Magnet Catalog Introduced

The 28-page MAG-MATE™ 101-H catalog on holding, lifting and fixturing magnets has been released. Containing more than 21 products, the catalog offers hundreds of standard magnets designed with ceramic, Alnico™, rare earth or electromagnetic materials. With applications in metalworking, fabricating, appliance, automotive, automation and robotics industries, the catalog offers a wide variety of magnetic solutions including raw materials, magnetic hand tools, holding, lifting, fixturing, transferring and sweeping magnets. Most magnets are available in stock for same-day shipment. Modified standards or custom designs are available upon request.

Industrial Magnets
116
1240 M-75 N., Bay City, MI 49712-0080

Brochure Features Pneumatic Tools

The company is offering a 60-page brochure on its complete line of pneumatic tools. The range of products include vertical, horizontal and right-angle grinders, die grinders, chipping hammers, rammers, air saws, air drills, air routers, sealers, power supply
potential inadvertent hazards. Various control measures, the development of laser safety programs, potential nonbeam hazards, criteria for exposure to eyes and skin, and measurements, as well as instrumentation related to outdoor laser use, are also detailed. The list price is $90, $70 for LIA members.

Laser Institute of America
13501 Ingenuity Dr., Suite 120, Orlando, FL 32826

Robotic Guide Available in Pocket Size

A pocket-sized guide with complete descriptions, specifications and photos for robots, positioners, cells, flexible manufacturing systems and robot traveling columns and tracks is available. Process equipment, torch products, sensors and off-line programming information is also provided. The guide

--- continued on page 87 ---
The Defense Manufacturing Conference (DMC), hosted by the Joint Defense Manufacturing Technology Panel, was held in Tampa, Fla., November 27-30. The conference served as a forum to present and discuss initiatives directed at Department of Defense (DoD) manufacturing technology and sustainment needs. Based on the theme “Foundation for Global Security,” attendees were given an overview of government and industry programs as well as a vision for the future of defense manufacturing and sustainment needs.

The Navy Joining Center (NJC) and more than 60 organizations exhibited to more than 700 attendees at the conference. NJC personnel gave several presentations during the technical sessions. Tim Trapp, NJC project manager, presented an “Overview of the Knowledge-Based Inspection Systems (KBIS)” and “Friction Stir Welding of Aluminum Armor for the Advanced Amphibious Assault Vehicle.” Dr. James Dydo, business development manager, presented work on “Transient Thermal-Tensioning Methods to Reduce Distortion in Thin Ship Panels.”

The KBIS project is directed toward the development and validation of a knowledge-based ultrasonic inspection system for steel ship structures. KBIS will lower weld reject rates and repair costs by providing more information about weld discontinuities. The intent of KBIS is to enhance manual ultrasonic inspection by using a computer-based neural network system to classify flaw type and determine discontinuity size. KBIS will provide both hard copy and electronic records of inspection results for independent review and audit.

Friction stir weld development is being done to join aluminum Alloy 2519 for armor on the Advanced Amphibious Assault Vehicle (AAAV). The project supports the AAAV program by developing procedures to improve productivity, reduce acquisition costs, reduce distortion and maximize ballistic performance. NJC activities are centered on the development of optimal welding procedures for a range of material thicknesses in the form of groove weld and corner- and T-joint configurations. Upon completion of the development activities, the project will provide friction stir welding tooling concepts, determine machine requirements and develop robust procedures and production methods to support efficient vehicle production.

The presentation on transient thermal-tensioning methods to reduce distortion in thin ship panels described an ongoing development effort aimed at reducing weld distortion in “thin” ship panels. Typical ship panels are fabricated from plate structure that is reinforced with welded T stiffeners. During welding, plastic deformation is induced in the plate creating out-of-plane distortion after cooling. This process involves the application of dynamic local auxiliary heating away from the welded area that causes the panel to “tension” in the weld area. The thermal tensioning effect greatly reduced distortion in the finished welded panel.

For more information regarding the NJC presentations at DMC 2000, please call Tim Trapp at (614) 688-5231, e-mail tim_trapp@ewi.org, or James Dydo at (614) 688-5116, e-mail jim_dydo@ewi.org.

Navy Joining Center Fellowships

As part of its commitment to further technical education and the advancement of materials joining technology, the Navy Joining Center supports two graduate fellowships each year. These fellowships are awarded through the American Welding Society Foundation to support graduate students whose research topics address materials joining.

The NJC Fellowships for the 2000-2001 academic year have been awarded to Chad S. Kusko of Lehigh University and Jason E. Mitchell of Vanderbilt University. Kusko has been a previous recipient of an NJC fellowship and is pursuing a doctorate degree in material science and engineering with a dissertation titled A Fundamental Study of Fatigue Crack Propagation along the Fusion Line in Dissimilar Weld Metals. Mitchell is pursuing a master’s degree in mechanical engineering with studies in “an investigation of the forces produced during friction stir welding with an objective of improved control.”

Please contact the AWS Foundation at (800) 443-9353 ext. 689 for more information on NJC Fellowships.
BYR. L. PEASLEE

Q: We are using a stored-energy resistance spot welding machine to tack honeycomb cells to the inside of seal rings before vacuum brazing. The spot welds are not reliable when welding on nickel-plated gamma-prime material surfaces. The nickel plating is applied to prevent oxidation of aluminum and titanium in the base metal during the vacuum brazing cycle, facilitating a good quality braze. Why are the welds weak, and what can be done to eliminate this problem?

A: Nickel plating is a lamellar structure made up of molecule-sized nickel particles, progressively laid on top of the substrate, and presents a different structure than the crystalline base metal. If spot welding is done within days of the plating, bond strength to the base metal will be more of a cohesive force than if the plating is held for long periods of time before spot welding. Also, spot welding may not take to the lamellar-type structure presented by the plated surface, resulting in unreliable welds. Another point to consider is that the plating on gamma-prime materials is difficult. Cleaning base metal prior to going into the nickel-plating bath is very important because it affects bond strength. When the base-metal surface is not adequately cleaned, blisters will be visible in the plating after the plated parts have been processed through the furnace.

Testing the plating bond can be easily accomplished by putting the parts in a vacuum furnace and heating them to 1800°F (980°C), holding the parts at temperature for five to ten minutes followed by cooling. This cycle allows you to see if there are any blisters. If there are, the bond between the base metal and the plating has been broken and the plating should be removed and the part recleaned and replated. If recleaning and replating are not done, spot welding or brazing would definitely yield poor results. Also, the cycle changes the lamellar structure to a crystalline structure and creates a diffusion weld between the plating and the base metal. Because titanium and aluminum will diffuse up through the plating, this cycle should not be run at a high temperature or for a long period of time. If the plating is thin, you will have titanium and/or aluminum oxide on the surface of the nickel, thus inhibiting the brazing wet-
**Stainless Q&A**

BY DAMIAN J. KOTECKI

**Q:** I am trying to qualify welding procedures for 304L and 316L equipment for cryogenic service in liquid nitrogen or liquid hydrogen. The December 2000 Stainless Q&A column proposed 3 FN minimum for 308L and 316L weld metals for freedom from hot cracking. But when I test welding procedures using covered electrodes or submerged arc with 5 to 10 FN, I fail toughness requirements of 15-mils lateral expansion at -320°F (-196°C, or 77 K). I have no trouble with the base metal tests. How can I meet this toughness requirement in the welds without hot cracking?

**A:** Austenitic stainless steels, including their weld metals, do not undergo the rather abrupt transition from ductile fracture to brittle fracture with falling temperature that is experienced by common mild steel and low-alloy steels. Rather, they experience a gradual decline in toughness, measured as either absorbed energy or lateral expansion in the Charpy V-notch impact test, with falling temperature. At cryogenic temperatures, the fracture mode in austenitic steel is still normally ductile tearing, not brittle cleavage. However, the ferrite in a nominally austenitic stainless steel weld metal can experience cleavage fracture, so it is often essential to limit the amount of ferrite to increase the fracture energy at cryogenic temperatures.

Also, keep in mind that the Charpy V-notch impact test becomes invalid at temperatures much below -320°F. It is valid for liquid nitrogen testing but not for liquid hydrogen testing since liquid hydrogen will not cause a fracture, so it is often necessary to limit the amount of ferrite in the weld metal. The -15 coating produces better toughness at a ferrite level of about 900 ppm, while the -16 coating produces lower oxygen (about 400 ppm). Therefore, to improve your chances of meeting cryogenic impact requirements, choose low-ferrite, low-nitrogen filler metal with a lime-fluoride coating. Low-ferrite, low-nitrogen filler metal with a lime-fluoride coating can be used for welding with a high-silicon flux with a low-ferrite, low-nitrogen filler metal.

But you can do better. The effect of oxygen continues below 400 ppm. A slag-free-inert-gas-shielded process (GTAW or GMAW) can produce on the order of 150 ppm or less of oxygen in the weld metal. I've routinely found low-nitrogen (0.04% or 400 ppm) AWS A5.9 ER308LSi and ER316LSi wires with about 10 FN, welded GMAW, spray transfer, with 98% argon-2% oxygen shielding gas, that produce Charpy V-notch toughness of about 30-mils (0.76-mm) lateral expansion at liquid nitrogen temperature. This is not specially melted material, just commercial quality. At this ferrite level, there are no fears of hot cracking.

On the other hand, if you want to use a flux-shielded process, you will have to look at filler metals below 5 FN, with highly basic slag systems. As a result of the Szumachowski and Reid work, AWS A5.4 E316L-15 covered electrodes and AWS A5.22 E316LT-3 self-shielded flux cored wires with a highly basic slag system were produced to 2 FN maximum. These were used for fabrication of 304L stainless steel magnet cases for superconducting magnets for the fusion energy program at Lawrence Livermore National Laboratory. Note that, today, the E316LT-3 filler metal would be classified as E316LT0-3 because the AWS A5.22 standard, as revised in 1995, now includes a welding position indicator (0° for downhand and horizontal positions only), which it did not when the filler metal for Livermore was manufactured. The steel ranged up to 4 in. (100 mm) thick. Welds were qualified by testing both for 15-mils lateral expansion at liquid nitrogen temperature and for fracture toughness at liquid helium temperature. The welds met the toughness requirements and did not hot crack. The 316L filler metals were chosen because 316L seems to be more resistant to hot cracking than 308L when the ferrite is very low. Low phosphorus, low sulfur and high manganese are also important to the hot cracking resistance of such weld metals.

Nickel-based-alloy filler metals (e.g., AWS A5.11 classes ENiCrFe-2, ENiCrFe-3 and ENiCrMo-3) can also meet the cryogenic toughness requirements. These have no ferrite, but are crack resistant. They cost considerably more than stainless steel electrodes.

To sum up, your choices for meeting cryogenic toughness requirements are GMAW or GTAW with filler metals of normal FN or slag-shielded filler metals with below 2 FN.

**DAMIAN J. KOTECKI** is Technical Director for Stainless and High-Alloy Product Development for The Lincoln Electric Co., Cleveland, Ohio. He is a member of the AWS ASD Subcommittee on Stainless Steel Filler Metals; AWS D1 Structural Welding Committee, Subcommittee on Stainless Steel Welding; and a member and past chair of the Welding Research Council Subcommittees on Welding Stainless Steels and Nickel Base Alloys. Questions may be sent to Mr. Kotecki c/o Welding Journal, 550 N.W. LeJeune Rd., Miami, FL 33126.
Z49... The "finest publication on welding safety in the world" has been thoroughly updated!

Unions, societies, trade groups, U.S. military and U.S. enforcement agencies all contributed to the latest edition of Safety in Welding, Cutting, and Allied Processes— including AWS, Sheet Metal Workers, OSHA, and NIOSH. 52 pages cover oxyfuel gas welding and cutting safety, arc welding and cutting equipment safety, resistance welding safety, electron beam processes, and laser beam cutting and welding safety. Four appendices. Published in 1999; ANSI-Approved.

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"What You Need to Know About Safety & Health Issues in the Welding Environment" Monday, May 7, 2001

- Proposed guidelines for manganese and chromium exposure that can affect all welding operations
- Update on OSHA activity in the welding area
- K. Brown, project research manager, The Lincoln Electric Co., Cleveland

- How to select the fume removal system that is best for your workspace
- Introduction to a new AWS ventilation document
- T. Pumphrey, The Lincoln Electric Co., Cleveland

- What type of welding curtain is best for your application?
- Introduction to a new AWS document on welding curtains
- B. Tucker, director, Technical and R&D, Dalloz Safety, Lakeland, FL

- Are you still worried about issues like these: contact lenses, pacemakers, or electro-magnetic fields (EMF)?
- AWS "Safety and Health Fact Sheets" are your quick guide to safety in the welding environment

- Fire Safety in Metal Fabrication
- See this new NFPA video along with expert commentary
- A. E. Manz, A. E. Manz Associates, Union, NJ

Chair: K. Lyttle, senior development associate, Praxair, Inc., Tarrytown, NY
CoChair: S. R. Flore, senior engineer, Edison Welding Institute, Columbus, OH

To learn more about the AWS WELDING SHOW 2001, go to aws.org or watch your mail for the 2001 Advance Program featuring the AWS WELDING SHOW 2001 and PMA's METALFORM 2001.
Air Products Elects Chairman/CEO

Air Products and Chemicals, Inc., Allentown, Pa., announced the election of John P. Jones III as chairman of the board, president and chief executive officer. He succeeds Harold A. “Hap” Wagner, who was the company’s chairman and chief executive officer since May 1992. Jones previously served as the company’s president and chief operating officer. Jones joined the company in 1972 as a participant in its Career and Development Program and subsequently worked in various management positions in the process gas international division; the International Coal Refining Company; and the Stearns Catalytic World Corporation. He also held executive assignments as vice president and general manager of environmental and energy systems, group vice president for the Process Systems Group and president of Air Products Europe. In 1996, Jones was named executive vice president, Gases and Equipment Group, and, two years later, assumed the position of president and chief operating officer. Since 1998, he has served on the company’s board of directors. Jones holds a B.S. in chemical engineering from Villanova University, is on the board of trustees of the American Chemistry Council and is a member of the board of trustees of the Rider-Pool Foundation.

