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Making the World Safe for Technical Standards

The Standards Development Organization Advancement Act of 2003 has been introduced in the House (H.R. 1086). This bill addresses the possible antitrust liability of standards developers and recognizes that “if relief from the threat of liability under the antitrust laws is not granted to voluntary consensus standards bodies...such bodies could be forced to cut back on standards development activities at great financial cost both to the Government and to the national economy.” The bill would require courts to consider the procompetitive effects of challenged standards, in addition to any alleged anticompetitive impact. Also, the bill would limit the ability of plaintiffs to recover treble damages, which is the usual measure of recovery for any antitrust violations.

While standards developers are infrequently found liable in antitrust lawsuits, many cases are settled before trial. In any event, insurance coverage can be difficult to obtain, and the costs of defending an antitrust claim can be prohibitive.

It has also been observed that technical standards currently developed or adopted by voluntary consensus standards bodies have replaced thousands of unique federal standards and specifications. Standards developed by governmental entities are usually not subject to challenge under federal and state antitrust laws, while private standards developers of technical standards do not enjoy such immunity and are therefore subject to legal actions.

Commerce: Are Industry Standards Fair to U.S. Industry?

The U.S. Department of Commerce has announced an eight-point plan to address complaints from the business community that technical standards are being used as a trade barrier by other countries. Divergent standards, redundant testing and compliance procedures, and unilateral and nontransparent standards setting processes are recognized as major impediments to free trade — estimated to affect 80% of world trade. Among the steps are sponsorship of a series of industry-specific roundtables to gather input from U.S. industry on the most pressing standards issues and priority foreign markets, and appointment of a Standards Liaison at the International Trade Administration.

OSHA Helps You Find Your Way Out

The U.S. Occupational and Health Administration (OSHA) has issued the first in a series of industry-specific guidelines for the prevention of musculoskeletal disorders (MSDs) in the workplace. MSDs include conditions such as low back pain, sciatica, rotator cuff injuries, epicondylitis (“tennis elbow”), and carpal tunnel syndrome. Last April, OSHA announced its strategy to reduce ergonomic injuries, the core of which is voluntary guidance on an industry-specific basis. Efforts by OSHA will also include research, outreach and assistance, and a limited amount of enforcement. The first set of guidelines is directed at the nursing home industry.

Labor Dept. Works Long and Hard on Overtime Rules

The U.S. Department of Labor has published a proposal to modernize its 50-year-old regulations defining exemptions from the Fair Labor Standards Act (FLSA) for “white-collar” employees with respect to entitlement to overtime pay. For the first time since 1975, the department’s proposed regulations would raise the salary threshold — below which workers would automatically qualify for overtime — from $155 to $425 a week. This increase of $270 a week would be the largest since Congress passed the FLSA in 1938. The impact of this revision will be to increase the wages of as many as 1.3 million lower-income workers and reduce the number of low-wage salaried workers currently being denied overtime pay.

For example, the proposed changes would guarantee overtime to:
- An employee working 50 hours per week managing a restaurant for $15,600 per year.
- A worker putting in 60 hours a week managing a department store for $18,000 per year.
- An employee working 42 hours a week supervising a machine shop for $17,000 per year.

Other proposed changes include revising job duties required to qualify for an overtime exemption to better correspond to twenty-first century workplace realities. The old regulations, written in 1949, mention job classifications that no longer exist, such as keypunch operators, straw bosses, legmen, and gang leaders. Hopefully, clarifying which job duties qualify for overtime pay will help workers and employers more easily determine overtime entitlement for millions of workers whose status is currently unclear.

Contact the AWS Washington Government Affairs Office at 1747 Pennsylvania Ave. NW, Washington, DC 20006; e-mail hwebster@wc-b.com; FAX (202) 835-0243.

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Mississippi Bond Sale to Help Expand Northrop Grumman’s Ingalls and Gulfport Operations

Mississippi Governor Ronnie Musgrove recently signed legislation authorizing proceeds from the sale of $48 million in bonds for Northrop Grumman Corp.’s Ship Systems sector to expand and modernize the company’s Ingalls Operations in Pascagoula, Miss.

As part of its partnership with the state, Northrop Grumman is allocating $96 million in capital funds to the project at Ingalls Operations and its Gulfport Operations in Gulfport, Miss. The plans for Ingalls include the addition of new blasting and painting halls, increased ship construction area of more than 400,000 sq ft to support the DD(X) and U.S. Coast Guard Deepwater programs, a state-of-the-art automated steel processing panel line, and additional technology design and procurement development space.

Gulfport is scheduled to undergo a three-year-long conversion into the United States’ first primary composite combatant ship manufacturing facility. Other improvements will include environmentally controlled enclosed buildings that will add 50% more work space, a new outfitting pier and building, and a new two-story administration building.

“The image of Mississippi in 2003 is unlike anything anyone could have imagined,” Gov. Musgrove said. “It’s an image of companies like Northrop Grumman doing business in the state with Mississippians building state-of-the-art ships for our nation’s military. I’m proud of what we’ve done to get to this point.”

The Pascagoula facility was originally established 65 years ago under the state’s “Balance Agriculture with Industry” program. A major new facility construction in 1967 was accomplished with $130 million in state revenue bonds. Since 1970, the company has invested an additional $900 million.

Steam Generator Replacement Completed in Near-Record Time with No Rejectable Indications

Constellation Energy Group, Baltimore, Md., recently completed its Unit 2 steam generator and refueling outage at Calvert Cliffs Nuclear Power Plant in 66 days, 32 days ahead of schedule, placing the plant near a world record for steam generator replacement. The 66-day outage was completed in 58 fewer days than a similar outage completed at Calvert Cliffs’ Unit 1 in 2002.

In addition, welding was completed with zero rejectable indications shown in radiography testing on the steam generator girth and reactor coolant system “hot” and “cold” legs. No rejectable indications meant no weld repairs were required in these locations, which cut the duration of the outage. The most significant weld was the girth weld, which covers 52 ft in circumference per steam generator. Calvert Cliffs uses two steam generators in each unit. Each girth weld required 2200 lb of weld material and was completed in 8.25 days.

During the outage, the reactor vessel head, including all nozzles, was also inspected. A bare metal visual inspection and ultrasonic testing showed the head to be in good condition, with no indications of cracking or boron acid damage. In addition to the normal refueling activities, the two main step-up transformers were replaced, the fuel thimbles modified, and routine maintenance work was conducted on the unit’s secondary systems, including the turbine and intake structure.

GSI Lumonics Acquires Spectron Laser Systems

GSI Lumonics Inc., Billerica, Mass., recently signed an agreement to acquire the principal assets of Spectron Laser Systems, a subsidiary of Lumenis Ltd., located in Rugby, U.K.

This acquisition adds both diode-pumped laser solid-state technology and products to GSI Lumonics’ offerings, as well as expanded product lines in lamp-pumped and CO2 based technologies. Spectron’s lasers are primarily used in material processing applications such as marking, cutting plastic and diamonds, silicon machining, and microwelding. The products will expand applications in the 7- to 100-W range.

The product lines included in the acquisition had sales of approximately $11 million in 2002. The assets are being acquired for $6.3 million in cash, subject to adjustment and the assumption of certain liabilities. Integration of Spectron into GSI Lumonics’s Laser Group is scheduled for completion by the end of August.
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Volunteers Are Our Strength

In preparation for my year as AWS president, I have given extra thought to the strengths and needs of our Society. While we have an outstanding staff at headquarters, I realized our greatest asset is our volunteers. As a consensus body, everything we do relies on input from volunteers who represent the various segments of the welding industry. From the members of the local Sections to our committee members to the board of directors and AWS Foundation trustees, we are blessed with outstanding people who give freely of their time and expertise.

Therefore, it is important that I and your board of directors work to continuously improve volunteer management and put the right kind of programs in place to aid our thousands of volunteers and to benefit the companies that support them. The time it takes to attend meetings, locally or beyond, is harder to justify in our current economic environment. As a board, we will be looking for best practice examples, and we look forward to sharing them with our Sections and committees.

I will mention some of the steps we have already taken, as well as the names of a few of the volunteers who have helped make AWS a success. The work these people have done is representative of the dedication shown by the thousands of other volunteers I can’t name today, but I feel it’s important to put a face and a name to this word “volunteer.” Each of these people and their companies have made a commitment to our Society and industry.

For example, we now provide a Leadership Symposium to help local volunteer leaders serve their members better. Lee Kvidahl of Northrop Grumman Ship Systems and the Membership Committee initiated and manage this service. You can see the success of their project within the current board of directors, five of whom attended the Leadership Symposium while at the Section level. There’s no doubt employers have also benefited from the strong leadership skills those who have attended the symposium acquired as a result of volunteering with AWS.

To make volunteering easier and more productive, AWS has invested in the technology to produce virtual meetings and is adding the OpenText system for standards development. These changes allow committee members to meet from their offices over the telephone and Internet. These changes will also make it easier to review and comment on documents. While some face-to-face meetings will still be needed, our new technology allows volunteers to maximize their contribution and learning and minimize their time commitment. At the same time, AWS reduces its costs and improves the efficiency of the document preparation system. Under the leadership of Dave McQuaid, the technical committees have been the most frequent users of this system, but we hope more committees will be taking advantage of the many benefits this technology offers.

To help support those volunteers willing to make the extra time commitment to attend international standards development meetings, we have established the ISO Participation Fund, which will be administered by the International Standards Activities Committee led by Walt Sperko of Sperko Engineering Services. While this fund will not cover the volunteer’s full expenses, it will provide some support for the extra cost and time required to attend overseas meetings. The work these volunteers are doing is essential if U.S. industry is to regain some of the worldwide influence it once enjoyed.

I would like to encourage every one of you to work with me this year to support our volunteers around the world or for you to become an active volunteer. In this way, we will continue to grow and improve our organization and our international reach, for the good of the welding industry and the people who work within it. As I have said before, the greatest benefit any of us receive from the American Welding Society is the opportunity to know and learn from each other. That can’t happen if you don’t get involved.

Thomas M. Mustaleski
AWS President

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Jesse James a Monster Hit at AWS Show

Jesse James (right), host of the Discovery Channel's Monster Garage, received an award honoring his contributions to welding from Ernest Levert (left), AWS president, and Rusty Franklin (center), chair of the AWS Image of Welding Presidential Task Group, during the recent AWS Welding Show.

The modern Jesse James has a welding gun at his side, tattoos on his arms, and hosts a wildly popular TV show on the Discovery Channel called Monster Garage. Jesse James and a cast of assistants take a highly recognizable vehicle and outfit it with apparatus that gives the viewer an outrageously different perspective on its use. For example, a mail truck is armed with cannons, catapults, and a crossbow to help speed delivery of those fragile packages, or a sleek Mustang with a lawn mower attached beneath its rear end can beautifully trim your lawn at 60 mph, or a SUV garbage truck, complete with hydraulic lift, collects your garbage with style. Of course, welding plays an integral part in all these transformations.

In recognition of the national publicity he gives to welding, James was an honored guest at the AWS Welding Show where, with one of his creations as a backdrop (a Kyle Petty NASCAR Winston Cup car able to moonlight as a street sweeper with its dual brushes and vacuum system), he was presented with a golden autodarkening welding helmet and a plaque acknowledging his contributions to welding. The presentation ceremony took place at the exhibit of ESAB Welding and Cutting, Florence, S.C.; the helmet was courtesy of Jackson Products, St. Charles, Mo.; and AWS's Image of Welding Presidential Task Group awarded the plaque. ESAB provides a variety of welding and cutting equipment for use on Monster Garage.

James is a strong supporter of welding education and he gets much mail from young people interested in welding. When asked what should be done to support this interest, he said, "Beef up the shop classes in the high schools." For his part in this effort,

The commercial diving industry wants qualified underwater wet welders. The College of Oceaneering offers all the education you need for a solid career in inland and offshore wet welding technology. We offer unparalleled certifications that you can't get anywhere else. Plus, take advantage of our lifetime career placement assistance.
James has established the Jesse James Foundation for Industrial Arts to which he donates both time and money. While the foundation currently operates only in the Long Beach, Calif., area, James said he plans to expand its efforts. Information on the foundation can be obtained by e-mailing James through his Web site www.westcoastchoppers.com.

He noted he started welding when he was 12, and jokingly told how he became so proficient "the other kids were paying me $10 to take their welding tests."

His interest in welding has not waned over the years. "If I don't turn my machine on at least once a day, I feel like I'm cheating myself," he said. "I want to learn it all. I'm like a sponge, learning all the time." He feels comfortable with any oxyfuel or arc welding process, and uses them all in his day job running his company West Coast Choppers, a custom shop for motorcycles. His skill and creativity in designing and building motorcycles has earned such a reputation that the rich and famous seek his Long Beach, Calif., facility to fulfill their biker fantasies. The 50-person shop personalizes each bike to the customer's wishes. "It might take 400 to 1000 hours to complete a bike," James noted. "On a special concept bike, we spent 2600 hours." One of the toughest welding jobs he's had recently was getting a virtually seamless joint welding a copper bike.

To view firsthand his imaginative mutations of vehicles, watch Monster Garage on Mondays at 8:00 p.m. ET/PT on the Discovery Channel.