Motoman Appoints Vice President and Director

Motoman, Inc., Dayton, Ohio, has named Steve Barhorst [AWS] as vice president of finance/chief financial officer. In this position, he is responsible for the Information Systems and Finance Departments. Barhorst earned a B.S. degree from Miami University. After receiving his Certified Public Accountant certification, Barhorst was employed for nearly nine years at Ernst & Young, where he advanced to senior manager status. His experience also includes serving as chief financial officer at Fidelity Health and vice president of finance and chief financial officer at Dolly, Inc.

Carl Traynor was named director of marketing. His background includes a B.A. in economics from the University of Michigan and a J.D. from the University of Minnesota Law School. Traynor was an attorney for Lincoln National Corp. and a technology business consultant at the Michigan Center for High Technology. Most recently, Traynor was vice president of business development at Dynalog, Inc.

Wall Colmonoy Names Vice President

Daniel C. Fulgham was appointed group vice president for the Process Business Units at Wall Colmonoy Corp., Madison Heights, Mich. In this position, he oversees the four processing facilities in Dayton, Philadelphia, Oklahoma City and San Antonio. Fulgham was previously vice president/general manager at Bristol Aviation Services in Oklahoma. He has more than 22 years of experience in the aviation industry and obtained a B.S. degree in aviation science and management from Oklahoma State University.

Panasonic Factory Automation Appoints Sales Engineer

Panasonic Factory Automation Co. (PFA), Franklin Park, Ill., announced Pat Clark [AWS] has joined the company...
pany as a senior sales engineer. His responsibilities are to support the sales of robotics, welding equipment and welding robotic systems. Prior to joining the company, Clark began his career with a major gas and equipment manufacturer. He was previously plant manager, director of purchasing, distributor manager and has worked both inside and outside sales.

DE-STA-CO Names Manager

DE-STA-CO, Madison Heights, Mich., announced the promotion of Brent Conn to the position of quality manager for its Industrial Products Group. He is responsible for the quality of all products purchased and produced at the company's Birmingham, Mich., plant. Conn joined the company in 1997 as a quality engineer. He holds both a bachelor's degree in journalism and a master's degree in written communications from Eastern Michigan University.

ESAB Announces Appointments

ESAB Cutting Systems, Florence, S.C., announced the following appointments:

Robert Scripnick was named director, machine tool sales. He will be responsible for sales of ESAB's specialty machines including the Alpharex laser and Hydrocut waterjet product lines. Scripnick was previously marketing manager and product manager for the company's gantry cutting systems.

Jeff Defalco [AWS] was named product manager for machine tools. His responsibilities include overseeing all aspects of the company’s laser, waterjet and Precision Plasma cutting systems. Defalco was previously the company's senior design engineer and regional sales manager for Asia.

Joe Blackmon III was promoted to the position of marketing manager. He assumes responsibility for overseeing all facets of marketing and advertising for the company's product lines. Employed with the company since 1988, Blackmon previously worked as business manager, senior product manager and senior buyer.

Hal Lawrence was named product manager, cutting tables and environmental equipment. He will oversee the development and production of cutting tables and environmental equipment used with the company's gantry cutting systems. An ESAB employee since 1977, Lawrence's previous duties included senior project manager, large gantry machines project manager and project administrator and small gantry machines production planner.

Jim Johnson was appointed manager of the company's standard products line. Johnson rejoins the company, where he worked as a software engineer from 1993 to 1999. In this position, Johnson oversees the marketing of small- to medium-sized mechanized cutting systems.

Tempil® Announces Staff Additions

Pramathesh Desai [AWS] has joined the sales and marketing team of Tempil®, Inc., South Plainfield, N.J. He joins the company after serving 13 years as welding services manager for the Kanoo Group, Dubai, United Arab Emirates. Desai holds a master's degree in materials engineering from the Cranfield Institute of Technology, United Kingdom, a B.E. in metallurgical engineering from M.S. University, Baroda, India, and a business management diploma from Indian Merchant's Chamber, Bombay, India.

Nainesh “Nate” Mehta [AWS] has joined the R&D staff of the company. His prime responsibilities include managing the R&D staff. Before joining the company, Mehta was with the R&D department of Dunmore Corp., Newton, Pa. He holds B.S. and M.S. degrees in chemistry.

Obituary

Bob White

Bob White, vice president of sales and marketing for Norris Cylinder Co., died on Friday, December 8, 2000.

White joined Norris in 1985 as southeastern regional sales manager and served in that capacity until February 1995, at which time he was promoted to vice president, sales and marketing. Prior to joining Norris, he spent 15 years with M&A Welding Supply in Atlanta, Ga. He was president of M&A from 1981 to 1985.

White is survived by his wife, Stephanie, three children and two grandchildren.
The #1 selling welding code now comes alive in a five-day seminar that begins with a roadmap of D1.1:2000, Structural Welding Code — Steel. This is your opportunity to learn from an expert AWS instructor and ask your toughest questions about D1.1. Code week continues with corresponding subjects geared toward engineers, supervisors, planners, welding inspectors and welding technicians. Since your work is based on a reputation for reliability and safety, you want the latest industry consensus on prequalification. If you want to improve your competitive position by referencing the latest workmanship standards, inspection procedures and acceptance criteria, you won’t want to miss this seminar! Each day will be in-depth and intense.

(Day 1, Monday) D1.1 Road Map
San Francisco, Calif. — March 5, 2001
St. Louis, Mo. — April 9, 2001
Chicago, Ill. — July 16, 2001
Las Vegas, Nev. — September 17, 2001
Atlanta, Ga. — November 5, 2001

(Day 2, Tuesday) Design of Welded Connections
San Francisco, Calif. — March 6, 2001
St. Louis, Mo. — April 10, 2001
Chicago, Ill. — July 17, 2001
Las Vegas, Nev. — September 18, 2001
Atlanta, Ga. — November 6, 2001

(Day 3, Wednesday) Qualifications
San Francisco, Calif. — March 7, 2001
St. Louis, Mo. — April 11, 2001
Chicago, Ill. — July 18, 2001
Las Vegas, Nev. — September 19, 2001
Atlanta, Ga. — November 7, 2001

(Day 4, Thursday) Fabrication
San Francisco, Calif. — March 8, 2001
St. Louis, Mo. — April 12, 2001
Chicago, Ill. — July 19, 2001
Las Vegas, Nev. — September 20, 2001
Atlanta, Ga. — November 8, 2001

(Day 5, Friday) Inspection
San Francisco, Calif. — March 9, 2001
St. Louis, Mo. — April 13, 2001
Chicago, Ill. — July 20, 2001
Las Vegas, Nev. — September 21, 2001
Atlanta, Ga. — November 9, 2001

Prices
Member Nonmember
(One-day seminar) $345 $420
(Entire week) $795 $870

UPCOMING CONFERENCES

WELD CRACKING: CAUSES AND CURES CONFERENCE
June 7-8, 2001 — Houston, Tex.
Hydrogen-induced cracking isn’t the only culprit that engineers and QC professionals need to be on the alert against. AWS experts will identify other, often unknown or overlooked cracking scenarios, along with the best use of counteroffensivees, including preheat and peening. Other areas covered include the best use of ultrasound and Charpy tests, plus the lowdown on new test options. This intense day-and-a-half program covers cracking in steels, aluminum, stainless steels and titanium.

THE CUTTING OF PLATES CONFERENCE
July 17-18, 2001 — Chicago, Ill.
For decades, the only plate cutting method was oxyfuel cutting. It is still used, but recently, methods like plasma cutting, high-definition plasma cutting, water jet cutting and both CO2 and YAG laser cutting are more frequently used. Many companies are in turmoil deciding which method is best. This conference will provide engineers with greater understanding of the issue, knowledge about the cost of equipment, payback, cutting performance and valuable information that can be implemented profitably into their company’s production lines. This conference will cover mostly steel, with some mention of stainless and aluminum. Topics include laser cutting, plasma cutting, high-definition plasma cutting, water jet cutting and innovations in oxygen cutting.

ELEVENTH INTERNATIONAL CONFERENCE ON COMPUTER TECHNOLOGY IN WELDING
September 19-20, 2001 — Columbus, Ohio.
The eleventh in a series of computer conferences will provide the welding industry with the latest information regarding the use of computers for welding. The conference brings together experts on sensors, equipment control, process modeling and data acquisition. Engineers, managers and system integrators will benefit from discussions of hardware and software installations and user experiences with these systems. Integration of welding systems with network and Web applications will be emphasized. Topics to be discussed include modeling of welds and welding processes; off-line planning/weld simulation/visualization; computerized data acquisition and sensing systems; real-time welding information and control systems; weld process automation; network and Web-based implementations; case histories/experiences with commercial software (by users); welding documentation (e.g., WPS, PQR); databases, database applications and knowledge bases; standards.

For further information contact: Conferences, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126. Telephone: (800) 443-9353 ext. 223 or (305) 443-9353 ext. 223, FAX: (305) 443-1552. Visit the Conference Department homepage http://www.aws.org for upcoming conferences and registration information.
Spot welding on a nickel surface with crystalline structure with a diffusion-welded bond to the base metal should improve the quality of the stored energy spot welds.

A blasting procedure using a nickel-chromium-silicon grit has been developed that eliminates the need for nickel plating. The process has been successfully applied to base metals containing lower amounts of aluminum plus titanium. Presently, it works on up to 2% of titanium plus aluminum. The process is not suitable for a 6% base metal containing aluminum, but, at this time, the cut-off point is uncertain, somewhere between 3 and 4%. Blasting is usually accomplished by using a pressure-pot type blast unit with a 100-lb plant air supply and special blasting grit. Caution must be observed when attempting to blast thinner materials. There is no problem blasting a 0.250-in. (6.350-mm) thick base metal, but when the thickness decreases to 0.032 in. (0.813 mm), and specifically 0.020 in. (0.508 mm) or lower, heavy distortion can be experienced. Remember that blasting puts compressive stress into the surface, so if a surface of 0.032-in. strip is being blasted, the strip will bow toward the blasted surface. This is caused by the compressive stress in the surface, which tends to make the blasted surface longer than the unblasted surface. This is similar to a bimetal strip that has two different coefficient-of-expansion materials joined together. When the temperature changes, the bimetal bows because one side increases in length over the opposite side.

Furnace cycle testing of the plating ensures the plating process is in control and that the strength of the plating bond is very strong, resulting from the diffusion welding. Use of the special blasting procedure, within limits, has been very successful, and should be of help.

R. L. Peaslee is Vice President, Wall Colmonoy Corp., Madison Heights, Mich. This article is based on a column prepared for the AWS Detroit Brazing and Soldering Division’s newsletter. Reader questions may be sent to Mr. Peaslee c/o Welding Journal, 550 N.W. LeJeune Rd., Miami, FL 33126.
Evolving since 1928, D1.1 Structural Welding Code — Steel is an industry consensus on the minimum welding requirements that can ensure quality fabrication for the vast majority of industrial and commercial applications. Developed under strict ANSI procedural rules; Dept. of Defense adopted.

For those involved in fabricating statically, or dynamically-loaded, steel structures including tubular shapes, D1.1 Structural Welding Code — Steel is indispensable.

Important areas with comprehensive coverage

- Design of welded connections including: tubular and non-tubular, statically or cyclically loaded
- Prequalification of Welding Procedure Specifications including: amperage, voltage, travel speed, shielding gas flow rate, joint designs and specifications
- Qualification including: procedures and personnel
- Fabrication including: base metal, consumables, tolerances, assembly, repair, cleaning
- Inspection including: qualification, acceptance criteria, NDE, RT, UT
- Stud Welding including: design, production control, inspection
- Strengthening and Repairing Existing Structures including: design, stress analysis, restoration or replacement, repairs

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- new steels and electrodes including ASTM A992 and metal cored GMAW electrodes
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Staff Welding Engineer with the American Welding Society in Miami, Florida

Principal duties include working with AWS technical committees that develop and issue standards for the welding industry, act as technical secretary for these committees, assist in writing and revising the standards and respond to inquiries relating to these standards. Involves approximately 20% travel.

Position requires a BS degree in engineering and a demonstrated ability to write and edit technical papers clearly and concisely. Experience in welding or allied processes is desirable. Must have excellent writing and verbal language skills. Must also be comfortable in a computer environment. Working knowledge of Windows, Microsoft Word and Wordperfect a plus. Excellent employee benefits and relocation allowance. Send resume and salary requirements to:

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The Tenth International JOM Jubilee Conference on Joining of Materials, JOM-10, is accepting papers for presentation May 11-14, 2001, in Helsingor, Denmark. Organized by the JOM Institute and held biennially since 1981, the conference encourages the presentation of the latest in welding research and development with an emphasis on relevance to industrial applications. It attracts engineers, scientists, and educators from all over the world.

Papers are invited on, but are not limited to, the following topics:
• Welding processes and systems
• Weldability of materials
• Welding robotization and automation in manufacturing
• Welding instruction
• Artificial intelligence and computer technology in welding
• Weld sensor systems
• Arc stability and metal transfer
• Brazing, soldering, and associated nonarc joining processes

Individuals interested in making a presentation should prepare a short abstract and include the name and address of the author(s), and title of paper. Send it by mail or FAX, no later than February 15, 2001, to JOM Institute Secretariat, Klintehoj Vænge 21, DK-3460 Birkerød, Denmark; FAX 45 45 94 08 55; e-mail jom_aws@post10.tele.dk
AWS Peer Review Panel

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

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A Fuzzy Logic System for Process Monitoring and Quality Evaluation in GMAW

Monitoring weld quality in real time is proposed using voltage and current for raw data to develop graphic histograms

BY C. S. WU, T. POLTE AND D. REHFELDT

ABSTRACT. This paper introduces a fuzzy logic system that is able to recognize common disturbances during automatic gas metal arc welding (GMAW) using measured welding voltage and current signals. A statistical method was employed to process the captured transient raw data, and the probability density distributions (PDDs) and the class frequency distributions (CFDs) were obtained. Based on the processed data (PDD values of welding voltage and current and CFD values of the short-circuiting time), the system automatically generates fuzzy rules and membership functions of linguistic variables, conducts inference and defuzzification, and completes the evaluation process without further expert knowledge.

Introduction

Gas metal arc welding (GMAW) is widely used in industry. The process's high metal deposition rate makes it well suited to automatic and robotic welding. Monitoring weld quality in real time is increasingly important since great financial savings are possible, especially in manufacturing where defective welds lead to losses in production and necessitate time-consuming and expensive repair (Ref. 1). The task of a weld monitoring system is to use captured signals to classify a weld into defective or nondefective groups. The internal signals of the welding process such as welding voltage and current, as well as external signals such as CCD camera output, can be used as variables. However, external sensors are expensive and restrict the mobility and flexibility of automated GMAW systems. By comparison, welding voltage and current are inherent process parameters and are easy to measure. Moreover, their curves reflect many peculiarities of the welding process in their shape. Each kind of arc welding process is characterized by certain shapes of the welding voltage and current typical for the process (Reis. 2, 3). Any disturbances or occurrences of faults during welding inevitably result in variation of these curves to some extent. Therefore, quality assurance in GMAW may be achieved through examining welding voltage and current.

To predict the quality of a weld joint, it is essential to process and evaluate the captured raw data. The raw voltage and current signals are not enough for weld process monitoring (Ref. 4). A method should be found to process and evaluate precisely the stochastic and nonlinear arc welding process. Statistical methods are effective in dealing with stochastic processes. The commonly used parameters for process monitoring are the mean values and the standard deviations of welding voltage and current (Ref. 4). But these values are not sufficient to the tasks of process monitoring and quality evaluation because they are just some numbers, not fully representing or depicting the actual dynamic behavior of the process. The description of a stochastic process is possible by means of the probability density distributions (PDDs) and class frequency distributions (CFDs). The principle is to distribute the frequency of the sampled values, e.g., different welding voltage values, into discrete classes. A graphical representation of such distributions are histograms (see Appendix). This approach involves a massive data reduction, but the essential process information is retained.

The commercially available Analysator Hannover XV (AH XV) was used to measure and calculate the PDDs of the transient welding voltage and current signals during a welding process (Ref. 5). Furthermore, CFDs of the process time signals are derived from the transient voltage. Each welding process has its own characteristic ("fingerprint") PDDs and CFDs. However, comprehensive expert knowledge is required to recognize and distinguish process disturbances and faults through evaluating the PDDs and CFDs of the welding process. If the evaluation is automatically carried out based on the PDDs and CFDs, it will be of great significance for industry applications. To this end, artificial intelligence methods, such as fuzzy logic and neural networks, should be applied. This paper introduces a fuzzy logic system for GMAW process monitoring and quality evaluation.

KEY WORDS

Fuzzy Logic
Weld Process Monitoring
Weld Quality Monitoring
GMAW
Weld Process Control

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Measurement and Experimental Method

Constant-voltage GMAW experiments were performed with a fully mechanized and computer-controlled welding system. The base metal was 1-mm-thick steel. Shielding gas was 18% CO₂ and 82% Ar with a flow rate of 12 L/min. The wire electrode was 1-mm-diameter SG 3 (equivalent to AWS A5.18-79: ER70S-G). Wire feed rate was set to 4.0 m/min. Welding speed was 76 cm/min, mean welding current was approximately 130 A, and welding voltage was set at the principle of the system.

The AH XV consists of an industrial PC (Intel® Pentium CPU) with a high performance ADC board and the processing software. A Hall sensor was used to monitor the welding current. The voltage drop between the torch contact tip and the workpiece was processed by a low pass filter (LPF) and a voltage divider. Each channel was sampled at 100 kHz with a resolution of 12 bits. The software ran under the Microsoft Windows® 95/NT 4.0 operating system.

In this experimental investigation, 48 welding tests were carried out. Undisturbed and intentionally disturbed welding experiments were evaluated. The disturbances were as follows:

1) Increasing the wire feed rate
2) Decreasing the wire feed rate
3) Increasing the gas nozzle diameter
4) Welding over two sheets
5) Welding over a lap joint with a clearance between the upper and lower sheets
6) Workpiece surface with some oil
7) Welding over a lap joint with the upper sheet having a cut in the middle.

Figures 2 and 3 show the PDDs of welding voltage and current. Figure 4 shows the CFDs of short-circuiting time.

Automatic Evaluation

Figures 2–4 show the differences between the disturbed and the undisturbed experiments, but there are obvious differences between both types of experiments. Expert knowledge and skill are required to reliably recognize and distinguish the PDDs and CFDs of the GMAW experiments. For a quality prediction without an expert, especially for quality prediction in production lines, automatic evaluation methods have to be developed. A possible solution for this is the implementation of neural networks, fuzzy logic or combinations of both. This paper concentrates on a fuzzy logic system. Figure 5 shows the principle of the system.

Basic Design of Fuzzy Logic Systems

To solve a problem based on uncertain or fuzzy observations or correlations, it is necessary to describe, map and process the influencing factors in fuzzy terms and to provide the result of this processing in a usable form. These requirements result in the basic elements of a knowledge-based fuzzy system — Fig. 5. The numeric values of the input variables are transformed into memberships of fuzzy sets by fuzzifying. This information, together with the declared rules, is given to the inference engine, the results again being a set of memberships of fuzzy sets (terms for the output variables). The last step is to transform these mem-
bership values into the required scalar variables by defuzzifying.

Linguistic Variables

As shown in Fig. 5, the developed fuzzy logic system works mainly with the PDDs and CFDs, which can be represented as n-dimensional vectors on discrete working computers. For the PDD of welding voltage, the whole range of voltage (0.125-60.125 V) is discreted into 121 classes, and the class width is 0.5 V. For the PDD of welding current, the whole range of current (0-451.172 A) is classified as 232 classes, and the class width is 1.95 A. For the CFD of short-circuiting time T₁ and arc-burning time T₂, the whole range of 0-19.75 ms is divided into 40 classes and the class width is 0.5 ms. If all values are used, the total number of input variables will be 433. Because each variable has 5-7 terms and a membership function, too many input variables would be prohibitively time-consuming and cause great difficulty in rule-generation and inference, making the problem unsolvable. Thus, additional data processing is necessary to reduce the values of PDDs and CFDs further.

After careful examination of the PDD and CFD curves, it was found that process disturbances affect the PDD curves of both welding voltage and current more markedly in some ranges. For the PDD of welding voltage, there are four sections with this characteristic, and two sections for the PDD of welding current. Thus, the voltage PDD values of every class are added together for the following four ranges of welding voltage: 0.125-4.625 V, 12.125-20.125 V, 20.625-35.125 V and 35.625-60.125 V, respectively. Then four sums SU1, SU2, SU3 and SU4 are obtained. Similarly, the current PDD values of every class are summarized within the following two ranges of welding current, 21.484-99.609 A and 234.375-351.563 A, respectively, and two sums SI1 and SI2 are obtained. For the CFD of short-circuiting time, all CFD values of every class are added together within the range 0-19.75 ms to produce a sum ST1. Therefore, seven values, i.e., SU1, SU2, SU3, SU4, SI1, SI2 and ST1, are available. These values contain the essential information on the PDDs and CFDs in a definite integral way. Each specific welding process condition should be characterized by these seven values of its own. They are the input variables for further processing.

In this research, seven disturbances were made intentionally during GMAW processes. The developed fuzzy logic system should be capable of recognizing and distinguishing them. The output variable is the evaluation result that is abbreviated to ER. Table 1 gives the terms of input and output linguistic variables.

Rule Base

The rule base includes “If-Then” rules, where the premise is a function of the input variables, and in the conclusion there are only terms referring to the output variable. Generalizing rules were used here, which means that not all input variables are necessarily combined in one premise. In this research, the software package WINROSAS (Ref. 6) was applied for automatic generation of relevant fuzzy rules on the basis of measured and processed data. This method needs to define the linguistic values for the “If” clause, as well as for the “Then” clause. For input variables, a data file can be established after a series of GMAW experiments. Since this is a diagnosis problem, the evaluation result is whether a GMAW process is normal or disturbed. Moreover, it also indicates the type of disturbance in the case of the disturbed condition. The output variable has no definite values, so different digits are attributed to the output variable ER. For example, a value 1 of ER is related with the normal welding condition without any disturbance; DT₁ = disturbance No. 1, and so on.

Figure 6 illustrates the rule-generation process of the fuzzy logic system. Table 1 is such a data file used for automatic determination of membership functions for input and output variables and rule generation.
Table 2 — The Data File for Automatic Rule Generation

<table>
<thead>
<tr>
<th>Test No.</th>
<th>SU1</th>
<th>SU2</th>
<th>SU3</th>
<th>SU4</th>
<th>SI1</th>
<th>SI2</th>
<th>ST1</th>
<th>ER</th>
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<td>21.164</td>
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<td>23.842</td>
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<td>21.003</td>
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<td>76.4</td>
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</table>

Fig. 6 — Principle of rule generation.

Fig. 7 — Membership function of the input variable SU1.
derived (i.e., the rule conclusion terms). An inference step (the evaluation of a rule) consists of three steps.

1) Aggregation. Aggregation is the calculation of the fulfillment of the whole rule, based on the fulfillments of the individual premises. This process generally corresponds to the logic and operator of the individual premise expressions. This connection can, in principal, be carried out using any of the following operators: Minimum, Maximum, Algebraic product, Algebraic sum, and Gamma-operator. In this research, the test results demonstrate that the evaluation result is of higher accuracy if the algebraic product \( p_A(x) \cdot p_B(x) \) is employed as the aggregation operator.

2) Implication. Implication based on the certainty factors calculates the corresponding degree of certainty for the conclusion. This is called the degree of fulfillment. This step represents the conclusion of the logic statement, "If A, then B." Implication is the connection between the certainty factor and the degree of fulfillment, the results being the degree of fulfillment of each of the conclusions. The algebraic product is used here as the implication operator.

3) Accumulation. In knowledge-based systems, often more than one rule leads to the same conclusion. If the conclusion of a rule has a degree of fulfillment of 0.7, but 0.3 with another rule, then the different degrees of fulfillment need to be summarized in just the one. This is achieved by a process of accumulation, which corresponds to unifying individual results with the logical "Or" operator. In the developed fuzzy logic system, the algebraic sum \( p_A(x) + p_B(x) \) is employed as the accumulation operator.

Defuzzifying

The results of the inference process must be translated from fuzzy logic (membership of terms of the linguistic variables) into (crisp) values, in other words, a concrete evaluation result. This is done by defuzzifying. Seen mathematically, the result of the inference process is a fuzzy set for the output variable. This set of fuzzy output has a membership function calculated from membership functions and the degree of membership of the different terms. The task of the actual defuzzifier is to transform the membership function of the fuzzy output set into a crisp result. In this work, the mean of maxima is used as the defuzzifying method.

Results and Discussion

GMAW experiments were conducted under eight conditions, i.e., one normal condition without any disturbance and seven conditions with intentional disturbances. For each condition, six welding experiments were carried out. The first three experiments were used to generate fuzzy rules, and three additional experiments were used to test the system. As shown in Table 3, for all 24 experiments tested, the developed fuzzy logic system can automatically recognize 22 cases. The correct recognition rate is 92%.

It should be pointed out that this work is only the initial step for weld process monitoring using the welding voltage and current signals. The so-called 92% correct recognition rate only corresponds to the available 48 GMAW experiments (24 for training, 24 for testing). Greater efforts are being made for further research and improvement of the fuzzy system. For one thing, the system will be modified to improve the fuzzy system. Also, the system will be modified to distinguish the process signal's variation caused by disturbances from that caused by an intentional weld schedule. For example, as a robot welds around a corner, the travel speed and the wire feed rate are often intentionally decreased. This changing of process signals is usually known in advance during the welding robot's programming phase so relevant information can be provided to the fuzzy system. Moreover, a large amount of GMA welding trials will be carried out to obtain more data for sufficiently training the fuzzy system.

Conclusions

The AH XV, fuzzy logic system for process monitoring and quality evaluation in GMAW has been developed. It is used to measure transient welding voltage and current and to process them into PDDs and CFDs during GMA welding experiments. The PDDs of welding voltage and current, as well as the CFD of short-circuiting time, are decomposed into several ranges within which the corresponding PDD values or CFD value of every class are summarized in a way that seven input variables are obtained. The measured data are further reduced, but the essential process characteristics remain. The WINROSA method is applied for automatic generation of linguistic terms, membership functions and relevant fuzzy rules on the basis of the processed experiment data. The rule base containing 399 "If-Then" rules with certainty factors are imported to an intelligent data analysis tool named DataEngine, which conducts inference and defuzzification processes so the evaluation results can be obtained.

The system is able to recognize and classify disturbed and undisturbed GMAW experiments. The entire evaluation process can be carried out automat-

<table>
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<th>Experiment Run No.</th>
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<th>The System Output</th>
<th>Is the Evaluation Results Correct?</th>
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</tr>
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<td>Workpiece</td>
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<td>3.97</td>
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<td>3.97</td>
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<td>4-6</td>
<td>oil</td>
<td>4</td>
<td>3.97</td>
<td>Yes</td>
</tr>
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<td>Welding over an</td>
<td>5</td>
<td>4.99</td>
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<td>7.02</td>
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<td>with the upper</td>
<td>5</td>
<td>4.99</td>
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<td>8</td>
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</table>
Fig. 8 — Principle of determining voltage PDD.

Fig. 9 — An example of short-circuiting time CFD.

Acknowledgment

The authors gratefully acknowledge support for this project from the DAAD Research Fellowship program of Germany.