Michigan Student Wins Gold at U.S. Open Weld Trials

Miles Tilley, a 19-year-old student from Washtenaw County Community College, South Rockwood, Mich., took first place at the AWS U.S. Open Weld Trials held April 7-10 during the AWS Welding Show in Detroit. To win, Tilley had to beat nine of the world's top welding students — five U.S. and four international competitors. Michael Whalan, Australia's national champion, and Vhusnu Khoesial, the top welder from The Netherlands, took silver and bronze, respectively.

Tilley's win gives him the opportunity to represent the United States at next year's International Welding Championship in Europe.
States at the World Skills Competition, which is being held this month in St. Gallen, Switzerland, and is sponsored by the International Youth Skills Organization. In addition, he will receive a $40,000, four-year scholarship sponsored by the Miller Electric Mfg. Co. Tilley said he plans to use the scholarship to complete his associate’s degree in Welding Technology at Washtenaw then to get a bachelor’s degree in Welding Engineering Technology at Ferris State University, Big Rapids, Mich.

Tilley said he felt the key to his win was that he stayed consistent throughout the competition and his pressure vessel project came out very well. “I came into the competition after the first day in eighth place and went on to become first,” he said. “That shows I kept my nose to the grindstone and should tell other contestants not to get discouraged if they don’t do well at first.”

“It was great to see what it will be like to compete internationally. It was good to meet the competitors,” said second-place finisher Michael Whalan of Bathurst, Australia. “This competition was run really well.” After Detroit, Whalan planned on spending a week in the St. Louis, Mo., area, then head home to train for the World Skills Competition.

Third-place finisher Vhusnu Khoesial from The Netherlands agreed that the opportunity to participate in the U.S. Open Weld Trials was good practice for the contest in Switzerland. He, too, felt the success of his pressure vessel project placed him among the top three.

Runners-up in the competition (with their instructors’ names in parentheses) were Joel Stanley II (David Hartley), Northern Penobscot Technical, Region 3, Lincoln, Maine; Cody Sarsland (Loren Hjelle), Ridgewater College Willmar, Willmar, Minn.; Mark Johnson (Leland Kennedy), Pearl River Community College, Poplarville, Miss.; J. T. Sayre (Jamey Valega), Meridian Technical Center, Stillwater, Okla.; Douglas Tennant (Scott Tennant),

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Northeast Wisconsin Technical College, Green Bay, Wis.; André Morin (Guy Langais), Roberval, Que., Canada; and John Kelleher, Cork, Ireland. Tilley’s instructor is Bill Figg. For the competition, Whalan was advised by Australian welding expert Paul Condron; Khoesial was under the advisement of Netherlands welding expert Johan Daniels.

In addition to the Miller Electric scholarship, Tilley received up to $1000 in AWS publications, a four-year AWS membership, and AWS certification. The other U.S. contestants were awarded a $1000 scholarship for books, tuition, or lab fees; a one-year AWS membership; and AWS certification.

Bankruptcy Court Confirms Thermadyne Reorganization Plan

Thermadyne Holdings Corp., St. Louis, Mo., recently announced the U.S. Bankruptcy Court has confirmed its reorganization plan, which will enable it to emerge from Chapter 11. The plan, which was approved by the company’s senior secured lenders and general unsecured creditors, reduces the company’s long-term debt to approximately $230 million from nearly $800 million in debt and $79 million in preferred stock when Thermadyne filed for protection under Chapter 11 in November 2001. It was expected the plan would go into effect the latter part of May 2003.

Thermadyne Chairman and CEO Karl Wyss said, “This marks a major milestone for our company. This key event frees up funds for investment in our future — the skills of our people, our technology, our manufacturing capabilities, our service levels, and our marketing initiatives. We are now well positioned to move forward and capitalize fully on the strengths of our leading brands, in both current and emerging markets.”

Under the plan, 13.3 million shares of new common stock will be issued. Subject to a subscription offering to the company’s existing bondholders and note holders, Thermadyne’s senior secured lenders will own 94.5% of the stock and will continue to hold about $180 million in long-term bank debt. A group of bondholders will own the remaining 5.5% of Thermadyne’s stock. Bondholders and note holders who are accredited investors have the opportunity to purchase substantially all the new stock to be issued to the senior secured lenders, for cash, provided they elect to do so before the company emerges from Chapter 11. Preferred and common stock outstanding before the filing for Chapter 11 protection will be cancelled.

The plan also provides for cash distributions to the company’s general unsecured claims, which include trade creditors, equal to the lesser of a holder’s pro rata share of $7.5 million and 50% of such holder’s claim (estimated by the company to provide a recovery of such claims of 30 to 37% of the amount of such claims).

Global Robotics Industry to Nearly Double by 2007

The current global robotics market, which includes both whole robots and parts, is estimated at more than $8 billion, according to RG-270 Robots/Automation Devices, a report from Business Communications Co., Norwalk, Conn. It is estimated to grow an average of 14.7% yearly and reach $16 billion by 2007. Although robots used in industrial processes will continue to be applied to currently automated manufacturing activities, the largest gains in whole robot consumption will be in families of mobile robots that are currently being developed.

— continued on page 14
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Sandvik Specialty Steels Changes Name

Sandvik Specialty Steels recently changed its name to Sandvik Materials Technology and the organizational structure within the Sandvik Specialty Steels business area has been changed. Under the new organization, the Sandvik Steel business area no longer exists. Sandvik Materials Technology will include five product areas: Tube, Strip, Wire, Kanthal, and Process Systems. Peter Goassas, former president of Sandvik Steel, has been appointed president of the newly named company. Overall, the business area has about 8000 employees and annual sales of approximately $1.7 billion.

Taylor-Winfield and HBS Studwelding Form Alliance

The Taylor-Winfield Corp., Brookfield, Ohio, and HBS Studwelding, Inc., of Germany recently formed a business and
technology alliance that makes the two companies a source for resistance welding, drawn arc welding, capacitor discharge stud welding, weld studs and pads, and automation equipment.

The alliance allows Taylor-Winfield to add magnetic arc pad welding, which HBS developed, to its product line. This metal fastening method is achieved by rotating the arc and features low heat input.

Bridge Honors Illinois Boy Scout; Lincoln Electric Donates Materials

Volunteers built this bridge using materials donated by The Lincoln Electric Co. to honor Keith J. Hunter, an Eagle Scout who died in an attempt to save a friend.

Volunteers recently built a walking bridge at the Rhodes France Scout Reservation just outside Pana, Ill., dedicated in honor of Keith J. Hunter, an Eagle Scout from Decatur, Ill., who perished during an attempt to save a friend.

In spring 2001, 18-year-old Hunter and his friend Steven A. Morris, Jr., 20, were helping to prepare a pool in Decatur, Ill., for the summer. Morris dove in to cool off and was soon seen to be in distress. Hunter immediately dove in to rescue him. Unbeknownst to any of the workers, a defective underwater light fixture was releasing electrical current into the water. Both men were electrocuted and perished.

Bob Webb, chairman of the Boy Scouts’ Lincoln Trails Council Property Committee and welding engineer for Caterpillar’s Decatur plant, volunteered to do the welding for the bridge and contacted Lincoln Electric about providing materials for the project. Lincoln donated 150 lb of Fleetweld® 180 ½-in. welding electrodes, and its equipment was also used to weld parts for the 90-ft-long, 4-ft-wide bridge, which is located at a reservation where Hunter and his troop regularly camped.

Linde Gas Acquires Air Products’ Puerto Rico Industrial Gas Business

Linde Gas, through its wholly owned subsidiary, AGA Gas, Inc., recently acquired the assets of the Puerto Rico industrial gas business of Air Products and Chemicals, Inc. The business includes bulk liquid production and sales, packaged gas production and sales, specialty gases, and on-site gas supply systems.

The new acquisition will be combined with AGA’s existing business in Puerto Rico. The combined businesses will have annual sales of $36 million and employ 230 workers.

Custom Metals Wins Award in International Metalcraft Competition

Custom Metals, Inc., Madison, Wis., recently won a gold award for outstanding craftsmanship in the Furniture and Accessory Fabrication category of an international competition sponsored by the National Ornamental & Miscellaneous Metals Association (NOMMA). Custom Metals specializes in architectural metalwork and metals restoration.

NOMMA’s annual Ernest Wiemann Top Job Awards Competition is open to the organization’s more than 1000 member firms throughout the United States and 14 other countries. To win an award, entrants must submit photos and a description of their work, which is then put on public display. The organization’s member firms are then given the opportunity to vote on the winners. The winning entries can be viewed at www.nomma.org by clicking on “Top Jobs Gallery.”

Industry Notes

Manufacturing companies in North America ordered 10,575 robots valued at $811 million from North American-based robot suppliers in 2002, an increase of 6% in units and 5% in revenue from 2001, according to figures released by Robotic Industries Association (RIA), the industry’s trade group. When sales to companies outside North America are included, North American robot suppliers saw overall increases of 2% in units and revenues.
Friends and Colleagues:

The American Welding Society established the honor of Counselor to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counselor shall be based on an individual's career of outstanding accomplishment.

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

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

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the Welding Journal. The deadline for submission is February 1, 2004. The committee looks forward to receiving these nominations for 2005 consideration.

Sincerely,

H. E. Cahle
Chairman, Counselor Selection Committee
CLASS OF 2005
COUNSELOR NOMINATION FORM

DATE ___________________ NAME OF CANDIDATE ___________________

AWS MEMBER NO. ___________________ YEARS OF AWS MEMBERSHIP ___________________

HOME ADDRESS ___________________

CITY ___________________ STATE ___________________ ZIP CODE ___________________ PHONE ___________________

PRESENT COMPANY/INSTITUTION AFFILIATION ___________________

TITLE/POSITION ___________________

BUSINESS ADDRESS ___________________

CITY ___________________ STATE ___________________ ZIP CODE ___________________ PHONE ___________________

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION ___________________

MAJOR & MINOR ___________________

DEGREES OR CERTIFICATES/YEAR ___________________

LICENSED PROFESSIONAL ENGINEER: YES ______ NO ______ STATE ___________________

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE ___________________

POSITION ___________________ YEARS ___________________

COMPANY/CITY/STATE ___________________

POSITION ___________________ YEARS ___________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

SUGGESTED CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS COUNSELOR. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

**MOST IMPORTANT**

The Counselor Selection Committee criteria are strongly based on and extracted from the categories identified below. All information and support material provided by the candidate’s Counselor Proposer, Nominating Members and peers are considered.

SUBMITTED BY:

PROPOSER ___________________

AWS Member No. ___________________

The proposer will serve as the contact if the Selection Committee requires further information. The proposer is encouraged to include a detailed biography of the candidate and letters of recommendation from individuals describing the specific accomplishments of the candidate. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER: ___________________

AWS Member No. ___________________

NOMINATING MEMBER: ___________________

AWS Member No. ___________________

NOMINATING MEMBER: ___________________

AWS Member No. ___________________

NOMINATING MEMBER: ___________________

AWS Member No. ___________________

NOMINATING MEMBER: ___________________

AWS Member No. ___________________

SUBMISSION DEADLINE FEBRUARY 1, 2004
Nomination of AWS Counselor

I. HISTORY AND BACKGROUND

In 1999, the American Welding Society established the honor of Counselor to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counselor shall be based on an individual's career of outstanding accomplishment.

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

- Leadership of or within an organization that has made a substantial contribution to the welding industry. (The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, VIICA, NEMA, NSRP SP7 or other similar groups.)
- Leadership of or within an organization that has made substantial contribution to training and vocational education in the welding industry. (The individual’s organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, VIICA, NEMA, NSRP SP7 or other similar groups.)

II. RULES

A. Candidates for Counselor shall have at least 10 years of membership in AWS.

B. Each candidate for Counselor shall be nominated by at least five members of the Society.

C. Nominations shall be submitted on the official form available from AWS headquarters.

D. Nominations must be submitted to AWS headquarters no later than February 1 of the year prior to that in which the award is to be presented.

E. Nominations shall remain valid for three years.

F. All information on nominees will be held in strict confidence.

G. Candidates who have been elected as Fellows of AWS shall not be eligible for election as Counselors. Candidates may not be nominated for both of these awards at the same time.

III. NUMBER OF COUNSELORS TO BE SELECTED

Maximum of 10 Counselors selected, as determined by the committee

Return completed Counselor nomination package to:

Wendy S. Reeve
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

Telephone: 800-443-9353, extension 215

SUBMISSION DEADLINE: February 1, 2004
All the Muscle Needed for E71T-1 Welding

Select-Arc, Inc. offers a complete line of E71T-1 flux cored, gas-shielded, carbon steel electrodes including the proven Select 710 and the innovative Select 727.

Since Select-Arc commenced tubular welding electrode production in 1966, Select 710 has served as the mainstay of the product line. That is because Select 710 is an excellent general-purpose electrode with outstanding welder appeal. It features smooth, arc transfer with low spatter emission and delivers better penetration than most "flux core" products.

Select 710 is a superb choice for general plate fabrication, structural steel welding and other applications where strength and toughness properties are primary requirements.

The new Select 727 is an exceptional all-position, lower film electrode and Select 710. Formulated to provide improved deposition rates and enhanced welder appeal, Select 727 offers significant reductions in fume emission (50-55%) and spatter levels with superior bead geometry compared to conventional E71T-1 electrodes.

Select 727 is well-suited for situations where weld line occurs in areas where reduced fumes are required. This electrode's strength and toughness make it ideal for applications such as structural steel, farm machinery, construction equipment, railroad fabrication and shipbuilding.

For more information on the time-tested Select 710 and the new Select 727 electrodes, call Select-Arc at 1-800-341-5215 or contact

SELECT ARC INC.
P.O. Box 250
Fort Loramie, OH 45844-0250
Phone: (937) 341-5215
Fax: (937) 341-5217
www.select-arc.com

Circle No. 52 on Reader Info-Card
Q: I have a welding shop that manufactures small- to medium-sized welded structures. I have been acquiring some larger contracts lately in both steel and aluminum structures. Some of my larger steel customers have requested that we have welding procedures and qualified welders for some of the structural steel work. We have used AWS D1.1, *Structural Welding Code—Steel*, to qualify our procedures and welders for steel. I am currently trying to increase the amount of aluminum fabrication business, and think I should consider the possibility of producing welding procedures and qualifying my welders for aluminum. Is there a welding code like AWS D1.1 that can be used for aluminum? If so, can I transfer my D1.1 procedures and performance qualifications from steel to aluminum?

A: First, before I answer your questions, I would like to say that I think you are extremely sensible to have considered welding procedures and welder performance qualifications for the various types of welding work in which you are engaged. In general terms, working with a welding code or standard designed for any material, in my opinion, has merit.

I have to believe that the use of welding codes and standards are an opportunity for welding fabricators to control quality and improve the reliability of their product. If we consider the move by more manufacturing organizations toward the implementation of quality management systems, such as ISO 9000, and the requirement of such systems for process control, we must consider welding as a special process and, consequently, its formal control. Welding codes and standards can be used by welding fabricators to assist with the development of their process control system. If we examine the major elements of process control, as specified by such standards for quality systems, we will recognize those same elements as being addressed within most welding codes or standards. The first requirement for process control is to have documented procedures defining the manner of production. For welding aluminum, this is the welding procedure specification (WPS). The second requirement is criteria for workmanship, which shall be stipulated in the clearest practical manner. For welding aluminum, this may be the code or standard quality acceptance criteria.

The third requirement is qualification of personnel. For welding aluminum, this is addressed by the code or standard welder performance qualification test. In adopting a welding code or standard, we can acquire these three main elements of a welding control system, along with the reassurance that our fabricated product has been manufactured in accordance with a nationally recognized standard, which may be invaluable if we should ever have to defend the integrity of our welded product.

In direct answer to your questions, yes, there is a welding code like AWS D1.1 that can be used for welding aluminum. It is AWS D1.2, *Structural Welding Code—Aluminum*. And no, you cannot transfer your procedures and performance qualifications from steel to aluminum. If you desire to qualify welding procedures and welders for aluminum welding, you will have to start from scratch, so to speak, and perform this qualification totally independent of your current steel qualifications.

In many ways, the welding code for
aluminum structures is similar to the AWS DI.1 document. However, the similarity of D1.2 to DI.1 is only in format, which has been chosen to match DI.1 for its simplicity of use, particularly for personnel who employ both of these codes in practice. Because of the totally different characteristics of steel and aluminum, relating to their metallurgical structure and associated reactions during welding, method of welding, design criteria, and inspection and testing requirements, these two codes are completely independent.

Developing the Code for Aluminum Structures

The 2003 edition of AWS D1.2, Structural Welding Code — Aluminum, is now available.

Some background on the aluminum code: AWS has been developing codes for the welding of various steel structures since 1928. In the early 1970s, the need for developing a code for the structural welding of aluminum was recognized. Because of the interest of both The Aluminum Association and AWS, it was decided in the mid-seventies to begin the task of developing a structural welding code for aluminum. Initially, a task force from The Aluminum Association undertook the effort. In 1979, this task force became a subcommittee of the AWS Structural Welding Committee, and the D1.2, Structural Welding Code — Aluminum, resulted from the continued activity of that subcommittee.

The new edition of AWS D1.2 is the 2003 edition. This 201-page document is divided into seven sections and contains annexes A through L and a comprehensive commentary prepared to generate better understanding of the code to welding in aluminum construction.

Dimensional tolerances and weld quality requirements are provided for non-tubular structures under static and cyclic loadings. For tubular structures, two classes of structures are identified. Class I structures are those designed for static loading, and Class II are those designed for cyclic loading.

Recommended joint details have been prepared for various complete joint penetration groove welded joints. One of the major differences between the Structural Welding Code — Steel and the code for aluminum is that, while the steel code allows for prequalified welding procedures, the code for aluminum does not. This is mainly because of the many and varied possible welding conditions that can be obtained with the semiautomatic welding variables most often used with aluminum and the wide range of both heat-treatable and non-heat-treatable alloys that may be welded under this code.

Therefore, all of the joint details and the welding procedures used with the code must be individually qualified and included in the Welding Procedure Specification (WPS).

Procedures and standards are outlined in the code for several methods of nondestructive testing. Methods included are visual, radiographic, and dye penetrant. Ultrasonic testing is permitted, but the procedure and acceptance criteria must be specified in the contract documents.

Unlike the steel structural code, the aluminum structural code (D1.2) does not cover design considerations such as the allowable stresses for load-carrying members. This information is covered by reference to the Aluminum Design Manual published by The Aluminum Association.

TONY ANDERSON is Technical Services Manager for Alco Tec Wire Corp., Traverse City, Mich. He is Chairman of the AWS D10H Subcommittee on Aluminum Piping and D8G Subcommittee on Automotive Arc Welding — Aluminum, Vice Chairman of the AWS D1G Subcommittee 7 on Aluminum Structures, and Chairman of the Aluminum Association Technical Advisory Committee for Welding and Joining. Questions may be sent to Mr. Anderson c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126 or via e-mail at tanderson@alcotec.com.
Automotive Laser Welding System Features Root Closing Technology

The Soutrac laser welding system for the production of tailored blanks used in auto manufacturing features a welding wire feed system controlled by a joint-tracking and root-measuring camera to fill root openings as large as 0.4 mm.

Soudronic Automotive 100
31640 Chendale Ave., Livonia, MI 48151

Dust Filter Encases Mini-Tower Computers

The DB8-18 filter system encases mini-tower computers up to 18-in. tall or wide to prevent dust and airborne particle contamination. The bag-like unit includes adhesive flaps for access to disk drives.

Dirt Bag, Inc. 101
25200 Renaissance Rd., Lakemont, MI 48913

Quiet Generators Introduced

The Ultra-Silent series of six diesel-powered generator models features soundproof housings to limit noise levels at 23 ft to 56–63 dBA at full load. The units range from 25 to 150 kVA and feature a minimum 24-h run time.

MQ Power 102
18910 Wilmington Ave., Carson, CA 90221


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A welder is a welder is a welder. Unless it's Blue. Strip away the cover, copper wire and controls, and you'll find the most dedicated, passionate and skilled people in the world. Empowered by a common sense of purpose — your success — Miller people take their work seriously. While you may never meet line reps Lori and Larry, or need an applications engineer like Kevan, one thing's for sure: there are 1200 other folks just like them who bleed Blue just for you. To learn more, visit MillerWelds.com or call 1-800-54-MILLER. And experience The Power of Blue for yourself.
Hardfacing Alloy Improves Abrasion Resistance

Postalloy 2813-SPL is a high-hardness nickel-based hardfacing alloy that can be used to surface nickel base materials to improve abrasion resistance in high-temperature applications.

Postal Industries
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Moveable Downdraft Table Keeps Breathing Zone Clean

The self-contained, roll-around Model 73-923 downdraft table helps eliminate ~k A • THE WORLD’S LEADER IN SUBMERGED ARC FLUX RECOVERY SYSTEMS. From Pipe Mills to small welding tractors, we have the right equipment for all your flux handling needs! System shown below, enables subarc welding and flux recovery of ID and OD of small cylinders.

Optional HPFR-3000-100H Pressure feed and recover system with 100 lb heated tank and 200 lb heated hopper.

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dust and smoke particulates from welding, grinding, and cutting operations. The 24-in. x 36-in. steel working top, with a 500-lb capacity, features a set of “U” channels that allow air to be drawn into the table’s filtration system at a rate of more than 500 ft/min.

Ace Industrial Products
5043 Farlin Ave., St. Louis, MO 63115

Metal Degreaser Is Biodegradable

BioT 300B is a metal parts cleaning solution that is noncaustic and needs no heating. The formulation is biodegradable, has a bath life of up to one year, and produces no toxic vapors.

BioChem Systems
8100 E. 22 St. N., #1700-3, Wichita, KS 67226

Ice Blasting System
Deburs Metal Parts

The company’s systems use high-pressure blasting of frozen water chips to deburr and clean metal components and assemblies. The compressed air that sprays the ice dries workpieces as they are blasted.

Universal Ice Blast, Inc.
533 Sixth St. S., Kirkland, WA 98033

Lightweight Travel Carriage
Can Be Used for Cutting or Welding

The Light’ n Bug will ride on any 6-in. V-groove track at a precise speed ranging from 4 to 85 in./min to perform cuts, bevels, or welds in plate.

BUG-O Systems
3001 W. Carson St., Pittsburgh, PA 15204-1899

Clamps Are Compatible with Auto Standards

Series PFC frame clamps feature a cam design that provides 11,250 lb of total clamping force for large, heavy parts. The clamps are compatible with North American Automotive Metric Standards (NAMS) tooling specifications.

PHD, Inc.
P.O. Box 9070, Fort Wayne, IN 46899

Digital Weld Monitor
Features Color Display

The MG3 series of weld monitors can provide simultaneous color display of data.
from two welding machines, including up to two channels each of current, voltage, and displacement. The monitors feature built-in Compact Flash support for capturing data.

Unitek Miyachi
1820 S. Myrtle Ave., Monrovia, CA 91016

Lighter Version of Spool Gun for Aluminum Welding Introduced

A lighter, more affordable version of the Spoolmatic® 30A spool gun for aluminum welding, the Spoolmatic 15A, features a 15-ft cable instead of 30 ft. The gun holds a 4-in. spool of 0.023-in. to ¼-in. diameter wire, with feed speeds from 70 to 875 in./min.

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

Handheld Monitor Detects Combustible Gases and Oxygen Level

The Pac Ex 2 measures and displays levels of combustible gases and oxygen volume-% and provides audible, visible, and vibrating alarms. A rechargeable battery provides more than 12 h of protection.

Draeger Safety, Inc.
101 Technology Dr., Pittsburgh, PA 15275-1057

Kit Available for Construction of Carriage for Longitudinal Welds

The BKT Builders Kit provides key components for a welding carriage with DC motor and solid-state control. The customer manufactures the track and mounting columns based on a supplied drawing package, or the company can custom build them. The carriage carries the GMA or SA welding process, with a load capacity of 300 lb at 12 in. from the faceplate of the carriage.

Jetline Engineering
15 Goodyear St., Irvine, CA 92618

Acoustical Curtain Systems Offer Modular Flexibility

Modular quilted acoustical curtain panels can be assembled into custom syst-
terns, joined by hook and loop fasteners. Noise reduction of up to 25dB can be obtained. The Class "A" fire-rated systems can be designed with roof panels, ventilation systems, and view windows.

Sound Seal
P.O. Box 545, Agawam, MA 01001

Positioning System Helps Measurement of Stress

The company’s rotation and positioning table aids in the measurement of residual stress and retained austenite processes. The bottom plate features motorized rotation and part-holding capability. Parts can be mounted, measured, removed, and remounted quickly.

American Stress Technologies
267 Kappa Dr., Pittsburgh, PA 15238-2817

Die Grinder Works

in Tight Spaces

The G500 is a compact straight grinder for deburring, sharpening, and grinding applications. Its 4.4-A motor provides 27,000 rpm no-load speed (16,000 rpm at rated load) to a hardened ¼-in. collet, which can accommodate a variety of attachments, including flexible shafts. The unit weighs 3.7 lb and measures 9 in. in length.

Die Grinder Works

Small, but Powerful, Robot Introduced

The ARC Mate 100iB/6S is a compact, six-axis welding robot with a payload capacity of 6 kg. The robot can work in tight spaces, such as in auto production, and can be mounted on floors, walls, angles, and overhead.

FANUC Robotics
3909 W. Hamlin Rd., Rochester Hills, MI 48309
Abrasive Wheels Promise Faster Cut Rate

NorZon Plus depressed center wheels combine zirconia oxide with seeded-gel abrasives using a premium bond to perform faster and longer than other wheels, the company says. The ½-in.-thick grinding wheels are available with 4½- to 9-in. diameters.

Norton Abrasives
P.O. Box 15008, Worcester, MA 01615-0008

Eyewear Fights Fogging

The company’s Genesis® safety eyewear features a ventilation channel and an anti-fog lens coating to prevent buildup of moisture in hot and muggy work environments.