References


Appendix

Probability Density Distribution (PDD) and Class Frequency Distribution (CFD)

The principle of determining the PDD is to distribute the frequency of the sampled values, e.g., different welding voltage values, into discrete classes. Figure 8 shows the PDD of welding voltage from a welding trial under short-circuiting GMAW conditions. During the welding process, the transient signal of welding voltage is captured and digitized. For these large masses of raw data, it is useful to distribute them into classes and to determine the number of measured values of the voltage belonging to each class, called the class frequency. The whole range of welding voltage is divided into many classes, such as 0-0.5, 0.5-1.0, 1.0-1.5, ..., 60-60.5 V. A symbol defining class such as 0.5-1.0 V is called class interval. The difference between the lower and upper class limits is called class width. Regarding the above example the class width is equal to 0.5 V. A tabular arrangement of data by classes with the corresponding class frequencies is called a frequency distribution, or frequency table. Table 4 is an example of frequency distribution. The relative class frequency is the frequency of the class divided by the total frequency of all classes and is generally expressed as a percentage — Table 4. A general representation of a frequency distribution is the histogram — Fig. 8. A histogram consists of a set of rectangles with centers at the class marks (the midpoint of the class interval) and widths equal to the class interval size and areas proportional to class frequencies. If all the rectangles have the same width, then their heights are proportional to the corresponding class frequencies, and it is then customary to take the heights numerically equal to the class frequencies. The frequency scale can be relative frequency or logarithmic frequency. In addition to the amplitude, a time analysis in short-circuiting welding is also valuable. There are two important time signals, i.e., the short-circuiting time \( T_1 \) and the arc burning time \( T_2 \). The CFD of these times are derived from the transient voltage. To determine \( T_1 \), count the time or number of samples where the voltage is below a threshold voltage. A counter is running between the transition from arc burning to short-circuiting up to the transgression of the threshold voltage. Different counts (different duration of \( T_1 \)) determine the distinct classes of the \( T_1 \)-CDF. For example, a test lasts 5 seconds. If the counted number of short-circuiting time 100–150 microseconds is 88, then the CFD value corresponding to the class 100–150 microseconds is \( 88/5 = 17.6 \) (1/s). After determining all CFD values for all short-circuiting time classes, a histogram can be obtained. Figure 9 shows an example for the differences between the undisturbed and disturbed CFD of short-circuiting time.
Effects of Surface Depression on Pool Convection and Geometry in Stationary GTAW

Arc pressure at peak duration produces deep penetration in pulsed current gas tungsten arc welding

BY S. H. KO, S. K. CHOI AND C. D. YOO

ABSTRACT. The effects of surface depression on pool convection and geometry in stationary GTAW are simulated numerically under DC and pulsed-current conditions. Welding current and Marangoni flow affect surface depression and velocity such that inward flow by the current and positive surface-tension gradient acts to decrease surface depression. Arc pressure is found to be a major factor in surface depression and in fluctuations of free surface and flow velocity. While arc pressure at the low current range has negligible effects on surface depression and pool geometry, it should be considered in the high current range. Under the pulsed current condition, deep penetration is produced mainly by arc pressure at peak duration. The solid-liquid interface profile at the pool center and periphery becomes similar to that of peak and base current, respectively, and penetration is closely correlated to surface depression.

Introduction

Because weld pool convection was found to have significant effects on the bead width and penetration in arc welding (Ref. 1), extensive research has been undertaken to reveal the relationship between pool convection and geometry (Refs. 2–10). Among the various factors affecting pool convection, electromagnetic force and surface-tension gradient are the most important. Because the electromagnetic force generates circulation within the molten pool in a downward direction, penetration increases by pool convection. The rotating direction of Marangoni flow depends on the surface-tension gradient, which is affected by minor elements such as sulfur composition in the base metal. These convection patterns with heat input from the arc determine pool geometry.

Numerical methods have been employed to predict pool convection, and the calculated pool geometry was in agreement with the experimental result (Refs. 2, 5). One of the general assumptions made to simplify numerical computation is the molten pool surface is flat (Refs. 2–4). Another assumption of a deformed surface depression was employed (Refs. 6–8) using the surface profile in an equilibrium state by minimizing the potential energy (Ref. 9). Several attempts were made to include the free surface under the direct current (DC) condition (Refs. 10, 11). While three-dimensional pool geometry was calculated for nonautogenous welding using surface elevation, the effect of arc pressure was not considered (Ref. 10). A numerical model for a full penetration weld with two free surfaces was presented (Ref. 11). Because the focus was the Marangoni effect on a free surface, the effect of the electromagnetic force was ignored and the pool had a cylindrical shape. Therefore, dynamic effects of surface depression on pool convection and its geometry have not been fully understood under DC and pulsed-current conditions.

In this work, dynamic variations of surface depression and pool convection in DC and pulsed-current gas tungsten arc welding (GTAW) are calculated numerically by employing the Volume of Fluid (VOF) method (Ref. 12). The solid-liquid interface of a molten pool is computed by solving the energy equation, and the effects of arc pressure, current and surface-tension gradient on surface depression and convection are analyzed based on the calculated results. Causes of deep penetration by the pulsed current are also simulated.

Formulation

Since the effects of a free surface are emphasized in this work, the following assumptions are made in the formulation: 1) fluid flow in the axisymmetric molten pool is incompressible and laminar, 2) the effect of the drag force from the plasma jet is neglected, and 3) material properties are constant. The principle of the VOF method for calculating fluid flow with a free surface is described briefly because it was explained in detail in other works (Refs. 8, 12, 13). The solution domain is divided by the staggered grid and the function F is defined to describe the fluid volume ratio within the cell. The governing equations consist of the continuity, momentum equations and an additional equation relating to the function F as follows:

\[ \nabla \cdot \dot{\mathbf{v}} = 0 \]  
(1)

\[ \frac{\partial \mathbf{F}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{F} = -\frac{1}{\rho} \nabla P + \mathbf{v} \nabla^2 \mathbf{v} + \frac{1}{ho} \mathbf{j} \times \mathbf{B} + \mathbf{g} \beta (T - T_{\text{mb}}) \]  
(2)

\[ \frac{\partial \mathbf{F}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{F} = 0 \]  
(3)

where \( \mathbf{v} \) represents the velocity vector, \( P \) the pressure, \( \rho \) the mass density, \( \nu \) the viscosity, \( f \) the current density, \( \mathbf{B} \) the magnetic flux, \( \beta \) the thermal expansion and \( T_{\text{mb}} \) the melting temperature. The electromagnetic and buoyancy forces in equation 2 are included as the body force.

The energy equation is solved in an implicit manner to calculate the temperature and solid-liquid interface as follows:

KEY WORDS

Surface Depression  
Pool Convection  
GTAW  
Direct Current  
Pulsed Current  
Marangoni Flow  
Volume of Fluid Method

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\[ \rho C_p \left( \frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T \right) = k \nabla^2 T + q \]

(4)

where \( \rho \) represents the specific heat, \( k \) the thermal conductivity and \( q \) the joule heating per unit volume. The latent heat, \( \Delta H \), is considered by increasing the specific heat in the temperature range of phase change as follows:

\[ C_p^* = \frac{\Delta H}{T_{eq} - T_{sol}} + C_p \]

(5)

As for the boundary conditions, the free-slip and no-slip conditions are imposed along the z-axis and on the solid-liquid interface, respectively. The arc pressure of a Gaussian distribution is exerted on the pool surface as shown in Fig. 1.

Table 1 — Material Properties of Mild Steel Used for Calculation

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Density, ( \rho )</td>
<td>7860 (kg/m³)</td>
</tr>
<tr>
<td>Kinematic Viscosity, ( \nu )</td>
<td>5.6 x 10⁻⁵ (m²/s)</td>
</tr>
<tr>
<td>Surface Tension Coefficient, ( \gamma )</td>
<td>1200 (dyne/cm)</td>
</tr>
<tr>
<td>Surface Tension Gradient, ( \partial \gamma / \partial T )</td>
<td>±4.9 x 10⁻⁴ (N/mK)</td>
</tr>
<tr>
<td>Electrical Conductivity, ( \sigma )</td>
<td>8.54 x 10⁵ (mho/m)</td>
</tr>
<tr>
<td>Permeability, ( \mu )</td>
<td>4.0 x 10⁻⁵ (H/m)</td>
</tr>
<tr>
<td>Thermal Conductivity, ( k )</td>
<td>30 (W/mK)</td>
</tr>
<tr>
<td>Specific Heat, ( C_s )</td>
<td>795 (J/kgK)</td>
</tr>
<tr>
<td>Latent Heat of Fusion, ( \Delta H )</td>
<td>272 (kJ/kg)</td>
</tr>
<tr>
<td>Liquidus Temperature, ( T_{liq} )</td>
<td>1809 (K)</td>
</tr>
<tr>
<td>Solidus Temperature, ( T_{sol} )</td>
<td>1789 (K)</td>
</tr>
<tr>
<td>Distribution Parameter of Current Density, ( \sigma_i )</td>
<td>3 (mm)</td>
</tr>
<tr>
<td>Distribution Parameter of Heat Flux, ( \sigma_q )</td>
<td>3 (mm)</td>
</tr>
</tbody>
</table>

with surface depression, they are assumed to be constant because these distributions are not known. Marangoni flow due to the surface-tension gradient, \( (\partial \gamma / \partial T) \), is considered by imposing shear stress on the free surface as follows:

\[ \tau = \left( \frac{\partial \gamma}{\partial T} \right) \left( \frac{\partial T}{\partial \psi} \right) \]

(7)

where \( \gamma \) and \( \psi \) denote the surface-tension coefficient and tangential direction of the free surface, respectively. The SOLA-VOF code written in FORTRAN is modified to include the effects of electromagnetic force and surface-tension gradient.

Results and Discussions

Effects of Welding Parameters under the DC Condition

In order to investigate the effects of the process parameters on surface depression and pool convection, the molten pool is assumed to be a hemispherical shape having a radius of 5 mm without solving the energy equation. Physical properties corresponding to those of mild steel are listed in Table 1 (Refs. 14, 15). Initial flow velocity within the molten pool is set to zero. When the pressures of \( P_{100} \) and \( P_{300} \) are exerted on the surface without the current and surface-tension gradient, the calculated free surface profile and flow pattern are like that illustrated in Fig. 2. Small surface depressions and flow velocity are developed at \( P_{100} \) and they continue to fluctuate until the steady state is reached, which represents
weld pool oscillation (Ref. 16). With a higher arc pressure of $P_{300}$, surface depression increases and faster flow velocity is induced.

Variations of surface depression at the surface center and average axial velocity along the z-axis are shown in Fig. 3. As expected, surface depression increases for higher arc pressure. While free surface and flow velocity vibrate periodically for $P_{100}$ and $P_{200}$, the amplitude of $P_{300}$ decays rapidly with the lapse of time because high arc pressure acts as a restraint force on surface fluctuation. Since the free surface and axial velocity vibrate at the same frequency, velocity fluctuation is induced by arc pressure.

With the arc pressure fixed to $P_{200}$, the effect of current on surface depression and axial velocity is shown in Fig. 4. For the low current of 100 A, surface depression is not affected and is almost similar to the case of 0A in Fig. 3A. When the current increases, surface depression and the amplitude of surface fluctuation decrease. The reason is explained using axial velocity in Fig. 4B. As the electromagnetic force increases with higher current, the inward flow on the pool surface fills the depressed pool center, which reduces the surface depression and its fluctuation.

To identify the causes of free surface and flow velocity fluctuation, comparisons are made for the cases with $P_{300}$ and without arc pressure (i.e., $P = 0$) as shown in Fig. 5. Without arc pressure, the free surface at the pool center rises slightly to 0.1 mm because of the inward flow and the amplitude of surface fluctuation is quite small. When arc pressure of $P_{300}$ is imposed, surface depression and its amplitude increase significantly. Flow velocity also fluctuates with large amplitude as shown in Fig. 5B, but its magnitude becomes smaller than that of $P = 0$. It clearly indicates arc pressure is responsible for surface depression and fluctuations of free surface and flow velocity, while current affects flow velocity and decaying of fluctuation.

The effects of surface tension are illustrated in Fig. 6 where the surface tension coefficients of 1200 and 1800 dyne/cm, fixed arc pressure and current of $P_{300}$ and 200 A are used for calculation. In this case, the effect of surface-
Fig. 5 — Comparison with and without effects of arc pressure \( I = 200 \text{ A}, \gamma = 1200 \text{ dyne/cm}, \) A — Surface depression; B — average axial velocity.

Fig. 6 — Effects of surface tension on surface depression and axial velocity \( P = P_{200}, \) \( I = 200 \text{ A}. \) A — Surface depression; B — average axial velocity.

Fig. 7 — Surface profiles and convection patterns due to surface-tension gradient \( P = P_{200}, \) \( I = 200 \text{ A}). \) A — \( \gamma \frac{dT}{dt} = -0.49 \text{ dyne/cmK}; \) B — \( \gamma \frac{dT}{dt} = 0.49 \text{ dyne/cmK}. \)

tension gradient is ignored. Surface depression decreases with higher surface tension coefficient as in Fig. 6A because higher pressure is required to deform the pool surface of higher surface tension. However, the axial velocity is not affected by the surface tension coefficient as in Fig. 6B.

When the surface-tension gradients of \( \pm 0.49 \text{ dyne/cmK} \) are used with fixed pressure of \( P_{200} \) and current of 200 A, the surface profile and flow pattern are illustrated in Fig. 7. In the case of the negative surface-tension gradient, a double loop circulation is calculated as in Fig. 7A. When the surface-tension gradient is changed to the positive value, Marangoni and electromagnetic flow rotate in the same inward direction, which results in faster axial velocity. These flow patterns are similar to those of previous works.
Variations of surface depression and axial velocity are shown in Fig. 8. With the negative surface-tension gradient, the pool surface continues to oscillate periodically as in Fig. 8A. Average axial velocity is small because the double-loop circulation cancels the axial velocity components along the z-axis. With the positive surface-tension gradient, surface fluctuation decays rapidly and surface depression becomes almost negligible after 0.1 s. This phenomenon by the surface-tension gradient is more pronounced than that by the current in Fig. 5A because the inward flow velocity on the surface becomes much faster than that by the current in Fig. 5B. Therefore, the depressed pool center is filled by the inward flow at a much faster rate.