Uvex Safety
10 Thurber Blvd., Smithfield, RI 02917

Welding Foot Control Reduces Fatigue

The FC200E foot control for GTA welding utilizes a new potentiometer design to reduce range-of-motion and operator fatigue. The control is available in models for Miller 14-pin and Lincoln 5-pin welding machines and includes a 25-foot cable.

ETI Systems
2251 Las Palmas Dr., Carlsbad, CA 92018

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Specifications
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Force feedback is the key to providing automated control of heavy-duty industrial robots for robotic three-dimensional friction stir welding.

Since its invention by The Welding Institute (Ref. 1), friction stir welding (FSW) has found applications in a number of industries, including automotive, railway, marine, construction, land transportation, and aerospace. While FSW has been shown to be capable of successfully welding titanium, steel, and dissimilar materials, most of the current applications involve the welding of aluminum alloys. Its process advantages stem from the fact that welding takes place in the solid phase below the melting point of the materials being joined. Benefits of FSW include low distortion, excellent mechanical properties, and, in comparison to arc welding, no fume, porosity, or spatter, and invariant welding performance in all positions. FSW can weld alloys that are very difficult
The Friction Stir Welding Process

Friction stir welding is a solid phase welding process in which a cylindrical-shouldered pin tool is rotated and plunged into the joint between two metals. The pin tool traverses the length of the weld and stirs and forges the two pieces together by plastic flow, heat, and force. The pin may take on any of a number of designs from a smooth cylinder to a threaded pin or to a tri-fluted configuration (Ref. 2). The rotational speed of the tool may vary from a few hundred rev./min to several thousand rev./min. The axial force required to counteract the pressure formed in the weld zone may vary from several hundred lb to several thousand lb (on the order of 1 kN to 15 kN). The mechanical power input to the rotating tool is typically on the order of 2 to 5 hp (1.5 to 3.7 kW). In addition to the axial force and torque acting on the tool, there is a transverse force acting toward the advancing side of the pin at an angle of 90 deg to the direction of travel, and a translational force acting at an angle of 180 deg from the direction of travel and in the same plane.

Feedback Control

To achieve successful robotic friction stir welding, it is important to maintain a consistent axial force on the pin tool. With a milling machine, or similar heavy-duty machine tool, this is done by simply moving the rotating pin tool precisely parallel to the parts being welded. With very low deflection in the machine tool arm and rigid tooling, the force is maintained without the need for force sensing and feedback. In concept, this could be done with a robot. In reality, however, there will be enough compliance in the manipulator arm that the force will change and it will be difficult to consistently maintain a proper axial force. The first solution that might come to mind for solving this problem is to sense the position of the tool relative to the workpiece and use feedback to alter the z-axis position as necessary to correct for any deviations from the pre-programmed path. As we will see, however, this approach proves not to be practical, because of the very small changes in position that equate to very large changes in force. Instead, a better approach is to sense the force directly and use feedback to maintain the force as the weld is being made.
Perhaps the simplest force control scheme is one that closes an "outer" force control loop around an "inner" position control loop, which may be the ordinary position control system of the robot manipulator. This approach to force feedback (Ref. 3) is depicted in Fig. 1. The basic position feedback associated with the robot remains unchanged. The pre-programmed z-axis position of the robot is changed, however, as required to maintain zero error between the desired force and the actual sensed force. This approach to force control is attractive because it does not require any modification of the basic robot kinematical control. As with any feedback system, however, the major concern is designing the system to be stable over its expected range of operation.

Stability of the feedback system depicted in Fig. 1 will largely depend on the indentation characteristic (force vs. position) of the rotating tool pressed against the workpiece. If this function is nonlinear, or time dependent, or if it varies as a function of the welding parameters (e.g., tool rotation rate and travel speed), then special considerations may be required to avoid oscillation of the manipulator arm as it tries to maintain the force. As we will see, experiments show that the indentation characteristic is indeed ill behaved.

Another approach that may be used is shown in Fig. 2. Here, the robot actuator torques are sensed and related to the force through the manipulator Jacobian (Ref. 4). This approach does not require external force sensing, but the computation time needed to compute the Jacobian is significant. This might result in delays comparable to the force/plunge delay and result in oscillations. This approach has been used by Smith (Ref. 5) and demonstrated to work well under proper conditions.

The Welding Setup

Some of the experiments were conducted at Vanderbilt University, and others were conducted at the Idaho National Engineering and Environmental Laboratory (INEEL). A description of each of the experimental setups is given.

The welds for the experiments conducted at Vanderbilt (Ref. 11) were done on a Milwaukee Model K horizontal milling machine. The spindle speed on this machine was adjustable from 20 to 1620 rev/min (2.1 to 169.6 rad/s) in discrete steps. The mill also had a three-axis travel bed with automatic feed along all three axes. Feed rates could be set from 0.250 to 60 in/min (0.1 to 25.4 mm/s), also in discrete steps. On a horizontal mill, the bed is positioned so that it is parallel to the tool's axis of rotation. For friction stir welding, the sample should be perpendicular to the axis of rotation, so a backing plate had to be fabricated that would allow the sample to be positioned accordingly.

The backing plate was made of 28 x 14 x 0.75 in. (711 x 356 x 19 mm) plate with I-beam reinforcements welded onto the back. Another smaller plate 14 x 7 in. (356 x 178 mm) was welded onto the larger plate that could be removed and replaced if it were damaged without replacing the entire fixture. The backing plate was constructed to accept samples from 3 to 6 in. (76 to 152 mm) in width and up to 24 in. (610 mm) in length. The samples were held in place by metalworking clamps that were bolted into the face of the backing plate.

The axial force was measured by means of a Muse Measurements M105 load cell that had an 8000-lb (35.6-kN) capacity. The load cell was located inside the tool holder at the base of the tool. The load cell contained four 350-Ω strain gauges in a Wheatstone bridge configuration. The output of the load cell went through an AD624 amplifier with a gain of 1000.

To measure the torque, two sets of two torsion gauges were located at the base of the tool. 180-deg apart to cancel out cross talk in the same manner as the bending gauges above.

Torsional gauges are similar to other gauges except that they are oriented at a 45-deg angle to the torsion axis. Torque causes a shear strain to take place about the torsion axis, which causes an elongation at a 45-deg angle from the direction of shear. In this way, the gauges measure the strain caused by the shearing action of the torque. A torque wrench was used to calibrate the tool in torsion.

To measure the other forces imparted to the tool, four strain gauges were mounted on the tool surface in full Wheatstone bridge configuration. The gauges were all nominally 350-Ω strain gauges from Vishay Micro-Measurements, Inc.

The tool used in the experiments conducted at Vanderbilt had a shank diameter of 1 in. (25.4 mm) with a smooth pin 0.25 in. (6.4 mm) in diameter and 0.225 in. (5.7-mm) long. A lead-in angle of 6 deg was used so that the edge of the shoulder would not gouge into the sample. The tool was designed so that when the pin was
plunged to within 0.008-0.021 in. (0.2-0.5 mm) of the backing plate, a shoulder area of 2-3 times the material thickness would be touching the sample. The tool detail is shown in Fig. 4.

The tool was made from H-13 tool steel. The part was roughed to size on a lathe and then hardened to an approximate Rockwell C hardness of 48. The part was then ground to exact size using a centerless grinder to ensure that runout or eccentricity would be minimal.

To get the excitation and signal voltages between the rotating gauges and their stationary sources, a set of Fabricast type 19810 slip rings was used. The signals were passed from the slip rings through wires in the drawer. The rings were made of coin silver and the brushes made of graphite. These slip rings proved to be dependable and had very little noise. The slip ring assembly had a set of ten rings, and two rings each were used for the positive and negative reference voltage. The remaining six rings were used for the positive and negative signal voltages for the bending, torsion, and axial strain gauge circuits.

The experimental setup at Vanderbilt is shown in Fig. 5 with a weld in progress (Ref. 12). Plates of 6061-T651 aluminum, nominally 0.250-in. (6.4-mm) thick were friction stir welded bead on plate. The samples were 3-in. (76.2-mm) wide by 24-in. (510-mm) long. Three holes 0.036 in. (0.91 mm) in diameter were drilled to a depth of 0.125 in. (3.2 mm) from the bottom side of the sample to accept thermocouples. The holes were located 4-in. (101.6-mm) apart along the centerline of the sample with the hole pattern shifted to one side by 2 in. (50.8 mm). Slots, 0.0625 in. (1.6 mm) in width, were milled in the underside of the sample to allow thermocouple wires to pass from the hole to the edge of the sample. For most of the experiments a starter hole was drilled in the sample so that the tool would not have to be plunged, and its depth could be set more precisely.

The experiments conducted at INEEL were made on a Willis vertical CNC milling machine modified for friction stir welding. The mill setup was similar to that at Vanderbilt except that the tool axis is in a vertical position, and the workpiece is horizontal.

The forces and torque acting on the tool pin were measured with a Kistler Model 9124B rotating cutting force dynamometer. The dynamometer is a very accurate four-component load cell that is assembled with a high preload to measure forces with virtually no displacement.

A view of the dynamometer and CNC mill is shown in Fig. 6. The top of the dynamometer is inserted into the milling machine spindle where the tool holder is normally placed. An integrated spindle adapter is attached to the bottom of the dynamometer to facilitate the attachment of various size tools. The dynamometer has the ability to measure the forces along the x, y, and z axes, and also the moment about the z axis. Voltage is supplied to the load cell via inductance, and the force data is transmitted from the load cell to a signal-conditioning module by RF telemetry to a pickup located at the periphery. The signal-conditioning module filters and scales the forces appropriately before sending the data to the data acquisition software. Angular position is calculated by using a proximity sensor located along the circumference. It outputs a pulse once per revolution when a notch cut into the shoulder of the dynamometer passes by the sensor. The angular position is needed to resolve the output of the load cell from polar to Cartesian coordinates.

The samples used for the experiments conducted at INEEL were 12 in. (305 mm) in length by 3-in. (76.2-mm) wide. The samples were made shorter to correspond to the length of the backing plate being used. All welds were made bead on plate, as they were at Vanderbilt. The material was 6061-T651 aluminum.

The tool used at INEEL was shorter than the tools used at Vanderbilt to decrease the bending moment on the milling machine. Since the tools were shorter, the heat loss from the surface would be lower. In order to have the heat loss approximate that of the larger tool, grooves were cut in the tool to increase the surface area.
Experimental Results

To check the conclusions drawn from the Nunes, Berstein, and McClure rotating plug model (Ref. 6), experiments were conducted at INEEL at different tool rotation rates and travel speeds. In each case the force and torque were measured and the spindle power was computed from the measured data. Figure 8 shows the spindle power for three different spindle speeds for a travel speed of 4 in./min (1.7 mm/s). These experiments were conducted with the smaller tool design shown in Fig. 7. As can be seen, the power is approximately 1.3 kW (1.75 hp) for all three spindle speeds — 750, 1250, and 2000 rev./min (78.5, 130.9, and 209.4 rad/s). The corresponding axial force is plotted in Fig. 9. It can be seen that the axial force decreases by approximately a factor of 2 when the spindle speed is increased from 750 to 2000 rev./min (78.5 to 209.4 rad/s). Other tests were conducted at higher travel speeds, and while the power input remained fairly constant for varying spindle speeds, the results did not show the power as constant as that in Fig. 8. Extensive additional testing will be required to fully characterize the axial force vs. tool rotation rate relationship. Certainly these preliminary tests support the rotating plug model conclusions, however.

Another purpose of the experiments conducted at INEEL was to characterize the force vs. position indentation characteristic. One such set of tests conducted at INEEL is shown in Fig. 10. This figure shows the axial force vs. changes in axial position for welds made with the tool design shown in Fig. 7. The spindle speed was 700 rev./min (73.3 rad/s), and the travel speed was 2 in./min (0.85 mm/s). Step changes of 0.002 in. (0.05 mm) were made in the axial position, and the resulting changes in axial force were measured. An examination of the result shows that there is a delay between position change and force change, and that the force changes substantially for the relatively small change in position. It is also noted that the force tends to eventually return to approximately where it started. This latter phenomenon is due to the tool simply plunging into the material as the position is increased, resulting in excess flash but no significant increase in force other than in the initial transient.

In another series of experiments conducted at INEEL, the axial position of the tool was incrementally varied from too much penetration of the shoulder into the material resulting in excess flash, to not enough, resulting in a surface void. It was found that relatively small variations in axial position — approximately 0.015 in. (0.38 mm) — produce large changes in the weld. These relatively small changes in axial position are also reflected in rather large transient changes in axial force. A conclusion one can reach from these tests is that force control is a more appropriate feedback approach than position control, as stated earlier.

In many current FSW applications, the beginning and end of the weld occurs on start and stop tabs that may be removed later. As FSW techniques evolve, however, we can expect an interest in controlling the weld during the start/stop portions, as well as the weld itself. This will probably call for force control during the weld plunge, for example, as shown in Fig. 11. This experiment was conducted at Vanderbilt using the larger tool design shown in Fig. 4. In this experiment, the pin tool was plunged into the metal at a rate of 0.25 in./min (0.1 mm/s) and a rotation rate of 400 rev./min (41.9 rad/s). It can be seen that the plunge force reaches a maximum value in excess of 3000 lb (13.3 kN) before dropping back to less than 1000 lb (4.4 kN) during forward travel. This weld was made without any kind of force feedback. It shows the demands that would be placed on a force feedback control system if control were attempted during the full start/weld/stop cycle. The indentation characteristic (axial force vs. position) is quite different during the weld than it is during the start. Furthermore, it can be expected to vary substantially for different weld travel speeds and tool rotation rates, which we might want to vary to enhance the weld start/stop. It is interesting how these control problems parallel so closely
were conducted at INEEL at 1750 rev./min (183.2 rad/s) and travel speeds varying between 4 and 64 in./min (1.7 and 27.1 mm/s). The axial force and power are shown in Fig. 12. Both the axial force and spindle power are larger than the data plotted in Figs. 8 and 9. This is perhaps attributable to a different temper (6061-T6511) for the material used in obtaining the results shown in Fig. 12. This again shows the rather wide variations that can be expected in the indentation characteristic.

While control system problems might arise under conditions of widely varying operating parameters, it is a relatively straightforward task to achieve stable control when the parameters, i.e., tool rotation speed and travel speed, do not vary substantially over the weld. Smith, Hinrichs, and Crusan (Ref. 13) have reported a robotic FSW system based on the use of an ABB IRB 960 articulated robot arm — Fig. 13. This robot has a 500-kg payload. The spindle and motor drive for rotating the pin tool are attached to the end plate of the manipulator. The spindle is designed to accept the forces (both axial and radial) required for FSW, and it additionally contains force sensing for force feedback control. Smith, Hinrichs, and Crusan (Ref. 15) have reported the use of a parallel robot for robotic FSW with force feedback control. They report excellent results with the system.

**Conclusions**

Robotic FSW requires feedback control to compensate for any compliance in the robot or fluctuating. Force feedback is chosen over position feedback because of the very large changes in force that equate to rather small changes in axial position. The indentation characteristic (force vs. position) of the rotating tool acting against the workpiece is a forward loop "gain" of the feedback control system, and directly affects the closed-loop stability of the system. The indentation characteristic varies as a function of welding parameters, and is relatively ill behaved under widely varying conditions.

The axial force requirements on the robot may be reduced by operating at increased tool rotation speeds. It is shown that the axial force of FSW may be expected to go down as the tool rotation speed goes up. However, complete characterization of this relationship has not yet been established. The axial force is also shown to increase with travel speed. For robotic FSW there may be a tradeoff between travel speed and axial force requirements.

Robotic FSW systems are available that have been demonstrated to be capable of welding 3-D contours in various positions with excellent weld control through the use of force feedback (Refs. 13, 15). As techniques and procedures continue to be developed for starting and stopping the friction stir weld, increased demands may be expected to be placed on the feedback control system.

---

**Modeling the Forces and Torque Acting on the Tool**

Nunes, Bernstein, and McClure (Ref. 6) have proposed a "rotating plug" model of the FSW process. With this simplified model, metal in the vicinity of the rotating tool is represented as a superposition of two flows: 1) a primary flow consisting of a plug of metal rotating with the pin tool and shearing over a cylindrical surface (assuming a cylindrically shaped pin), and 2) a secondary flow driven by threads on the pin (assuming a threaded pin design) and resembling a vortex ring around the pin. The metal transport around the pin takes place by a wiping action on the shearing surface of the plug (Ref. 7). The flows associated with the rotating plug model (Ref. 6) are depicted in Fig. 3. The thickness of the inner volume of the rotating plug is shown greatly exaggerated relative to experimental observations (Ref. 8). Hence, for purposes of developing a simplified understanding of the forces and torque acting on the rotating tool, the rotating plug may be assumed to have the same dimensions as the pin tool itself. Furthermore, the secondary flow may be neglected for smooth pin designs (or threaded pins, as well, for a first-order analysis).

With these assumptions, the torque acting on the pin tool is computed as a function of the forces acting between the rotating plug shearing with respect to the adjacent metal. If we let the rotating plug be taken approximately as the tool/workpiece contact surface and include the shoulder contact as well as contact at the bottom of the pin, the torque on the plug rotating against boundary shear stress $\tau$ is given (Ref. 6), approximately by

$$M = \int_0^R 2\pi \tau d\tau + 2\pi R^2 \tau + \int_0^R 2\pi r^2 dr = \frac{2\pi R^3}{3} \left(1 + \frac{r^2}{R^2}\right) \tau$$

(1)

where $M$ represents torque, $r$ is the pin tool radius, $R$ is the shoulder radius, $\tau$ is the pin tool depth, and $\tau$ equals shear flow stress.

The mechanical power input to the tool is essentially given by,

$$P = M \Omega$$

(2)

where $\Omega$ equals the angular velocity of the pin tool.
There are other mechanical power inputs, principal among which is the translational power, but these are of a lower order of magnitude and can be neglected. Substituting the torque, given in Equation 1, into Equation 2, the power input can be expressed as:

\[ P = \frac{2\pi R^3}{3} \left( 1 + \frac{R^2}{R^3} \right) \tau \Omega \]  
(3)

The mechanical power input is balanced by the thermal loss \( Q_b \) and the plastic work \( Q_p \). \( Q_b \) may be neglected in comparison to \( Q_p \) (Ref. 6). \( Q_p \) is comprised of the following components: 1) conduction loss to the workpiece, 2) conduction loss to the tool, 3) conduction loss to the anvil, and 4) convection heat loss as the tool moves from hotter to colder metal. Each of these is a direct function of the shearing zone temperature, which varies only a small amount over a wide range of operating conditions (Refs. 6, 9). Therefore, the power input remains approximately constant over a wide range of spindle speeds.

If the power input is approximately constant, Equation 3 shows that an increase in spindle speed \( \Omega \) must be balanced by a decrease in shearing flow stress \( \tau \). All of the forces (axial, translational, and transverse) and the input torque (Equation 1) vary directly as the shearing stress (Ref. 4). Nunes, Bernstein, and McClure (Ref. 6) model the axial force as the indentation force needed to push an indenter into a metal surface (Ref. 10), i.e., as

\[ F_i = 6\pi R^2 \tau \]  
(4)

Therefore, one would conclude that a reduction in axial force could be achieved by an increase in the spindle speed. It has not yet been established, however, how far one can go in load reduction by increasing spindle rotation rate. However, as seen in the experimental results, early experiments certainly support this modeling observation.

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References

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Are Your Parts Ready for Robotic Welding?

Not all parts are ready, but this checklist will help you decide if robotics is a good fit for your application

BY CHUCK KEIBLER

A great deal of planning and preparation must go into your application before considering robotic welding.

From the moment you first consider automating a welding process, you have already entered the planning stages. You first need to ask yourself, “Are my parts ready for robotic welding?” This critical question leads to many others a qualified robotic integrator can help answer.

CHUCK KEIBLER (ckeibler@gensysgrp.com) is Vice President-Engineering at Genesis Systems Group, Davenport, Iowa.

Questions to ask about how a part is welded include the following:
1) If it is an existing part that was welded manually before, how will it fit into a robotic workstation for automated welding?
2) If the part is new, how can it be designed for robotic welding?
3) What welding process is currently being used (gas metal arc, gas tungsten arc, submerged arc, etc.), and what are its present challenges?
4) Are there root openings that an operator must fill in, or are there distortion problems?
5) If there are root opening and distortion concerns, are they consistent or predictable?
6) What are the weld requirements?
7) Are there special visual or strength requirements?

Then, ask questions from a robotics standpoint.
1) Can or should the process be changed?
2) Is there a way to make the process better when switching from manual to robotic welding?

When a part experiences problems — such as fitup, distortion, or repeatability, those problems only get worse with robotic welding if they are not addressed at the outset of planning. Through all of the planning stages, return on investment (ROI) must be considered and clearly defined.

Deciding Factors

Other keys to determining whether or not a part is ready for robotic welding include (but are not limited to):
1) Part design This determines the type of robotic workstation required and the type of positioner necessary. The positioner dictates how a part is presented to
the robot for welding. Some parts require multiaxis positioning with coordinated motion; others can utilize single-axis simultaneous positioning to reposition the part during the weld cycle; others require no positioning at all.

2) **Preferable joint designs.** Some joint designs are preferred over others in robotic welding. During the product design (or redesign) stage, weld joints should be reviewed for robotic welding. The goal should be to provide weld joints that are as repeatable as possible and as easy to weld as possible for the robot. For example, lap and fillet welds are more desirable types of welds because melt-through and head sizes are easier to control. An outside corner weld is difficult because it can lead to gaps or one part can slide over another. A groove weld is less desirable because of issues such as part fitup, weld volume variations, and melt-through.

3) **Repeatability.** Part and weld joint repeatability are important related factors. Obviously, joint repeatability is magnified with any variations in part repeatability. Typical weld joint repeatability should equal one-half the wire diameter used. A 0.045-in. welding wire is commonly used in robotic welding, so repeatability of the joint should be ±0.023 in. A greater variance in repeatability may require adaptive robot controls or procedures. Such adaptations may include touch sensing with the weldwire, through arc joint tracking while welding, arc-on or arc-off vision, or a multistep welding procedure using progressive fixtures (progressively building a part with subassemblies before putting them all together).

4) **Weld head access.** A robotic welding integrator can assist in considering possible alternatives for the weld head access to a part's weld joint. It is possible a weld head on a robotic arm may not be able to access all areas of all candidate parts.

### Manufacturing Processes for Part Repeatability

Other factors for determining if robotic welding is appropriate for a simple part relate to how the part is manufactured before it is welded. Common manufacturing processes include laser, plasma, or oxyfuel cutting; stamping; sawing; shearing, and bending.

With oxyfuel cutting, parts may vary 1/8 in. When oxyfuel cut parts are assembled in the welding fixture, the tolerance is high. Gaps often appear, and the weld joints tend to vary significantly in their location.

Plasma cutting reduces part variation to 1/16 in. and allows the tolerance to be lower than with oxyfuel cutting but still can cause the problems listed above.

Laser cutting and high-definition cutting are preferable because the variation is as low as 0.005 in. The cut tolerance is low and the part repeatability is high.

A simple part also can be stamped or formed with a press brake. In general, these processes are very repeatable. Be sure to watch for variation in the angles of the part caused by springback. Putting a reverse bend in a stamped or formed part can reduce the variation.

Roll forming, which is used infrequently with heavy-gauge parts but more often with light-gauge parts, produces variations from batch to batch and has the same angle challenges as stamped parts. Springback makes bend angles less certain. If it is possible to avoid formed parts, do so. The more forming done, the more problems are likely with joint location. As a result, the part generally won't repeat as well as those without forming.

Sawing and shearing are two more ways to process simple parts. Shearing can produce a very good or very bad part, depending on the type of equipment used. A good shear can work well, but a shear that is not set up correctly can cause variations from part to part and/or batch to batch.

The same holds true for sawing. A high-quality cut length is possible with a saw, but if you bundle cut with a band saw, a poor cut is more likely because the saw typically wanders as it goes through a stack of parts.

These issues must be understood when designing a part. You need to understand what processes are being used in the shop for simple parts and how those processes affect the welding process. Address all of these factors at the beginning with the simple parts in order to weld another part (and the robot envelope has been dynamically limited). Achieving this balance comes only by discovering the robot's welding capabilities on the specific part. Does each weld repeat well? Are the root openings too large for the robot to fill? It takes time to determine how these issues affect the robot welding once a system is installed.

A good rule of thumb is the 80/20 rule. The operator does up to 20% of the welding to improve the overall quality by handling the problem welds caused by the tolerances that cannot be designed out. The robot does the remaining 80% of the work.

### Finding Work Balance between the Robot and Operator

Optimizing the work balance between the robot and operator takes time. In the case of a larger part with a longer cycle time, the operator may perform manual welding, such as tacking or finish welding in the robot fixture, or other manufacturing functions. This is accomplished safely since the robot is not active in this station (it has moved to a second station to weld another part) and the robot envelope has been dynamically limited. Achieving this balance comes only by discovering how the robot's welding capabilities on the specific part. Does each weld repeat well? Are the root openings too large for the robot to fill? It takes time to determine how these issues affect the robot welding once a system is installed.

A good rule of thumb is the 80/20 rule. The operator does up to 20% of the welding to improve the overall quality by handling the problem welds caused by the tolerances that cannot be designed out. The robot does the remaining 80% of the work.

### Keep Your Goals in Mind

Not every part is an ideal candidate for robotic welding. Keep in mind the primary goals for automation, such as reducing costs, increasing throughput, and improving quality and consistency. The robotic system integrator's goal is to gain as much information as possible about your goals, manufacturing processes, and priorities to help you determine whether a part is ready for robotic welding.
World's Leading Developer and Manufacturer of High Nickel Alloy Welding Products
Automatic Multiwire GMAW Multiplies Productivity

Doubling welding wires can more than double production line throughput

BY TIM MOREHEAD
Originally popular in submerged arc welding, tandem-wire technologies were extended to the automated gas metal arc welding (GMAW) process in the early nineties. Since their introduction, more than 1000 tandem-wire GMAW systems have been installed worldwide, most replacing single-wire systems that had been pushed to the limits of their weld metal deposit rate and productivity range — Fig. 1.