The calculated results of the flow pattern and solid-liquid interface in the steady state are illustrated in Fig. 9 where the surface-tension gradient of -0.49 dyne/cm² and current of 100 A are used. Comparing the results with $P_{100}$ and without arc pressure (i.e., $P = 0$), there is almost no difference in pool geometry because surface depression due to arc pressure is very small. When current and arc pressure are increased to 200 A and $P_{200}$, surface depression and the resultant penetration increase substantially, as shown in Fig. 10A. Without arc pressure as in Fig. 10B, the effects of surface depression become negligible, and penetration becomes shallow. Therefore, assumptions of the flat surface and surface depression in a steady state may not be valid in the high current range where the arc pressure and resultant surface depression have significant effects on pool geometry.

The effects of arc pressure distribution are illustrated in Fig. 11 where $P_{100*}$ and $P_{200*}$ in Fig. 1 are used for computation. In the case of $P_{100*}$, surface depression and penetration are similar to those of $P_{100}$ in Fig. 9A because of low arc pressure. When arc pressure is increased to $P_{200*}$, deep penetration and narrow pool radius are calculated. Therefore, if the arc pressure distribution changes in the high current range due to arc length variation or other disturbances, the pool geometry is also influenced.
Fig. 11 — Flow pattern and solid-liquid interface for modified arc pressure distributions \((\text{dy/dT} = -0.49 \text{ dyne/cmK})\). A — \(P = P_{100}^\ast\); B — \(P = P_{200}^\ast\).

Effects of Pulsed Current

The effects of pulsed current on pool geometry are illustrated in Fig. 12 where the surface-tension gradient of \(-0.49\) dyne/cmK, the base and peak currents of 100 and 200 A, and corresponding arc pressure of \(P_{100}^\ast\) and \(P_{200}^\ast\) are used for calculation. When the pulsing frequency is 5 Hz and peak duration is 10 ms (average current of 105 A), the penetration in Fig. 12A becomes deeper than that of DC 100 A in Fig. 9A. When the pulsing frequency and peak duration increase to 10 Hz and 20 ms (average current of 120 A), penetration in Fig. 12B becomes more pronounced and is almost equal to that of DC 200 A in Fig. 10A. The pool radius and penetration at the outer radius are almost the same as that of DC 100 A so the pool geometry becomes similar to a finger shape. When the peak duration of 10 ms and pulsing frequency of 20 Hz are used (Fig. 12C), penetration does not increase to that in Fig. 12B though the average current of 120 A is the same for both cases. It implies that the peak duration is an important factor in determining penetration, and sufficiently long peak duration is needed to provide enough momentum within the molten pool.

To find out the causes of deep penetration under the current pulsing condition of Fig. 12B, two cases of pulsing of arc pressure and heat flux are simulated as shown in Fig. 13. The condition of pulsing arc pressure and constant heat flux generates deep penetration similar to a finger shape as shown in Fig. 13A. However, another condition of pulsing heat flux and constant arc pressure becomes similar to that of DC 100 A as in Fig. 13B. These results clearly show deep penetration is produced mainly by pulsing of arc pressure at peak duration rather than by pulsing of heat flux.

The relationship between surface depression and penetration is illustrated in Fig. 14 where pulsing frequency and peak time are 10 Hz and 20 ms, respectively. In this case, arc pressures of \(P_{100}^\ast\) and \(P_{200}^\ast\) are used for calculation. A close correlation between surface depression and penetration is observed such that the free surface is depressed just after current pulsing and penetration increases rapidly. After peak current, penetration decreases gradually. Peaks of surface depression and penetration coincide up to 0.5 s, because axial momentum by surface depression is delivered immediately in the small weld pool. When the pool size becomes larger after 0.5 s, there is a time delay between the maximum surface depression and penetration because it takes time to deliver axial momentum and heat by convection in the larger molten pool. The experimental verification and effects of temperature-dependent material properties need to be considered in future work.

Conclusions

Surface depression and pool geometry of DC and pulsed-current arc welding are calculated numerically, and the results lead to the following conclusions:

1) The free surface of a molten pool is depressed mainly by arc pressure, and in-
ward circulation by the current and Marangoni flow decreases surface depression and its fluctuation.

2) While arc pressure in the low current range has negligible effects on surface depression and pool geometry, the effects of arc pressure and surface depression should be considered in the high current range above 200 A.

3) Deep penetration in pulsed current welding is produced mainly by arc pressure at peak duration, and sufficiently long peak duration is needed for deep penetration.

Correction

Figure 8 as it appears on page 353-s in "A Martensite Boundary on the WRC-1992 Diagram — Part 2: The Effect of Manganese," by D. J. Kotecki, published December 2000, is a duplicate of Fig. 7. The correct Fig. 8 appears below. The editors regret this error.
Partially Melted Zone in Aluminum Welds — Planar and Cellular Solidification

Liquated grain boundaries mostly resolidify with the planar mode but the cellular mode has also been observed

BY C. HUANG AND S. KOU

ABSTRACT. Aluminum Alloy 2219 was gas metal arc welded to study the solidification modes of liquid in the partially melted zone (PMZ), including grain boundary (GB) liquid and liquid spots in the grain interior. GB liquid mostly solidified with the planar solidification mode. The average temperature gradient G across the PMZ was taken as

\[ G = \frac{T_0 - T_p}{W_p} \]

where \( T_0 \) is the liquidus temperature, \( T_p \) the eutectic temperature and \( W_p \) the PMZ width, which was measured with a microscope. The average solidification rate \( R \) of the GB liquid was taken as

\[ R = \frac{W_t}{t} \]

where \( W_t \) is the thickness of the GB liquid, and \( t \) the solidification time of the GB liquid, which was determined from the measured thermal cycle. The \( G/R \) ratio was estimated to be on the order of 10°/C cm/s, which is close to the minimum \( G/R \) required for planar solidification of the alloy. Most GB liquid was too thin to allow enough space for a planar growth front to gradually evolve into a cellular one before solidification was over. Cellular solidification, however, was observed in the PMZ at the bottom of the weld, where \( G \) was lowest. It occurred in thicker (15 μm) GB liquid that had to solidify at a higher \( R \) and, hence, lower \( G/R \) and more room for cellular solidification to develop. Liquid spots away from the weld were smaller and solidified with the planar mode. Near the weld, however, they grew much larger and had to solidify at a much higher \( R \). Both the lower \( G/R \) and the larger space for cellular solidification to develop helped break down planar solidification.

Introduction

Extensive liquation can occur in aluminum alloys during welding in a very narrow region immediately outside the fusion zone called the partially melted zone (PMZ) (Ref. 1). Liquation can result in hot cracking during welding (Refs. 1-7) or loss of ductility after welding (Refs. 8-10).

Huang, et al. (Refs. 11, 12), recently studied the PMZ in gas metal arc welds of 2219 aluminum alloy, which is essentially a binary Al-Cu alloy with a Cu content between 6 and 7 wt-% Cu. It was observed that extensive liquation occurs both along grain boundaries (GBs) and at large 0 (Al,Cu) particles, which are present in the grain interior and sometimes at GBs as well. The most significant findings are as follows. First, liquation is initiated at the eutectic temperature \( T_e \) by the eutectic reaction between the 0 phase and the 0 (Al-rich) matrix to form the liquid eutectic, and is intensified by further melting of the matrix above \( T_e \). Second, solidification of the GB liquid is directional — upward and toward the weld regardless of the position of the GB relative to the weld. Third, severe Cu segregation occurs both at the GB and in the grain interior, resulting in a Cu-depleted α phase next to a Cu-rich eutectic. The Cu-depleted α either forms a strip along the GB eutectic or surrounds the eutectic particle in the grain interior. Fourth, the PMZ is rather weak and it fractures prematurely under tensile loading; the brittle eutectic fractures badly, while the weak, ductile, Cu-depleted α elongates.

The solidification modes of the liquated material in the PMZ have not been investigated so far. In the present report, the solidification theories for metal casting and crystal growth are applied on a microscopic scale to study solidification in the PMZ. One interesting question to ponder is how a partially melted grain can resolidify with a planar growth front just like a very slowly growing semiconductor crystal (Refs. 13, 14), even though the welding speed is obviously orders of magnitude higher than the crystal growth speed.

Experimental Procedure

Aluminum Alloy 2219 is a commercial, high-strength aluminum alloy, selected because it is a binary Al-Cu alloy with an easy-to-understand solidification. The actual composition of the workpiece is Al-6.79% Cu-0.27% Mn-0.13% Fe-0.12% Zn-0.01% Si. The wire was a 1.2-mm-diameter wire of alloy 2319; the actual composition was Al-6.3% Cu-0.3% Mn-0.18% Zr-0.15% Ti-0.15% Fe-0.10% V-0.10% Si. The wire was 26.5-V arc voltage, 195-A average current and Ar shielding. The welding wire was 2.2 mm/s (17 in./min) welding speed, 26.5-V arc voltage, 195-A average current and Ar shielding. The welding wire was a 1.2-mm-diameter wire of alloy 2319; the actual composition was Al-6.3% Cu-0.3% Mn-0.18% Zr-0.15% Ti-0.15% Fe-0.10% V-0.10% Si. The wire was welded in the as-received condition of T851 in the 20-cm direction. T8 stands for solution heat treating and cold working, followed by artificial aging; T51 stands for stress relieving by stretching (Ref. 15).

Two gas metal arc welds, weld 1 and weld 2, were made perpendicular to the rolling direction under the same welding condition. The welding parameters were 7.20 mm/s (17 in./min) welding speed, 26.5-V arc voltage, 195-A average current and Ar shielding. The welding wire was a 1.2-mm-diameter wire of alloy 2319; the actual composition was Al-6.3% Cu-0.3% Mn-0.18% Zr-0.15% Ti-0.15% Fe-0.10% V-0.10% Si. The wire was welded in the as-received condition of T851 in the 20-cm direction. T8 stands for solution heat treating and cold working, followed by artificial aging; T51 stands for stress relieving by stretching (Ref. 15).

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Feeding speed was 13.5 cm/s (320 in./min).

An earlier weld, called weld 3 hereafter, was made in the same work piece and with the same welding wire but under a different set of welding parameters. The welding speed was 12.7 mm/s, the welding voltage was 30 V, the average welding current was 250 A and the wire feeding speed was 18.6 cm/s.

Temperature measurements were initially conducted by inserting thermocouples into holes drilled from the workpiece bottom. However, it was difficult making thermocouples to position at the targeted positions in the PMZ and the heat-affected zone.

Subsequently, temperature measurements were conducted during welding by plunging a thermocouple into the weld pool from behind the arc, at about 45 deg from the vertical plane along the welding direction. This was done with the help of a mechanical device on which the thermocouple was mounted. Only one thermocouple was used in each weld because it was difficult for the device to hold more than one thermocouple at a time and push them to the targeted positions, given the rather limited space between the arc and the trailing pool edge.

The thermocouple was K-type with 0.025-mm-diameter wires and the response time was 0.05 s in air and 0.002 s in water. To protect it from the arc, the thermocouple was inserted in an alumina sheath with a 0.5-mm ID and a 0.15-mm wall. The tip of the sheath was ground thinner to reduce the wall thickness at the tip to less than 0.15 mm. The thermal cycle was recorded with a computer-based data acquisition system.

The resultant welds were etched with a solution of 0.5 vol-% HF in water for optical microscopy.

Results and Discussion

Melting and Solidification in the PMZ

For convenience of discussion, the aluminum-rich portion of the Al-Cu phase diagram is shown in Fig. 1 (Ref. 16). The workpiece is considered here as a binary Al-6.79% Cu alloy as an approximation.

The melting and solidification in the PMZ are shown schematically in Fig. 2. Figure 2A is a vertical cross section of the weld pool and its surroundings that is parallel to the welding direction. Points 1, 2 and 3 are, respectively, located ahead of, inside and behind the region in which liquation is happening. Their corresponding microstructures are shown in Figs. 2B-D.

Large θ particles are present in the grain interior and sometimes at the GB, as shown in Fig. 2B. The liquated material at the GB and in the grain interior is shown in Fig. 2C. Liquation is initiated at the large θ particles at the eutectic temperature T_e by the eutectic reaction between θ and the surrounding α matrix. Liquation is intensified by further melting of the surrounding α at temperatures above T_e.

Point 2 reaches its peak temperature T_l, and the width of the GB liquid w, reaches its maximum when the bottom of the weld pool touches point 2. Solidification of the GB liquid at point 2 begins when the bottom of the weld pool begins to pass point 2 and ends when the eutectic isotherm T_e just passes point 2. The solidification time, t_s, is the same as the residence time of point 2 in the freezing temperature range of T_l to T_e, which can be measured with a thermocouple positioned at the bottom of the weld pool.

The solidification mode of the GB liquid at point 2 depends on the temperature gradient, G, and the solidification rate, R. If the G/R ratio is high enough for planar solidification to occur, the GB liquid will solidify with the planar mode, that is, with a planar solidification front. Solidification occurs from the cooler side of the GB liquid to the warmer. As such, the GB actually shifts toward the weld, as can be seen by comparing the GBs in Figs. 2B-D.
Figs. 2B and D. This, in fact, is like Bridgman crystal growth on a microscopic scale. Growth occurs epitaxially from upon the unmelted portion of the grain below the GB liquid, an interesting occurrence because the GB liquid in between two neighboring grains is usually thought to solidify from both grains, not just one.

The GB liquid solidifies first as a solute-depleted, eutectic-free material, then as a solute-rich eutectic at the GB. Grain boundary segregation of Cu has been measured and reported in a previous study (Ref. 12).