The tandem-wire GMAW process employs two electrically isolated wire electrodes, one behind the other in the direction of welding — Fig. 2. The first wire electrode is referred to as the “lead electrode” and the second as the “trail electrode.” The spacing between the two wires is close enough to enable them both to deliver metal to a single weld pool. The lead electrode generates most of the base metal root penetration, while the trail wire controls the weld pool for bead contour and edge wetting while it adds to the overall deposition rate.

The process works best with a large-diameter lead wire and a small-diameter trail wire. The larger lead wire may represent as much as 65% of the total process deposition rate while providing greater process penetration. Focused on the back edge of the molten weld pool, the trail wire, drawing a lower current, is better able to cool and control the pool. Sometimes wires of equal diameter are specified because of inventory constraints or if the welding direction is reversed somewhere on the weldment, but this compromise limits travel speed and reduces the productivity of the process — Fig. 3.

Tandem-wire GMAW depends on specialized power control software to manage the stable operation of two independent direct current welding arcs working in very close proximity, where disruptive electromagnetic influences would cause severe instability if not precisely regulated.

Equipment Configuration

In order to provide individual parameter control for each of two separate, electrically isolated welding arcs, a pairing of equipment is required: two specially designed inverter power sources, two wire drives, and two separate welding wire payoff sources — Fig. 4. The power sources rely on fast digital control and specialized
software. Welding parameters are set at the power sources via digital communication from a programmable logic controller associated with a dedicated hard-automation workcell or by a robot controller.

The tandem-wire welding gun (Fig. 5) is a critical component of the system, engineered with specific contact tip alignment and spacing to achieve proper arc control. To withstand high-amperage, high-duty-cycle production runs, welding guns are generally rated at the total current flowing in both electrode wires — typically in the 600- to 1200-A range. The maximum current specified for each wire is typically in the 400- to 800-A range.

**Process Benefits**

The tandem-wire GMAW process can dramatically increase travel speed in sheet metal welding, and significantly increase weld metal deposition rates in heavy plate welding. The increased productivity of the tandem-wire GMAW process can improve the profitability of existing automation. In addition, it may justify the cost of new automation equipment since it can reduce the number of weld stations that would otherwise be needed and shorten payback periods associated with investment in welding automation.

Welding operators involved in thin-gauge metal industries such as automotive, tank, and general sheet fabrication, are traditionally faced with two quality issues — melt-through and lack of metal follow characteristics — when pushing travel speeds to the limit.

Operating at speeds in excess of 100 in./min (with 0.040- to 0.120-in. materials), the tandem-wire GMAW process addresses both of these speed-limiting issues. Distributing the welding current over two wires allows the lead wire to generate the required joint penetration while the trail wire rides on the back edge of the lead weld pool, creating added fill as well as additional force against the weld pool for better follow and wetting characteristics. This riding of the weld pool with the trail arc provides excellent root filling capabilities, especially important to industries processing large numbers of stamped or formed parts — Figs. 6, 7.

In heavy plate fabrication, the tandem-wire GMAW process can represent a 30 to 80% increase in deposition potential compared to single-wire processes — Fig. 1. The tandem-wire process typically employs smaller-diameter (0.035 to 0.062 in.) electrodes. As higher welding currents are applied, the electrode melt-off rate rises geometrically. For a given current draw, the melt-off rate for the tandem-wire process is greater than that of a single wire of larger diameter. This higher melt-off rate leads to higher production throughput, while the lower amperage draw (and lower heat input) reduces plate distortion and cooling time between multipass welds. The process is capable of producing X-ray quality welds with excellent mechanical properties — Fig. 8.

**Return on Investment**

The tandem-wire GMAW process was designed for use in automated welding cells or automated lines. Investment in these high-volume production lines is a capital expenditure that must be cost-justified. Welding-speed-critical floor-to-floor time of parts is an important factor in the equation. Compared to single-wire processes, tandem-wire GMAW's higher travel speed capabilities can help justify greater capital expenditures and accelerate equipment payback periods — Figs. 9, 10.

Tandem-wire GMAW systems can reduce the cost of new production lines by meeting output needs with fewer welding stations. This is particularly true for high-volume production lines producing automotive components or similar parts where tooling and part-handling equipment constitutes a sizeable portion of the initial installation.
Accelerated equipment payback time
Tandem VS single wire GM AW

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Fig. 7 — Truck side panels being welded by a system using robot touch sensing software to locate the weld joint and real-time through-the-arc joint tracking software. The tandem-wire system, welding at an average speed of 60 in./min, replaced a single-wire robotic system that was averaging 24 in./min.

Travel Speed Comparison
Tandem dual-wire GMAW Vs Conventional single wire GMAW

Fig. 8 — Eight-ft truck bolster plates being joined with tandem-wire GMAW. A ½-in. fillet weld is placed on both sides of a ¼-in.-thick vertical support member. The tandem-wire process increased production from 5 to 6 units per day to 25 units per day. The process uses two 0.045-in.-diameter welding wires depositing 28 lb/h.

Fig. 10 — Production capabilities of single-wire vs. dual-wire GMAW.

cost. Using fewer welding stations with a higher per-station throughput may reduce the cost of expensive tooling and handling equipment. Additionally, the expenses of upkeep and maintenance time for managing consistent part dimensions coming off of duplicate tooling sets are minimized.

Cost-justification for workcells welding large components (for example, earth-moving equipment or offshore drilling rigs) is based more on welding time than part count. These cells utilize capital-intensive positioners to handle large, heavy weldments that can take two or more hours to weld, often in a flat or horizontal position that allows access for only one robot per cell. In order to improve the return on these large cells, overall welding time must be reduced by increasing the weld metal deposition rate. The industry has responded by replacing single-wire robotic systems, with average deposition rates of just 15–20 lb/h, with tandem-wire systems operating in the 28–34 lb/h range. The increased weld metal deposition rate has been used to justify the cost of purchasing new, more technically sophisticated workstations.
accompanied challenges from its customer, Caterpillar, Inc., to improve quality at a lower cost, while still remaining profitable. Wrayco, Inc., needed to develop an improved welding process for building bulldozer fuel tanks. To facilitate the process, the Slow, Ohio, steel fabricator collaborated with ABB’s Welding Systems Division, Ft. Collins, Colo., to design and build a robotic welding cell.

Wrayco builds the fuel tanks for Caterpillar’s Model D6 through D10 Track-Type Tractors (bulldozers). The fuel tanks feature capacities ranging from 100 to 300 gallons and numerous exterior brackets and fittings that require leakproof welds. The largest tank, which weighs 1000 lb dry, has joints in excess of 8 ft. By assembling and robotically welding the tanks in a 40- x 120-ft bay, the company eliminated difficult and time-consuming part positioning and handling associated with manual welding. Since the tanks are produced in one bay, movement to various weld booths throughout the shop was eliminated. This, in turn, simplifies the process, saves time, reduces cost, and minimizes handling and subsequent part damage.

Creating a Robotic Solution

Although Wrayco has built fuel tanks for Caterpillar equipment for nearly two decades, the geometries and numerous difficult-to-reach areas of these tanks presented unique challenges. The company analyzed the tank joint configurations, which included long lap joints as well as gaps caused from stackup tolerance, yielding extensive variation for a robotic process.

It was decided a carefully designed robotic arc welding system would ensure production capacity and quality. After developing a preliminary design, the specific cell requirements were determined based on the positioning that was required. RobotStudio™ software, an interactive 3-D, graphics-based simulation tool for designing, programming, and optimizing robotic applications, was used to develop several cell configurations. The cell configurations were then shown to Caterpillar.

The cell is configured with an inverted IRB 2400L robot, which is suspended from a rotating column assembly — Fig. 1. Below the robot, two Orbit IRBP 2000SH positioners are mounted to the floor, one placed in each station. The steel fabricator then decided on various options, including a PowerWave 450 power source from The Lincoln Electric Co., AWC (advanced weld control) through-the-arc joint tracking, and SmarTac touch sensing — Fig. 2.

Peripheral to maintain the welding torch included BullsEye®, a device that defines the tool center point; an automatic torch cleaner and wire snipper; and an air blaster that removes spatter from the welding nozzle.

Saving Programming Time

With the software, off-line programming and simulation of robot systems can be done using a standard Windows®-based PC. The steel fabricator used the
software to complete the programming and design the fixture while the customized cell was being built.

Rick Monaco, a robot programmer, attended training at ABB to learn to work with the software effectively and efficiently. He noted the software was an asset in designing tooling because the part to be programmed can be attached in midair and move with the positioner (requiring no graphical attachment) and it offers the ability to bring in new part programs without having to interrupt the flow of current production.

"When the robot arrived at Wrayco, I felt very familiar with the cell, as if I had already worked with it. Although I had never jogged an inverted robot, it felt natural in a short time because of my simulation work. The movable work object and its coordinates became quite clear. Traditionally, inverted robots are challenging to program using conventional methods. The simulation software minimized these difficulties," said Monaco.

Software capabilities also enabled the company to make changes once the system became operational without production interruption. Monaco recalled a situation in which a boss and fitting on the side of one of the fuel tanks were not included in the original program. He programmed the fitting and boss off-line, transferred the file directly from his PC to the controller, did a quick touch-up, and incorporated it into the program with minimal production interference.

Since programming was completed ahead of time, the robotic cell was producing the D6 fuel tank to meet daily shipping requirements within a week after installation. The welds showed smooth edges and uniform characteristics — Fig. 3. Weld penetration profiles were sampled to ensure subsurface and surface characteristics were being achieved.

**Robotic Choreography**

The process for building a fuel tank begins with the presentation of a tack-welded assembly to the robot. The assembly is crane lifted into a cradle that has the same profile as the tank's bottom. (Different cradles are used for each model of tank.) The operator can hand lift the different cradles into the positioner and locate them in place quickly with a couple of attachment pins. This cradle is compact in size, allowing for maximum robot reach with minimal interference.

Once the tank assembly is in the cradle, the operator sets the safety lights and depresses the start button. Depending on the model, the run time varies between 30 and 60 min. While the robot is welding the part, the operator is performing final tank assembly, which is required because the mounting plates located on the outside of the tank have seams under them that must be welded and leak tested prior to being attached. The robot cell features two stations: as one station is being loaded/unloaded, the robot welds on the opposite side. The average size of the program (for each tank assembly) contains more than 1000 lines of code. The robot reads the code and transforms it into motion and process. Portions of the program define the variable location of the parts through data manipulation, which is derived from tactical touch sensing. This data rotates and translates the program coordinates, therefore adjusting to part variation. Thus, the part can be set in the cradle and be off an inch or more without affecting the outcome. Additionally, the code controls the arc welding process, robot movement, and various inputs and outputs.

Total integration of the equipment and positioner make it possible to fully coordinate the welding process and positioner movements from one control unit. Coordinated motion enables the robot and positioners to weld joints that are off center with a fully controlled process speed. With the positioners' acceleration and speed of rotation, they can achieve higher production output and improved quality.

Within the cell, a power source is interfaced to the robot controller, which features joint tracking that monitors the welding process and adjusts the weld path using through-the-arc sensing technology. The robot's controller includes an Ethernet card, which enables PC communication and is ideal for program transfer from a PC. This provides a method for off-site data storage in the event of program corruption. Both skyhook positioners have manual jog capability, which can be used when the robot is working in the opposite station. The robot features collision detection, which eliminates the need for cumbersome torch breakaway devices.

According to Monaco, the spherical rotation of the tank mounted to the skyhook positioner, enhanced by the robot's coordinated motion, creates a truly impressive choreography. The joint tracking is an asset when fitted with the power source that has the ability to apply welds that have fit-up variation and positional inaccuracies. "Anyone who is hesitant about implementing robotics because of part variation has not witnessed the versatility of today's robotic technology. This technology is only limited by the user's imagination," said Monaco.
The Navy Joining Center (NJC) and more than 275 exhibitors participated in the AWS Welding Show 2003. Celebrating 50 years of service, the Welding Show was held April 8-10 in Detroit, Mich., with the theme, “It's the Whole World of Metal Joining.” Within the exposition, NJC shared with conference attendees its mission and an overview of new joining development activities underway for the U.S. Navy.

The NJC, as a Navy Manufacturing Center of Excellence (COE), provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to the U.S. Navy, U.S. Department of Defense, and the defense-manufacturing base. This is accomplished in a cooperative work environment with industry, academia, and technology development organizations. From development to deployment, NJC projects involve process development, design and modeling, automation, sensors and control, inspection, and repair of metallic and nonmetallic materials. Serving as a corporate residence of expertise in materials joining, the NJC also provides consultation to the U.S. Navy and its subcontractors.

Several projects were highlighted in the NJC exhibit that are benefiting the Naval Sea Systems Command (NAVSEA), the Naval Air Systems Command (NAVAIR), and the Marine Corps Systems Command (MARCOR). A project of keen interest benefiting NAVSEA and the shipbuilding industry is “The Reduction of Shipyard Worker Exposure to Welding Emissions.” Harvey Castner, NJC director and recently elected AWS director-at-large, presented this project activity during a Safety and Health seminar session. The project demonstrated that a reduction in exposure to welding emissions can be accomplished by the development of low-fume flux cored arc welding electrodes, pulsed gas metal arc procedures, and improved fume extraction and ventilation.

Other projects highlighted in the exhibit benefiting NAVSEA were gas tungsten arc welding (GTAW) fluxes for enhanced penetration, distortion, and accuracy control through thermal tensioning, adaptive weld mechanization for ship erection, and adhesive bonding of composite to steel structures. Project development activities highlighted for NAVAIR were GTAW fluxes, translational friction welding for turbine engine manufacture and repair, and adhesive bonding for aircraft primary structures.

Several projects are being performed for the Marine Corps. Of primary interest are the weld development activities for the Advanced Amphibious Assault Vehicle (AAAV) and the XM777 Howitzer, which will fire 155-mm projectiles and is to be transportable by a wide variety of NATO helicopters. Advancements in friction stir welding and gas metal arc welding are contributing to improvements in productivity and performance for the AAAV. Similar project development activity is being performed to improve productivity and performance in GTAW automation for fabrication of titanium structures on the howitzer.

During its operation over the past ten years, the NJC has maintained an outstanding record of implementing new technology, providing customer satisfaction, and generating an increasing demand for new projects by improving affordability and reliability for the U.S. Navy through emerging materials joining technology.

For more information, please contact Larry Brown at (614) 688-5080 or via e-mail at larry_brown@ewi.org.

Mark Your Calendars

What: Navy Joining Center Materials Joining Technology Review and Open House
When: September 23
Where: The Navy Joining Center at Edison Welding Institute 1250 Arthur E. Adams Dr. Columbus, Ohio

Don’t miss it! Space is limited, so register today. To register, call Debra Knight at (614) 688-5170.
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Magnetic Fields in Arc Welding

Magnetic fields interact with arc current to produce force fields that strongly influence arc blow, plasma streaming, and metal transfer. Magnetic flux may be associated with the arc current, produced by residual magnetism in the material being welded, or result from an external source interacting with the welding arc.

Lorentz force determines the effects of external magnetic fields on welding arcs. The usual effect of external magnetic fields is arc deflection. The arc behaves as a flexible conductor with an elastic stiffness that resists the overall Lorentz force. The arc deflects from a fixed point at the electrode tip to the base metal. The magnitude of the deflection is proportional to the applied field strength.

Think of arc deflection as flux lines encircling a conductor, adding vectorially to the applied field lines on one side and canceling applied field lines on the other side. The arc will deflect to the weak flux side. Arc deflection forward in the direction of travel may result in a wide, uniform, but less penetrating weld. This condition might result in improved bead appearance and reduced undercut at high welding speeds. A backward arc deflection can have a detrimental effect of more undercut and excessive reinforcement.

The proximity of multiple arcs can induce arc deflection. A two- or three-wire submerged arc operation utilizes the magnetic fields of neighboring arcs to obtain high-travel speeds without undercut. Alternating magnetic fields cause the arc to oscillate back and forth across the weld axis.

Under certain conditions, the arc is forcibly directed away from the point of welding, resulting in a phenomenon termed arc blow. Generally, arc blow is caused by two conditions: current flow changes direction as it enters the work and is directed to the work lead, or there is an asymmetric arrangement of magnetic material around the arc.

Arc blow cannot always be totally eliminated, but it can be controlled or reduced to an acceptable level. In Fig. 1, the lines of force are represented schematically as circles concentric with the current path. They are concentrated on the inside of the bend in the current path, consequently, the magnetic field is much stronger on the side of the arc toward the workpiece connection.

Figure 2 shows magnetic flux takes the shortest air distance, which is between the beveled edges of the joint. When the arc is near the end of the joint, the magnetic flux becomes more concentrated between the arc and the ends of the plates. Figure 3 illustrates the effect of arc blow.

When welding with alternating current (AC), the magnetic effect is lessened by eddy currents induced in the work, as shown in Fig. 4. Low voltage results in a short, stiff arc that resists arc blow better than a long, high-voltage arc.
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Friends and Colleagues:

We’re into the eleventh year of the program, and 99 individuals have now entered into the fraternity of Fellows. Again, I encourage you to submit nomination packages for those individuals whom you feel have a history of accomplishments and contributions to our profession consistent with the standards set by the existing Fellows. In particular, I would make a special request that you look to the most senior members of your Section or District in considering members for nomination. In many cases, the colleagues and peers of these individuals who are the most familiar with their contributions, and who would normally nominate the candidate, are no longer with us. I want to be sure that we take the extra effort required to make sure that those truly worthy are not overlooked because no obvious individual was available to start the nomination process.

For specifics on the nomination requirements, please contact Wendy Sue Reeve, at AWS headquarters in Miami, or simply follow the instructions on the Fellows nomination form in this issue of the Welding Journal. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is February 1, 2004. The Committee looks forward to receiving numerous Fellow nominations for 2005 consideration.

Sincerely,

Dr. Alexander Lesnewich
Chairman, AWS Fellows Selection Committee
CLASS OF 2005
FELLOW NOMINATION FORM

DATE __________________________ NAME OF CANDIDATE ________________________________

AWS MEMBER NO. ___________________________ YEARS OF AWS MEMBERSHIP ___________________________

HOME ADDRESS ___________________________________________________________

CITY ____________________________ STATE ____ ZIP CODE __________ PHONE __________

PRESENT COMPANY/INSTITUTION AFFILIATION ___________________________________________

TITLE/POSITION _________________________________________________________________

BUSINESS ADDRESS ___________________________________________________________

CITY ____________________________ STATE ____ ZIP CODE __________ PHONE __________

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION _______________________________________________________

MAJOR & MINOR ___________________________________________________________

DEGREES OR CERTIFICATES/YEAR _________________________________________________

LICENSED PROFESSIONAL ENGINEER: YES ______ NO ______ STATE ______

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE ___________________________________________________________

POSITION ___________________________ YEARS ___________________________

COMPANY/CITY/STATE ___________________________________________________________

POSITION ___________________________ YEARS ___________________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

SUGGESTED CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS FELLOW. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

**MOST IMPORTANT**

The Fellows Committee selection criteria are strongly based on and extracted from the categories identified below. All information and support material provided by the candidate's Fellow Proposer, Nominating Members and peers is considered. Provide as much detailed information as possible regarding:

A. Research & Development
B. Education
C. Manufacturing
D. Design and Inventions
E. Other (e.g., Standards Development, National and International Liaison)

Evidence of accomplishment should include sustained service and performance in the promotion of joining technology; publication of papers, articles and books; innovative development of joining technology; service to AWS and other technical societies; and list and description of patents, awards and honors.

SUBMITTED BY: PROPOSER ___________________________ AWS Member No. ________________

The Proposer will serve as the contact if the Selection Committee requires further information. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the Proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER: ___________________________ NOMINATING MEMBER: ___________________________

AWS Member No. ________________ AWS Member No. ________________

NOMINATING MEMBER: ___________________________ NOMINATING MEMBER: ___________________________

AWS Member No. ________________ AWS Member No. ________________

SUBMISSION DEADLINE FEBRUARY 1, 2004
American Welding Society

Fellow Description

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

- Sustained service and performance in the advancement of welding science and technology
- Publication of papers, articles and books which enhance knowledge of welding
- Innovative development of welding technology
- Society and chapter contributions
- Professional recognition

RULES
1. Candidates shall have 10 years of membership in AWS
2. Candidates shall be nominated by any five members of the Society
3. Nominations shall be submitted on the official form available from AWS Headquarters
4. Nominations must be submitted to AWS Headquarters no later than February 1 of the year prior to that in which the award is to be presented
5. Nominations will remain valid for three years
6. All information on nominees will be held in strict confidence
7. No more than two posthumous Fellows may be elected each year

NUMBER OF FELLOWS
Maximum of 10 Fellows selected each year, as determined by the selection committee.

AWS Fellow Application Guidelines

Nomination packages for AWS Fellow should clearly demonstrate the candidates outstanding contributions to the advancement of welding science and technology. In order for the Fellows Selection Committee to fairly assess the candidates qualifications, the nomination package must list and clearly describe the candidates specific technical accomplishments, how they contributed to the advancement of welding technology, and that these contributions were sustained. Essential in demonstrating the candidates impact are the following (in approximate order of importance).

1. Description of significant technical advancements. This should be a brief summary of the candidates most significant contributions to the advancement of welding science and technology.
2. Publications of books, papers, articles or other significant scholarly works that demonstrate the contributions cited in (1). Where possible, papers and articles should be designated as to whether they were published in peer-reviewed journals.
3. Inventions and patents.
4. Professional recognition including awards and honors from AWS and other professional societies.
5. Meaningful participation in technical committees. Indicate the number of years served on these committees and any leadership roles (chair, vice-chair, subcommittee responsibilities, etc.).
6. Contributions to handbooks and standards.
7. Presentations made at technical conferences and section meetings.
8. Consultancy — particularly as it impacts technology advancement.
9. Leadership at the technical society or corporate level, particularly as it impacts advancement of welding technology.
10. Participation on organizing committees for technical programming.
11. Advocacy — support of the society and its technical advancement through institutional, political or other means.

Note: Application packages that do not support the candidate using the metrics listed above will have a very low probability of success.

Supporting Letters
Letters of support from individuals knowledgeable of the candidate and his/her contributions are encouraged. These letters should address the metrics listed above and provide personal insight into the contributions and stature of the candidate. Letters of support that simply endorse the candidate will have little impact on the selection process.

Return completed Fellow nomination package to:
Wendy S. Reeve
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126
Telephone: 800-443-9353, extension 215

SUBMISSION DEADLINE: February 1, 2004
SHOWCASE YOUR PRODUCTS in the American Welding Society's Filler Metal Comparison Charts, 2004 Edition

Take advantage of the opportunity to promote your products in the industry's most popular reference tool, the American Welding Society's (AWS) 2004 edition of *Filler Metal Comparison Charts*. This publication is rated one of the best sources of information for the selection of competitive commercial products. Each page fully describes filler metal classifications; related specifications; and a variety of companies, manufacturers, and products.

This edition will include International Standards Organization (ISO) classifications for the first time. The global community is moving closer together in establishing the comparability of various classifications. The cross-referencing of specifications is becoming increasingly important in this era of multinational enterprises.

A complete company directory is also included so you can easily contact any manufacturer listed. No other publication has a longer shelf life and is referred to more often when making critical filler metal purchasing decisions. Distributors, specification writers, production managers, purchasing agents, engineers, and welding research scientists find this book invaluable.

In light of the global effort to repair and develop infrastructures, the *Filler Metal Comparison Charts* including the (ISO) Filler Metal Classifications provides a listing of your products and facilitates the selection of filler metals anywhere in the world.

The American Welding Society would like to add your company and affiliates in the global community to the 2004 edition of the *Filler Metal Comparison Charts*.

Contact Nancy A. D'Azevedo at nancy@aws.org or by phone at (800) 443-9353, ext. 311.

American Welding Society
Founded in 1919 to Advance the Science, Technology and Application of Welding
Q: How does hydrogen cause brazing filler metals to wet out? I thought only another fluid, such as a flux, could cause the brazing filler metals to wet out. What principle causes hydrogen to promote the wetting and flow of the brazing filler metal?

A: You have asked an interesting question.

The American Welding Society's AWS A3.0:2001, *Standard Welding Terms and Definitions*, defines a flux as "a material used to hinder or prevent the formation of oxides and other undesirable substances in molten metal and on solid metal surfaces, and to dissolve or otherwise facilitate the removal of such substances."

While this is written with a mineral flux in mind, it is just as applicable to a protective atmosphere. Fluxes, however, are formulated to melt before the brazing filler metal. When molten, the flux is drawn into the joint by capillary action and cleans the surface of oxides and protects it. If the joint is too tight, such as a press fit, the flux may not get into the joint. If the joint clearance is too large, the flux may be pulled into the joint but may leave voids or bubbles that would not clean all of the joint surfaces.

After mineral flux has been applied to a joint of the proper clearance and has removed the oxides from the metal surfaces, the capillary force of the molten filler metal, which is greater than that of the flux, pushes the flux out of the joint.

If the joint clearance is too small, the flux may be pulled into the joint but held into it with such force that the filler metal cannot push it out. The flux does not pull the filler metal into the joint.

With respect to hydrogen systems, the standard belief is that hydrogen reduces metal oxides. This is what my professor taught me in my chemical engineering courses, many years ago.

Hydrogen removes and prevents the oxidation of the liquid filler metal and the surfaces to be brazed. This is what the AWS flux definition is saying. Both the flux and the protective atmosphere clean the surfaces, so the filler metal will wet and flow on the cleaned oxide-free metal surface.

If an active gas atmosphere such as hydrogen will remove the oxides, the inert inactive gases such as argon and helium should not be able to remove oxides. The same should also be true of a vacuum.

When working with many base metals and pure elemental metals over the years, we have found that, in fact, argon and helium of the proper purity and low enough partial pressure of oxygen (dew point) will dissociate the metal oxides similar to hydrogen "reduction." Each metal element has a different requirement for atmosphere purity and low partial pressure of oxygen to dissociate the metal oxide at a given temperature.