Width of the PMZ

Figure 3 is a micrograph taken from the transverse cross section of weld 1. It shows the tip of the alumina sheath of the thermocouple plunged into the pool of weld 1. As shown, the thermocouple sheath lands at the fusion boundary. The PMZ is the fusion boundary of the weld, that is, $T_f = 643°C$ from the phase diagram — Fig. 1. The lower boundary of the PMZ, that is, $T_e = 548°C$, needs to be determined with the help of a microscope. As shown in previous studies (Refs. 11, 12), the first sign of liquation is observed at the lower boundary of the PMZ, where large $\theta$ particles begin to react eutectically with the surrounding $\alpha$ matrix and form solid eutectic upon cooling. The workpiece microstructure is examined under the microscope upward from the bottom surface of the workpiece until these particles are found. This is repeated across the entire weld and its vicinity. The accuracy of the measurements of the distance between $T_f$ and $T_e$ is ±0.04 mm. It should be pointed out that at the location of these particles, GB liquation is usually not yet pronounced enough to be readily recognized because GBs are often free of $\theta$ particles (Refs. 11, 12). Therefore, the size of the PMZ can be seriously underestimated if it is measured based on GB liquation.

As shown in Fig. 4, the PMZ is wider at the bottom and narrower on the top. In the vertical direction, the widths of the PMZ in weld 1 are $W_p = 2.41$ mm at point A, 1.98 mm at point B and 1.76 mm at point C. During welding, the workpiece was free from contact with any materials except at its four corners. As such, the workpiece’s bottom surface acts as a thermal barrier to heat flow from the top. This reduces temperature gradients below the weld significantly. The isotherm corresponding to the edge of the dark-etching precipitation zone cuts the workpiece bottom at two separate locations. This is another indication of reduced temperature gradients below the weld. The reduced temperature gradients below a partially penetrating weld have been demonstrated by computer simulation of heat flow during welding (Ref. 17).

Thermal Cycles

Figure 5 shows the thermal cycles measured in welds 1 and 2. The locations of the thermocouples in the welds have been shown previously in Fig. 4. The residence time in the freezing temperature range, that is, from the liquidus tempera-
ture $T_e$ (643°C) to the eutectic temperature $T_e$ (548°C), will be called the solidification time $t_s$, hereafter. From Fig. 5, $t_s = 0.734$ s for weld 1 and $t_s = 0.749$ s for weld 2. These results are close to each other, thus suggesting the validity of the temperature measurement technique.

**Solidification Modes of GB Liquid**

As already mentioned, the workpiece was welded perpendicular to the rolling direction. In a micrograph on the transverse cross section of the weld, the grains in the PMZ appear elongated in the horizontal direction. As observed in previous studies (Refs. 11, 12), GB liquid tends to solidify upward and toward the weld under the influence of the high-temperature gradient in the PMZ. Since GB liquid is hypoeutectic in composition, it solidifies first as a Cu-depleted $\alpha$ strip and last as the eutectic.

The PMZ microstructure at point B of Fig. 4A is shown in Fig. 6A. The top left corner is in the fusion zone and the rest is in the PMZ. The light-etching strips along the top of the grains in the PMZ are the Cu-depleted $\alpha$, and the dark-etching GBs at the top of the strips are the eutectic. Some $\alpha$ strips are shown in Fig. 6B at a higher magnification. As shown, the $\alpha$ strips appear to be planar, that is, without cells or dendrites. The PMZ microstructure next to the thermocouple in weld 2 is similar.

The PMZ microstructure at point A of weld 1 (Fig. 4A) is shown in Fig. 7A. The fine grain structure at the top is in the fusion zone. The $\alpha$ strip appears to be thicker in some grains and thinner in others. In general, thinner $\alpha$ strips are planar in structure while thicker ones are more likely to be cellular. Some $\alpha$ strips with a cellular structure are shown in Fig. 7B at a higher magnification. The $\alpha$ strips are, on average, significantly thicker than those at point B — Fig. 6B.

The PMZ microstructure near the bottom of weld 3 is shown in Fig. 8A. The 590 J/mm heat input of weld 3 is lower than the 718 J/mm heat input of weld 1. The lower heat input of this weld results in less liquation, and the $\alpha$ strips are on average thinner than those at point A of weld 1 — Fig. 7A. GB solidification is planar everywhere in the PMZ, including at the bottom of the weld (not shown). This is consistent with the lower heat input of weld 3. However, near the sharp turn in the fusion boundary (indicated by the arrow in Fig. 8A), cellular solidification is observed. Some of the cellular $\alpha$ strips are shown in Fig. 8B at a higher magnification. The reason cellular solidification occurs here will be discussed later.

Figure 9A shows the PMZ microstructure near the top of the fusion boundary in weld 1 (point C in Fig. 4A). The upper left corner is part of the weld. The $\alpha$ strips are on average significantly thinner than those in the PMZ at the bottom of the weld (point A in Fig. 4A) shown previously in Fig. 7A. Furthermore, the $\alpha$ strips appear to be planar; no cellular $\alpha$ strips are visible. Some of the planar $\alpha$ strips are shown in Fig. 9B at a higher magnification. It is clear the $\alpha$ strips are either at the top of the grains or along the side of the grains that face the weld. This directional solidification behavior of the GB liquid, i.e., upward and toward the weld, has been previously discussed (Refs. 11, 12).

In order to understand the solidification modes of the GB liquid, the temperature gradient and the growth rate of the GB liquid will be discussed as follows.

**G/R Ratio at GB**

It is well known in both metal casting and crystal growth (Refs. 13, 14) that...
temperature gradient $G$ and growth rate $R$, both in the direction perpendicular to the growth front (the solid/liquid interface), are the two most fundamental parameters of solidification. They determine the solidification mode, which in turn determines the resultant solidification microstructure.

The temperature gradient and the growth rate of GB liquid in the PMZ will be estimated as follows. Consider point 2 in Fig. 2A. As an approximation, the temperature gradient is

$$ G \equiv \frac{T_L - T_E}{W_p} $$

where $W_p$ is the width of the PMZ. This $G$ is the average temperature gradient across the width of the PMZ.

Let $w_L$ be the thickness of the GB liquid, as shown in Fig. 2C. As an approximation, the growth rate of the GB liquid is

$$ R \equiv \frac{w_L}{t_s} $$

where $t_s$ is the solidification time of the GB liquid. This $R$ is the average growth rate of the GB liquid. From Equations 1 and 2

$$ \frac{G}{R} = \frac{(T_L - T_E)w_L}{W_p} $$

According to the constitutional supercooling theory (Refs. 1, 13), for a planar solidification front to be stable, the following criterion must be met:

$$ \frac{G}{R} \geq \frac{-m_L C_L (1-k)}{D_L} $$

where $m_L$ is the slope of the liquidus line in the phase diagram, $C_L$ the solute concentration of liquid at the growth front, $k$ the segregation coefficient and $D_L$ the diffusion coefficient of solute in the liquid. If $G/R$ is less than the right-hand side (RHS) of Equation 4, the planar solidification front will break down into a cellular or dendritic one.

Equations 3 and 4 can be further combined to give the following criterion for plane front solidification of the GB liquid

$$ \frac{(T_L - T_E)w_L}{W_p} \geq \frac{-m_L C_L (1-k)}{D_L} $$

The RHS of Equation 4 can be determined with the help of the phase diagram. As an approximation, the liquidus line and the solidus line of the phase diagram are both assumed to be a straight line. From Fig. 1, the slope of the liquidus line is $m_L = (548-660°C)/(33.2-0% Cu) = -3.37°C/\% Cu$. The equilibrium partition ratio, $k = 5.65% Cu/33.2% Cu = 0.17$. At the fusion boundary of weld 1, i.e., at the liquidus temperature 643°C, $C_L = 6.79% Cu$. The diffusion coefficient of Cu in liquid Al-5% Cu is about $5 \times 10^{-5} cm^2/s$ (Ref. 18). From these data, the RHS of Equation 4 becomes the following:

$$ m_L C_L (1-k) \leq 3.80 \times 10^5 \frac{^\circ C}{cm^2} $$

The left-hand side (LHS) of Equation 4, i.e., the $G/R$ ratio, has to be greater than this threshold value if the GB liquid is to have a stable planar solidification front.

To find the $G/R$ ratio, the temperature gradient $G$ and the growth rate $R$ will both have to be determined first. To de-
termine the temperature gradient \( G \) from Equation 1, the width of the PMZ is needed. Since the GBs are essentially horizontal because of rolling, the GB liquid is essentially horizontal, too. As such, the relevant temperature gradient \( G \) should be the one in the vertical direction, i.e., perpendicular to the GB liquid. Therefore, the PMZ width, \( w_p \), is taken as the vertical distance from the fusion boundary (the liquidus temperature \( T_L \)) to the location where \( \varphi \) begins to react with the surrounding matrix eutectically (the eutectic temperature \( T_E \)).

Consider point B in Fig. 4A. As already mentioned, at point B in weld 1, \( w_p = 1.98 \text{ mm} \). From Equation 1 and with \( T_L = 643°C \) and \( T_E = 548°C \), the average temperature gradient \( G \) perpendicular to the GB liquid at point B is the following:

\[
G = \frac{T_L - T_E}{w_p} = \frac{643°C - 548°C}{0.198 \text{ cm}} = 540°C/cm
\]  

The average growth rate \( R \) perpendicular to the GB liquid can be determined from Equation 2. As already shown, \( t_s = 0.734 \text{ s} \) at point B in weld 1. For an \( \alpha \) strip of about 5 \( \mu \text{m} \) thick, Equation 2 becomes the following:

\[
R = \frac{w_k}{t_s} = \frac{5 \times 10^{-4} \text{ cm}}{0.734 \text{ s}} = 6.81 \times 10^{-4} \text{ cm/s}
\]  

From Equations 7 and 8,

\[
\frac{G}{R} = \frac{480°C/cm}{6.81 \times 10^{-4} \text{ cm/s}} = 7.05 \times 10^5 °C \text{ s/cm}^2 \tag{9}
\]

This \( G/R \) is above the threshold value of \( 3.80 \times 10^5 °C \text{ s/cm}^2 \) in Equation 6 for planar solidification. This appears to be consistent with the micrograph in Fig. 6A. The \( \alpha \) strips have an average thickness of about 5 \( \mu \text{m} \) and they appear planar.

It is worth mentioning, however, that \( C_L \) in Equation 6 (the Cu content at the growth front of solidifying GB liquid) is not constant but increases during solidification. Therefore, at some point during solidification, \(-m_\varphi C_L (1-k)/D\) can become greater than \( G/R \) and planar solidification can break down. From the micrograph in Fig. 6, however, it does not look like this has happened. Discussion of this question follows.

According to the classic theory of interface stability of Mullins and Sekerka (Refs. 19-21), when instability occurs at the planar growth front, it initiates as a perturbation at a certain wavelength. The amplitude of the perturbation can gradually grow and eventually result in a cellular growth front. From Figs. 7B and 8B, the cellular spacing appears to be significantly greater than the width of GB liquid shown in Fig. 6B. This implies that for the GB liquid shown in Fig. 6B, a planar growth front would not seem to have enough space to evolve into a cellular one before solidification is over. This may explain why planar solidification did not break down before GB solidification was over. In fact, this also implies that even with a \( G/R \) ratio below the threshold value, cellular solidification may not necessarily occur if the GB liquid is too thin to allow enough room for a planar growth front to gradually evolve into a cellular one before solidification is over.

Consider point C in Fig. 4A, where the width of the PMZ in the vertical direction is 1.76 mm. The temperature gradient perpendicular to the GB liquid is, therefore, \( G = (643-548°C)/0.198 \text{ cm} = 480°C/cm \), which is higher than the 480°C/cm shown previously in Equation 7. From its micrograph shown in Fig. 9, the average thickness of the \( \alpha \) strips is about 5 \( \mu \text{m} \). The solidification time, \( t_s \), is not available. If it is assumed to be close to that at point B (\( t_s = 0.734 \text{ s} \)) as an approximation, the growth rate \( R = 6.81 \times 10^{-4} \text{ cm/s} \) and the \( G/R \) ratio = 7.93 \( \times 10^5 °C \text{ s/cm}^2 \), which is above the threshold value of \( 3.80 \times 10^5 °C \text{ s/cm}^2 \) for planar solidification. This appears to be consistent
with the planar χ strips shown in Fig. 9B.

Now consider point A in Fig. 4A, where the width of the PMZ in the vertical direction is 2.41 mm. The temperature gradient perpendicular to the GB liquid is \( G = (643-548°C)/0.241 \ cm = 394°C/\ cm \). From its micrograph shown in Fig. 7B, the average thickness of the GB strips is almost 15 μm thick. The solidification time, \( t_s \) is not available. Again, if it is assumed to be close to that at point B (\( t_s = 0.734 \ s \)) as an approximation, the growth rate \( R = 2.04 \times 10^{-3} \ \ cm/s \) and the \( G/R \) ratio = 1.93 \times 10^{10} \ °C/s/cm, which is below the threshold value of 3.80 \times 10^{10} \ °C/s/cm for planar solidification. This appears to be consistent with the cellular GB strips shown in Fig. 7.

It should be pointed out that considering the uncertainties in \( D \) and other values in the calculations, the \( G/R \) ratios of 1.93 \times 10^{10} \ °C/s/cm for point A, 7.05 \times 10^{9} \ °C/s/cm for point B and 7.93 \times 10^{9} \ °C/s/cm for point C are not really much different from the threshold value of 3.80 \times 10^{10} \ °C/s/cm. What is of primary importance, however, is that at points A, B and C of weld 1, the differences in \( G/R \) are consistent with the change in the solidification mode of the GB liquid. 

**Fraction of Liquid and Width of GB Liquid**

As previously mentioned, in weld 1 the grain boundary liquid is thicker at point A than at point B, which are about the same distance below the fusion boundary. This can be explained as follows:

Figure 10 shows the relationship between temperature and the fraction of liquid for the Al-6.79% Cu base metal, based on the Scheil equation (Refs. 1, 13). As shown, the fraction of liquid increases rapidly with increasing temperature as the liquidus temperature, \( T_{\text{L}} \) is approached. As already mentioned, the temperature gradient \( G \) is significantly (22%) higher at point B than point A. Therefore, as shown in Fig. 11A, the temperature at point A is higher than that at point B, even though they are at the same distance below the fusion boundary.

As shown in Fig. 11B, the fraction of liquid at point A can be significantly greater than that at point B because the fraction increases sharply as the liquidus temperature is approached. Since the local average fraction of liquid is higher at point A than at point B, the GB liquid is thicker at point A than at point B.

Since the temperature is higher at point A than at point B, from the phase diagram (Fig. 1) the composition of the GB liquid can be expected to be lower at A than at B. This suggests that, based on Equation 4, the threshold \( G/R \) ratio for planar solidification can be lower for point A than for point B, and not exactly fixed at a constant value as suggested by Equation 6. Although this is in favor of planar solidification at point A, cellular solidification can still occur at point A in view of its significantly lower \( G \) and higher \( R \).

Figure 11 can also help explain the cellular solidification in weld 3 shown in Fig. 8. As mentioned previously, the 590 J/mm heat input of this weld is lower than the 718 J/mm heat input of weld 1, and GB solidification is planar everywhere in the PMZ except near the arrow shown in Fig. 8A. The temperature gradient \( G \) is lower in the area because the material here has to absorb heat coming from two sides, rather than one, and because it has less mass to act as an effective heat sink. According to Fig. 11, the local temperature here is higher and the local fraction of liquid is also higher. Consequently, the width of GB liquid \( w \) is greater here and, from Equation 2, growth rate \( R \) is higher. As such, the lower local \( G/R \) ratio favors cellular solidification. The wider GB liquid also provides more room for cellular solidification to evolve.

**Solidification Modes within Grains**

In the PMZ, large \( β \) particles present in the grain interior react eutectically with the surrounding \( χ \) matrix and form liquid spots during welding. One such liquid spot has been shown schematically in Fig. 2C. As the fusion boundary is approached, the size of the liquid spot increases rapidly, i.e., the local average fraction of liquid increases sharply. According to Fig. 10, as the liquidus temperature (fusion boundary) is approached, the fraction of liquid increases sharply.

Particle X in Fig. 6B results from the solidification of a large liquid spot near the weld. In fact, as shown in Fig. 6A, several similar particles are present in the area to the left and above this one. Apparently, the solidification mode is not planar because the morphology of the eutectic in particle X appears complex. With a liquid spot, essentially one half of its perimeter faces the weld, allowing for a directional solidification toward the weld when it can occur. Since the growth front is concave toward the liquid rather than flat, solute rejected by the growth front can accumulate more rapidly. Perhaps this has helped trigger early breakdown of planar solidification. The liquid spot is much thicker than the GB liquid nearby, i.e., its diameter is several times the width of the GB liquid. This can suggest two things. First, the liquid spot has to solidify with a much greater solidification rate \( R \) and, hence, a smaller \( G/R \) ratio than the GB liquid. Second, the greater thickness of the liquid spot gives more room for nonplanar solidification to evolve.

Particle Y, which is farther away from the weld, is much smaller than particle X and it shows planar \( χ \). According to the phase diagram (Fig. 1), the lower the local temperature, the higher the solute content of the liquid. From Equation 4, the threshold \( G/R \) is greater at particle Y than at particle X, and thus planar solidification can break down more easily at particle Y than at particle X. However, the liquid appears to be too thin for cellular solidification to evolve: after solidification is over at particle Y. Similar particles are also shown in Fig. 9B.

**Conclusions**

In the present study on the PMZ in welds of aluminum Alloy 2219, planar and cellular solidification have been observed in the PMZ, both at the GB and in the grain interior. GB liquid tends to solidify with the planar solidification mode. This is because the \( G/R \) ratio is high and because the GB liquid is too thin for a planar growth front to evolve into a cellular one before solidification is over. The average temperature gradient \( G \) can be estimated from the width and temperature range of the PMZ. From the thickness of GB liquid and thermal cycle measured during welding, the average \( G/R \) can also be estimated. The \( G/R \) for the GB liquid in the PMZ near the weld is estimated to be on the order of 10^9°C/s/cm, which is close to that required for planar solidification of the GB liquid. However, in the PMZ at the bottom of the weld, cellular solidification can occur, especially where the GB liquid is thicker (15 μm) because of lower \( G \) and higher \( R \). For a partially penetrating weld like those in the present study, the lowest \( G \) in the PMZ appeared to be at the bottom of the weld. The average growth rate \( R \) is higher for a thicker GB liquid because it has to solidify faster. As such, the \( G/R \) ratio is low for a thicker GB liquid at the bottom of the weld, where cellular solidification is observed. Large prior \( β \) particles in the grain interior liquate and form liquid spots that solidify with a planar mode. However, near the weld, liquid spots become much larger and do not show R. The much lower \( G/R \) and greater spot size allow planar solidification to break down.

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References

Call for Papers

The Laser Institute of America (LIA) is seeking abstract submissions for the 20th International Congress on Applications of Lasers and Electro-Optics (ICALEO® 2001), to be held October 15-18, 2001, in Jacksonville, Fla.

ICALEO 2001 will consist of two conferences, the Laser Materials Processing Conference and the Laser Microfabrication Conference. Papers sought in the Laser Materials Processing Conference include innovative applications, aerospace and automotive applications and laser safety; topics on cutting, drilling, welding, rapid prototyping and surface modification; lasers and laser systems including diode, diode-pumped, gas, advanced laser sources and laser beam shaping.

The Laser Microfabrication Conference will emphasize papers on biomedical applications including catheters, stents, drug delivery, implantable devices and microsurgical components; photonics including diffractive optics, microlenses and microsculpting; electronics involving display devices, silicon machining, surface texturing and thin film patterning; and processes such as cutting, drilling, welding, marking and ultrashort laser processing.

Abstracts should relate original, recent and unpublished results on any of the above topics. Submission deadline is March 30, 2001. For further information visit www.icaleo.org or contact Beth Cohen at (800) 34-LASER or (407) 380-1553.
ABSTRACT. Conventional pulsed gas metal arc welding (GMAW-P) achieves stable and repeatable spray transfer by using correct pulse parameters. Because the optimal pulse parameters depend on welding parameters, technology is needed to improve the robustness of the transfer process respective to the variations in welding parameters. To resolve this problem, active control technology is proposed to ensure a desirable and repeatable metal transfer mode, i.e., one drop per pulse (ODPP) mode. It uses a peak current lower than the transition current to prevent accidental detachment and takes advantage of the downward momentum of the oscillating droplet to enhance the detachment. When the droplet moves toward the weld pool, the current is switched to peak level and the combination of increased electromagnetic detaching force and downward momentum ensures detachment. Hence, the metal transfer process becomes controllable and robust against variations in welding parameters. However, in order to ensure the combination of increased electromagnetic force and downward momentum, the oscillation process must be monitored. In this study, a modified method is proposed in which the droplet starts to oscillate by first moving toward the weld pool. As a result, the detaching pulse can be applied after a very short period of time and the combination of increased electromagnetic force and downward momentum is guaranteed. Thus, the control system is simplified and the metal transfer’s robustness is further improved. This modified active control technology has been used to weld titanium.

BY Y. M. ZHANG AND P. J. LI

Introduction

Titanium is characterized by its high strength and light weight. Such attributes make titanium a primary choice for more and more components and structures in aircraft, tanks and naval vessels (Refs. 1, 2), as well as in certain commercial applications (Ref. 3). In general, titanium alloys have good weldability and can be welded with most arc welding processes. However, a strict atmospheric shield is required to ensure weld quality. Gas tungsten arc welding (GTAW) uses a non-consumable tungsten electrode and generates a stable arc. It is an ideal process for titanium welding. However, its low productivity is not desirable for thick section structures and components. The use of a process such as gas metal arc welding (GMAW) would significantly improve productivity and reduce manufacturing costs if adequate shielding could be achieved.

GMAW of titanium has been investigated for decades. The mode of metal transfer plays a critical role in ensuring the shield. In particular, globular and uncontrolled short-circuiting transfers generate significant amounts of spatter, which cause turbulence. Also, the strong cathode jet in globular transfer, a unique phenomenon to the GMAW process with titanium, tends to project the droplets outward when they break up upon entering the weld pool (Ref. 4), making the shielding additionally difficult. On the other hand, spray transfer generates a low level of spatter and has a relatively stable arc. It provides a better shield. Unfortunately, when a constant current is used, spray transfer is only achieved at high currents in an argon shield. Low currents will produce globular and short-circuiting transfer, and thus, an unstable arc and severe spatter (Refs. 4–8).

Pulsed GMAW uses a low base current to maintain the arc and a high peak current to melt the electrode and detach the droplet. It is capable of achieving spray transfer at low mean currents (Refs. 9, 10). Also, GMAW-P tends to detach the droplet during the base current period. According to an earlier study by Eager, et al. (Ref. 4), droplets are subject to a rejecting force due to the plasma jet issuing from the weld pool, resulting in a condition that may eject coarse spatter. Because the rejecting force is proportional to the amplitude of the welding current, it is very low in the base current period of pulsed GMAW and the plasma-jet-related spatter is minimized. Hence, pulsed GMAW has been used to avoid globular transfer, reduce spatter and improve arc stability in titanium welding (Refs. 11, 12).

Although GMAW-P is capable of reducing spatter and improving arc stability through spray transfer, such capability is conditional. To ensure a stable arc and an adequate shield, the transfer process must be repeatable and controllable. That is, the transfer rate, number of droplets detached in a unit of time, and the droplet size must be consistent and in an appropriate range. For GMAW-P, an applicable method to ensure the repeatability and controllability has been to detach one, and only one, droplet per pulse (ODPP) with a droplet diameter close to that of the electrode (Refs. 10, 13, 14). In conventional pulsed GMAW, this is achieved by selecting an appropriate duration and amplitude for the peak current. However, in order to ensure the detachment or
avoid one-droplet multiple pulses (ODMP), a peak current higher than the transition current (Ref. 14) must be used.

The use of high current narrows the range of peak current duration for generating stable ODPP. If the duration of the peak current period is longer than required, multiple droplets may be detached in a single pulse (Ref. 15), resulting in a streaming spray transfer. If the duration is shorter, multiple pulses may be needed to develop and detach one droplet (Ref. 13). In addition, such peak current duration depends on, and varies with, welding parameters and conditions. In fact, to determine the peak current duration, studies have been conducted to experimentally correlate wire feed speed, peak current level, peak current duration, base current level and base current duration for a given electrode material, electrode wire diameter and composition of shielding gas (Refs. 10, 13, 14). However, because of the narrow range and its dependence on welding conditions, such an open-loop selection of duration is often not robust with respect to welding parameters and conditions. Repeatable and controllable metal transfer and adequate shielding are not guaranteed.

Modified Active Control

Active Control

To achieve a robust control technology for repeatable and controllable metal transfer, the authors have proposed oscillating the droplet, utilizing the downward momentum of the oscillating droplet to enhance detachment controllability (Refs. 17-19). As seen in Fig. 1, during period $T_1$, the droplet grows gradually and is dragged in the weld pool direction by a downward electromagnetic force generated by the exciting pulse. During period $T_2$, the current is switched to a low level and, therefore, the electromagnetic force is decreased significantly. As a result, the droplet moves towards the electrode and then springs back toward the weld pool due to the surface tension of the melted droplet. During $T_3$ period, the current is switched to a higher level (detaching pulse). With the assistance of downward momentum, the increased electromagnetic force ensures the droplet is detached with a current lower than the peak current needed in conventional pulsed current GMAW. This method has been referred to as active control of metal transfer (Refs. 17-19).

Analysis

Although satisfactory droplet transfer can be achieved with active metal transfer control technology, further improvements will be beneficial for production of high-quality GMAW, especially for titanium welding. Specifically, analysis shows that the free oscillation period $T_2$ is critical in ensuring detachment. Droplet mass, electrode material property and excitation level (the difference between the exciting pulse and the base current) all influence the selection of $T_2$ and the efficiency in using the downward momentum. To take advantage of the downward momentum, the phase match condition must be satisfied, i.e., the detaching pulse must be applied when the droplet moves toward the weld pool. To take maximal advantage of the downward momentum, the detaching pulse was applied when downward motion of the droplet was first detected based on analysis of vertical coordinates of the electrode tip after oscillation was excited in our previous work (Ref. 17).

This study reveals the active control method may be modified to further improve robustness of metal transfer repeatability and controllability. Such improvements could be particularly beneficial for titanium welding. As can be seen, in the previous method (Ref. 17), the droplet is dragged toward the weld pool by the electromagnetic force in the exciting pulse period. The droplet starts to oscillate toward the electrode when the current is switched from the exciting level to the base current level. When the droplet starts moving toward the weld pool, the detaching pulse is applied to detach the droplet. Because of the damping force, the oscillation energy decreases gradually. The downward momentum, which can be used to enhance the detachment, also decays. Because the droplet first moves toward the electrode after the current is switched to the base level, the detaching pulse can only be applied after the oscillation energy decays for a half oscillation period. As a result, the effective downward momentum for detachment decreases and the required amplitude of the detaching pulse increases. If the droplet begins the oscillation by first moving toward the weld pool, such decrease in the effective downward momentum and increase in the amplitude of the detaching pulse will be eliminated. In this paper, such a scheme is referred to as modified oscillation. The resultant control is referred to as modified active control.

In addition to the increase in effective downward momentum and the decrease in the detaching current, the modified os-
cillation scheme also generates two additional and important advantages. First, in active control, the droplet is not detached until half an oscillation period has gone. Such a mandatory waiting period lowers the upper limits of the transfer rate and achievable welding current. For example, when 0.9-mm (0.035-in.) wire is used, the upper limit of the metal transfer rate is 80 Hz, lower than it is in conventional GMAW where the typical range of transfer is from 40 to 120 Hz. If a greater diameter wire is used, the frequency limit will be further lowered. Second, the frequency of oscillation depends on the mass of the droplet (Ref. 17). In active control, the detaching current is applied after half an oscillation cycle. To ensure the phase match, the oscillation must be monitored. If the phase match condition is not satisfied when the detaching pulse is applied, the droplet cannot be detached. In that case, the performance of the active control would be even worse than conventional-pulsed GMAW. In previous studies, the oscillation was monitored by high-frame camera (Ref. 17) or the arc voltage signal (Ref. 19). If the modified oscillation scheme is used, the detaching pulse can be applied shortly after oscillation. The phase match is guaranteed. The monitoring system becomes unnecessary, the control system becomes simpler and the process becomes more robust.

Depending on the amplitude of the exciting pulse, the droplet can either be lifted towards the electrode or dragged downwards to the weld pool, as shown in the previous studies (Refs. 20, 21). In fact, when the welding current is low, the arc force pushes the droplet back to the electrode, as shown in Fig. 2A. The electromagnetic force directs to the electrode. As the welding current increases, the arc root covers more and more of the surface of the droplet. When approximately half the droplet is covered by the arc root, the arc force changes its direction, pointing to the weld pool, as illustrated in Fig. 2B. For a given diameter of electrode, the welding current can be selected to fully control the direction of the electromagnetic force, either toward or away from the electrode. For example, for the titanium electrode used in this study, a 100-A or lower current always produces an electromagnetic force pointing toward the electrode, despite the size of the droplet and other welding conditions. A 140-A or higher current always generates an electromagnetic force away from the electrode. That is, the direction of the electromagnetic force is controllable. Hence, the authors propose a method, as illustrated in Fig. 3, to realize the modified oscillation scheme.

Fig. 3 — Comparison of current waveforms for active control and its modification.

Fig. 4 — Experimental apparatus diagram.

Fig. 5 — Droplet detachment with pulsed current 200/5 A, 50 Hz, 22 V, and electrode positive. The electrode is 0.9-mm (0.035-in.) ERTI-1, 800 frames per second.
shown in Fig. 3, the modified active control uses a relatively low exciting current to lift the droplet toward the electrode. After the current is switched from the exciting level to the base level, the droplet moves toward the weld pool because of the reduction in the lifting electromagnetic force. After a short period, the detaching pulse current is applied. The detaching current has been designed to ensure the electromagnetic force is away from the electrode. The combination of the detaching electromagnetic force and the downward momentum of the droplet ensures detachment. Hence, the modified oscillation scheme and modified active control are realized.

Experiments revealed the time interval for "free" oscillation (the base current level is very low), i.e., $T_2$ in Fig. 3, determines the efficiency of the detaching pulse. A correct time interval maximizes the efficiency of the downward momentum, which offers the advantage of reducing the amplitude of the detaching pulse to guarantee the detachment. The relationship between the downward momentum and exciting pulse current value and period was investigated as well. The current waveform was modified based on all these results, as shown in Fig. 3. The details will be discussed later in this paper.

**Experimental Procedure**

All experiments were performed with bead-on-plate welding. Titanium alloy (ERTi-1) workpiece and 0.9 mm (0.035 in.) titanium wire (ERTi-1) were used. The shielding gas was pure argon (99.999% purity) with a flow rate of 20 L/min. The power supply was an inverter welding power source with current output range from 5 to 450 A (pulsed current). This power supply can be used for either constant current (CC) or constant voltage (CV) mode. In this study, the welding current was produced by CC mode. The welding equipment was computer controlled to produce a specific pulsed current waveform and constant arc length. The workpiece was clamped on a traversing weld table, allowing the welding torch to remain stationary. The experimental set-up is shown in Fig. 4.

Observation of the droplet was facilitated by a laser backlighting system. A high-speed camera, 800 frames per second, was positioned to record the transfer of the droplet. The camera's resolution is 128 x 128. For monitoring the droplet transfer process, a 15 x 15 mm field of view surrounding the end of the wire was selected. The corresponding resolution of the camera is about 0.12 mm (0.0048 in.). It can be seen from the images given in this work that the reso-
lution of the camera is sufficient to extract the geometrical parameters of the droplet. Thus, the droplet can be monitored at least 6 times per cycle during oscillation. Under this monitoring rate, the oscillation phase of the droplet can be monitored reliably. During experiments, the computer outputs the specific current form and grabbed the images. The images were processed later to investigate the effect of modified active control on droplet detachment.

Results and Discussion

Stability plays a critical role in reducing spatter and improving the shielding of the weld area in GMAW of titanium. In the conventional-pulsed GMAW process, if a constant ODPP transfer is obtained, the process is stable because the variation of arc length caused by droplet transfer is small. Furthermore, the droplet is detached in the base current period, resulting in a low rejecting force (Ref. 4). Figure 5 shows images taken during a constant ODPP transfer. The droplet was detached after the peak current period. The rejection effect is not observed.

However, the range of pulsed current parameters for achieving ODPP mode under a certain condition is narrow. Although parameters were tuned carefully, random interruption always impairs the stable droplet transfer process, such as the variation of arc length or contact tube wear. As shown in Fig. 6, with the same parameters for the process shown in Fig. 5, after the droplet detached from the wire tip, it returned to the wire due to relatively insufficient pulse energy. It appears the energy required by each pulse to detach the droplet reliably may vary according to the welding conditions. If pulse energy is relatively low, the droplet cannot transfer until its gravity is larger than the surface tension after several pulses. The process becomes unstable, especially for thin wire, because the variation of arc length is larger due to the relatively large surface tension. In order to ensure detachment, high peak current value and long peak current period may be used. However, in addition to high droplet impact speed, the corresponding detachment process tends to proceed asymmetrically. Also, due to the violence of the detachment, the droplet sometimes breaks apart, resulting in coarse spatter.

Stable droplet transfer has been ensured by using the active droplet transfer control technique. As shown in Fig. 7, during the exciting pulse, the droplet moves downwards to the weld pool due to electromagnetic force. The droplet moves symmetrically or asymmetrically about the electrode's axis, depending on the distribution of arc root on the droplet surface. Equilibrium is established between the electromagnetic force, gravity and the retaining force due to surface tension. When exciting pulse current is switched to the base current level, the droplet begins to oscillate because of the decrease of electromagnetic force, which is proportional to the welding current's power. The spring force derived from surface tension and the damping force from viscous stresses dominate the movement of the droplet. Because they are symmetrical, the motion of the droplet tends to be symmetrical about the electrode's axis. When the droplet starts to move downward, the current is switched to the detaching level and the droplet is detached reliably and axially. The oscillation of the droplet is beneficial for achieving a stable transfer process from two points of view. The oscillation retrieves the droplet's symmetric shape, and the downward momentum decreases the peak current needed for constant ODPP process. In Fig. 7, the droplet's form was asymmetrical when the exciting pulse was applied. After the oscillation, the motion of the droplet tends to be symmetrical and then it is detached axially. The detaching current needed is only 165 A. However, in the conventional-pulsed current GMAW process of titanium, the droplet is sometimes asymmetrical and when pulsed current is applied, the droplet does not move axially. The droplet may be detached away from the wire to produce coarse spatter, as shown in Fig. 8. The peak current needed is about 230 A for constant ODPP transfer mode.

Besides constancy, another characteristic of the transfer process with active control is the speed of the droplet. Figure 9 shows the average speed of the droplet in GMAW-P is 816 mm/s for 0.9-mm (0.35-in.) wire with ODPP mode using 230-A pulsed current. The average
speed of the droplet with the active control technique is 423 mm/s, with the same detaching current value. Furthermore, the active control uses a much lower detaching current than the peak current in conventional-pulsed GMAW, resulting in a droplet transfer speed decrease to 345 mm/s.

The modified active control inherits all of the advantages of the active control method. In addition, the modified control technique further eliminates remaining problems in its origin. As seen in Fig. 10, the droplet is first lifted toward the electrode by the exciting pulse current. Then it springs downwards to the weld pool after the exciting pulse current switches to base current level. After a short period, the detaching pulse current is applied to detach the droplet.

The modified method results in several advantages. First, because the detaching current is applied after less than half the period of droplet oscillation, the time needed for each droplet detachment cycle is decreased significantly. The upper limit of the frequency is increased to 120 Hz, reaching the same range as conventional-pulsed GMAW process. Thus, the welding current range is enlarged, especially for thicker wire, which has a longer oscillation period (Ref. 17). Second, the exciting current decreases to 100 A, which is much smaller than that used by the previous method (140 A). The duration of the exciting pulse is not correspondingly increased. Therefore, the energy used for exciting the oscillation of the droplet decreases significantly and less heat input is produced by the exciting pulse. This characteristic is useful for many applications that need low input energy. Third, the controllability of the droplet detachment is improved. As shown in Fig. 11, in conventional-pulsed GMAW, the droplet is detached only by the electromagnetic force. There is a trade-off between the robustness and the high pulse current. In the previous active control method, the droplet is detached by electromagnetic force and downward momentum. With the assistance of the downward momentum, the requirement for the detaching current is decreased and the allowance of the detaching current is increased. Thus, the controllability is improved. However, because in the exciting pulse current, the droplet is dragged down by electromagnetic force, the energy difference that assists the droplet detachment is not large. In the modified active control method, the electromagnetic force caused by the exciting pulse lifts the droplet. Hence, the energy difference caused by the detaching action and the exciting action is
larger. This difference eases the prevention of accidental detachment. As a result, the controllability is increased further, and both the size and transfer instant of the droplet become more controllable. Fourth, the robustness of the detachment process is improved because after the exciting pulse current switches to base current, the droplet must spring back due to surface tension. The detaching current is applied after a short period. The downward momentum must be in phase with the detaching arc force. Therefore, this method eliminates the necessity for real-time monitoring and analysis of the oscillation process.

Experiments have also been conducted to investigate the influence of the exciting pulse period on oscillation amplitude. It was found that the exciting pulse current value determines the maximum amplitude of the droplet movement. As can be seen in Fig. 12, for a certain exciting current value and electrode diameter, there is an optimal exciting pulse period. If the exciting period is set at this optimal period, the droplet can be lifted to maximum amplitude. The exciting pulse current period has been set slightly higher than the optimal period to ensure robustness of the process in this study.

This study has also investigated the optimal time to apply the detaching current. It was found the time used in the previous active method is not optimal. As shown in Fig. 13, the needed detaching pulsed current for reliable detachment varies with the instant to apply it during the droplet's downward motion. At a certain instant, the needed detaching pulse current reaches minimum value. The phenomenon is complicated. Oscillation of the droplet is like a vibration system with viscous damping. If the detaching pulse current is applied as soon as the droplet moves downwards, the velocity of the droplet is additionally accelerated, resulting in an excessive increase of the damping force, which is proportional to velocity. Thus, excessive energy provided by the detaching current is consumed during downward movement of the droplet. In order to detach the droplet reliably, either higher detaching current or longer detaching period should be used. If the detaching force is applied too late, phase mismatch may occur. In the modified method, the detaching current is applied shortly after the current is switched to the base level, so the phase match is guaranteed. Also, the efficiency of the detaching pulse is improved and the need for detaching pulsed current is decreased.

Robustness

In order to demonstrate the stability of the modified active control method, experiments were conducted to investigate droplet transfer under varied conditions. Welding parameters selected as variables include arc length and contact-tube-to-workpiece distance because they have significant influence on the droplet transfer process. Additionally, they are prone to variations during production welding, especially in semiautomatic welding. Variation in contact-tube-to-workpiece distance and arc length changes the heat...
generation and arc efficiency. If the allowance of the controllability of a droplet is small, the process cannot withstand changes of conditions. Multidroplet per pulse or multipulse per droplet mode will occur. However, with improved controllability, the modified active control method does not have these problems. As shown in Figs. 14 and 15, with quite different contac tube-to-workpiece distance, the droplet transfer process remains constant even though the heat generation conditions change. As seen in Figs. 16 and 17, the arc length changed from 9 mm (0.36 in.) to 3 mm (0.12 in.), but the active control method still detached the droplet constantly and reliably. The modified active control does withstand variation in the welding conditions within a reasonable range.

Conclusions

By utilizing active control technology, the robustness of the metal transfer process in GMAW of titanium is significantly improved in comparison with the conventional-pulsed GMAW process. The use of downward momentum decreases the peak current needed for constant ODPP process. The process is stable and free from spatter, which is highly desirable in GMAW welding of titanium.

The major difference between active control and modified active control lies in the method for oscillation generation. In active control, both the exciting and detaching pulses are selected to be at peak level. Hence, oscillation is generated by switching current from the peak level to the background level. The electromagnetic force corresponding to peak current is a detaching force. After the current is switched from peak level to background level, the droplet initially moves toward the electrode. The detaching action can be taken only after half of the oscillation cycle. Because oscillation depends on welding parameters such as material and diameter of the electrode, the oscillation process must be monitored. The system is complicated, and robustness of the metal transfer depends on the reliability of the monitoring system.

In the modified active control, the oscillation is generated by switching the current from the exciting pulse level to background level. Because the exciting pulse in this case is much lower than the detaching pulse, it can be so selected that the resultant electromagnetic force is a retaining force or support force. As a result, before the current is switched to the background level, the electromagnetic force pushes the droplet toward the electrode. After the current is switched, the droplet oscillates by immediately moving toward the weld pool. Hence, the detaching pulse can be applied after a short period of time, and the phase match between oscillation and the detaching force is guaranteed. Consequently, the need to monitor oscillation is eliminated. The system is simplified and robustness is improved. Of course, because of the elimination of a half cycle of waiting time, the modified active control also improves the range of the metal transfer rate. Because modified active control inherits all other advantages of active control, modified active control is a better solution for applications where highly repeatable metal transfer is desirable.

Acknowledgment

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References


Fig. 17 — Droplet transfer with 3-mm (0.12-in.) arc length with modified active control, 400 frames per second.
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