Dew point is an easy way of measuring the partial pressure of oxygen in the protective gas atmosphere. It is the oxygen atom in the water molecule that causes the oxidation problem and must be controlled. Therefore, we should be talking about the partial pressure of oxygen (ppO) in the atmosphere system.

At each temperature, there is a specific relationship between the protective atmosphere (its ppO), the base metal, and the filler metal. This also holds true for the vacuum atmosphere.

A vacuum furnace pumps out the required amount of air to produce a low enough ppO to dissociate the metal oxide and make the base metal clean enough, at the required temperature, to cause the filler metal to wet and flow on the base metal.

In the early days, chromium could not be kept free of oxides in a "protective furnace.
atmosphere," but this problem was conquered in the 1940s. One of the interesting items is that, even in the best vacuum or hydrogen atmosphere, chromium starts to oxidize at around 1000°F (538°C) and continues to oxidize up to approximately 1400°F (760°C). It then starts to dissociate and finally clean up around 1700°F (925°C). The best brazing starts around 1850°F (1008°C) and progressively improves as the temperature increases, depending on atmosphere quality, primarily ppO. Each element has its own atmosphere quality and temperature requirement. For some elements, such as aluminum and titanium, the oxide requirements are so high we cannot dissociate the oxides in the current furnace atmosphere conditions. Most common metals would melt at these temperatures.

Figures 1 and 2 show the effects of the protective atmospheres of hydrogen and vacuum. Figure 1 shows, on the left, the metal-metal oxide equilibria in pure hydrogen atmosphere (the right-hand scale is equivalent to vacuum pressure). Figure 2 represents the effect of varying atmosphere quality and the degree of oxidation and dissociation of chromium-chromium oxide in a chromium-containing base metal as the temperature increases.

For many years, I have been convinced that when the temperature is high enough and the ppO is low enough, the metal oxide will split and the oxygen will be swept out by the low-ppO flowing gas atmosphere or by the vacuum pumping system. I have observed pure metal and alloy base metals in many brazing atmospheres for more than 60 years, and can only come to this conclusion.

I know this statement flies in the face of data published for the hydrogen dew point vs. temperature showing reduction of metal oxides. However, I am still looking for someone to explain how the "hydrogen reduction" theory can be applied to chromium oxide that can be "dissociated" in a very low-ppO argon atmosphere. Helium also has been seen to dissociate metal oxides.

I would appreciate receiving any papers that explain the theory of the dissociation of chromium oxide in a low-ppO argon atmosphere at brazing temperatures. ♦
Conferences and Exhibitions

Third Phased Array Inspection Conference. June 9–11, The Mayflower Park Hotel, Seattle, Wash. Contact: Brent Lancaster, (704) 547-6017, e-mail: blancast@epri.com; http://interviewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&tstamp=1042655773355&postingForm=calendar.asp&bFromCalendar=1&event_schedule_id=1575.

ASME TURBO EXPO 2003: Power for Land, Sea, and Air and International Joint Power Generation Conference. June 16–19, Georgia World Congress Center, Atlanta, Ga. The two conferences will host a joint exposition. For more information, visit www.asme.org.


22nd EPRI Steam Generator NDE Workshop, June 30–July 2, Hilton Head Marriott Beach and Golf Resort, Hilton Head Island, S.C. Contact: Brent Lancaster, (704) 547-6017, e-mail: blancast@epri.com; http://interviewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&tstamp=1049726447678&postingForm=calendar.asp&bFromCalendar=1&event_schedule_id=1636.

13th Annual EPRI NDE Issues Meeting. July 23–25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claudon@epri.com; http://interviewcentral.com/events/cust/search_results.asp?event_id=1682&keyword=&archive_year=future&event_address_id=&postingForm=default&ascid=epri&pid=2&lid=2&cart_currency_code=&payment_type=0&orderby_location=0&orderby_date=0&newRegistration=0&errmsg=.

Welding Korea 2003. August 27–30, Indian Hall, COEX, Seoul, Korea. Organized by the Korea Welding Industry Cooperative and COEX. Contact: Welding Korea 2003 Secretariat, COEX World Trade Center, Samsung-dong, Gangnam-gu, Seoul, 135-731, Korea, (02) 6000-1055, 1056, FAX: (02) 6000-1309, e-mail: kbc@coex.co.kr or donhan@coex.co.kr; www.weldingshow.co.kr.


—continued on page 58
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2003 ASM Heat Treating Society Conference and ASM Heat Treat Show. September 15-18, Indianapolis, Ind. Contact: ASM Customer Service, (440) 338-5151 ext. 6, FAX: (440) 338-4634; e-mail: Cust-Srv@asminternational.org; www.asminternational.org.


7th International Seminar on the Numerical Analysis of Weldability. September 29-October 1, Schloss Seggau, Austria. Organized by IIW Subcommission IXB Working Group “Mathematical Modelling of Weld Phenomena” and Graz University of Technology, Institute for Materials Science, Welding, and Forming. Contact: Ernst Kozeschnik, 43 (316) 873-4304, FAX: 43 (316) 873-7187, e-mail: ernst.kozeschnik@iws.tugraz.at; http://iws.tugraz.at/seggau.html.

Aluminum USA 2003, The North American Event for Production, Processing, and Applications. September 30-October 2, Navy Pier, Chicago, Ill. For registration and complimentary tickets, e-mail: tickets@uk.dmgworldmedia.com. For conference details, contact: Group Managing Editor Ken Stanford, 44 (0) 1737 855156, FAX: 44 (0) 1737 855469, e-mail: kenstanford@uk.dmgworldmedia.com; www.aluminumtoday.com.


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Exam application must be submitted six weeks before exam date. For exam information and an 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.

Cities | Exam Prep Courses | CWI/CWE Exams
-------|------------------|------------------
Albuquerque, N.Mex. | August 3–8 (API 1104 Clinic also offered) | August 9
Baton Rouge, La. | July 13–18 (API 1104 Clinic also offered) | July 19
Beaumont, Tex. | June 8–13 (API 1104 Clinic also offered) | June 14
Boston, Mass. | EXAM ONLY | June 7
Charlotte, N.C. | August 24–29 (API 1104 Clinic also offered) | August 30
Chicago, Ill. | June 22–27 (API 1104 Clinic also offered) | June 28
Cincinnati, Ohio | EXAM ONLY | June 7
Columbus, Ohio | August 4–8 (API 1104 Clinic also offered) | August 9
Denver, Colo. | June 22–27 (API 1104 Clinic also offered) | June 28
Houston, Tex. | August 17–22 (API 1104 Clinic also offered) | August 23
Idaho Falls, Idaho | EXAM ONLY | July 12
Indianapolis, Ind.| August 17–22 (API 1104 Clinic also offered) | August 23
Kansas City, Mo.| July 27–August 1 (API 1104 Clinic also offered) | August 2
Kansas City, Mo.| August 4–9 (API 1104 Clinic also offered) | 9-YEAR RECERTIFICATION COURSE

Cities | Exam Prep Courses | CWI/CWE Exams
-------|------------------|------------------
Long Beach, Calif. | EXAM ONLY | July 26
Memphis, Tenn. | August 10–15 (API 1104 Clinic also offered) | August 16
Miami, Fla. | EXAM ONLY | June 19
Miami, Fla. | EXAM ONLY | July 17
Miami, Fla. | EXAM ONLY | August 14
Mobile, Ala.| EXAM ONLY | July 19
Orlando, Fla.| July 6–11 (API 1104 Clinic also offered) | July 12
Philadelphia, Pa. | July 6–11 (API 1104 Clinic also offered) | July 12
Pittsburgh, Pa. | June 8–13 (API 1104 Clinic also offered) | June 14
Pittsburgh, Pa.| June 23–28 | 9-YEAR RECERTIFICATION COURSE
Rochester, N.Y. | August 24–29 (API 1104 Clinic also offered) | August 30
Sacramento, Calif.| June 8–13 (API 1104 Clinic also offered) | June 14
Sacramento, Calif.| August 10–15 (API 1104 Clinic also offered) | August 16
Salt Lake City, Utah | July 13–18 (API 1104 Clinic also offered) | July 19
Seattle, Wash.| July 27–August 1 (API 1104 Clinic also offered) | August 2

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2003-04 NATIONAL SCHOLARSHIP RECIPIENTS

Heath Drone
Ferris State University
Welding Engineering Technology
Howard E. Atkins Memorial Scholarship

"It is an honor to receive this scholarship and recognition. I look forward to proving that your investment in my education will prove worthwhile."

Ashwin S. Raghavan
The Ohio State University
Welding Engineering Technology
Airgas - Jerry Baker Scholarship

"I am truly honored to receive such a prestigious award. I am extremely grateful to my professors and the AWS Foundation."

James M. Spencer
Ferris State University
Welding Engineering Technology
Airgas - Terry Jarvis Memorial Scholarship

"This scholarship will not only help me achieve my educational goals but my future endeavors in life."

Shaun J. McGrath
Ferris State University
Welding Engineering Technology
Arsham Amirikian Engineering Scholarship

"With their scholarship programs, the AWS truly is 'Building Welding's Future through Education.'"

Jackson Tracy
Ferris State University
Welding Engineering Technology
Edward J. Brady Memorial Scholarship

"This scholarship will help me tremendously and allow me to further my education. Thank you."

Ryan N. Kapustka
The Ohio State University
Welding Engineering Technology
William A. and Ann M. Brothers Scholarship

"Your support, encouragement, and belief in my academic future is infinitely appreciated. Thank you again, AWS."

Benjamin C. Woomer
The Ohio State University
Welding Engineering Technology
Donald P. Hastings Scholarship

"This scholarship will help me continue to stay involved and focused on learning at The Ohio State University."

Philip Wiegand
Pennsylvania College of Technology
Welding & Fabrication Engineering Technology
William D. Howell Memorial Scholarship

"Thank you for investing in me. This award will help further my education in the welding engineering field."

Sean Moran
Milwaukee School of Engineering
Management
Hypertherm International HyTech Leadership Scholarship

"Through this scholarship, Hypertherm and the AWS Foundation have shown their commitment to the advancement of the welding industry."

Kevin L. Gormont
The Ohio State University
Welding Engineering Technology
John C. Lincoln Memorial Scholarship

"This scholarship is an honor I do not accept lightly; I appreciate your confidence in my abilities."

George W. Meeker, II
Ferris State University
Welding Engineering Technology
Matsuo Bridge Company Ltd. of Japan Scholarship

"I would like to thank the AWS Foundation for the opportunity to travel to Japan this summer provided through the Matsuo Bridge scholarship."

Justin Nielsen
LeTourneau University
Welding Engineering Technology
Praxair International Scholarship

Linda Nicole Dutruch
University of Mobile Business Administration
James A. Turner, Jr. Memorial Scholarship

"Without organizations such as the AWS, many students would not be able to continue their education."

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Industry Leaders Honored at AWS Welding Show 2003 in Detroit

Each year, the American Welding Society honors those in the welding industry whose achievements have been recognized as advancing the science and technology of welding. This year, the following individuals were cited for their accomplishments at the Annual Awards Luncheon held in Detroit, Mich., during the AWS Welding Show 2003.

COMFORT ADAMS LECTURE AWARD

Akira Matsunawa received his Ph.D. in engineering from Osaka University and is currently an emeritus professor of Osaka University. His research career in welding physics spans more than 40 years.

Throughout his career, Matsunawa has engaged in studies on "Anode and Cathode Discharge Mechanisms of High Current Arc," "Underwater Arc Welding with Local Dry Cavity and Arc Characteristics in High Pressure," "Interaction between Supersonic Jet and Cutting Front Wall in Oxygen Flame Cutting," and "Heat and Mass Transfer in Arc Welding." Since 1980, he has been involved in scientific research on laser materials processing, particularly on beam-plume interaction, keyhole dynamics, defects formation mechanism in laser beam welding, mathematical modeling of arc and laser beam welding, modeling of rapid fusion and solidification, and laser welding of similar and dissimilar metals in microgravity.

Matsunawa is a member of AWS, the Japan Welding Society, Japan Welding Engineering Society, Light Metal Welding and Construction Association (LMWCA), High Temperature Society of Japan (HTSJ), the Laser Society of Japan, and the Laser Institute of America (LIA). He is also an active member of IIW Commissions IV (High Energy Welding), VI (Welding Terms), SG 212 (Welding Physics), and the Select Committee of Underwater Welding. He has served as chairman of IIW Commission IV since 2002, and was honored as a Fellow of LIA in 1994 and AWS in 1998.

ADAMS MEMORIAL MEMBERSHIP AWARD

Carl E. Cross is an associate professor in the Metallurgical and Materials Engineering Department at Montana Tech of the University of Montana, Butte, Mont. He has more than 20 years of experience in welding research in both the nuclear and aerospace industries and is a registered Professional Engineer in the state of Colorado.

Focusing on the weldability and solidification behavior of aluminum, titanium, and stainless steel alloys, Cross has published widely in the area of weld hot-cracking and weldability testing. He has made significant contributions to Al-Li weld development and holds a patent on filler alloy composition. This technology is now being used in the construction of the external tank for the NASA Space Shuttle.

After receiving undergraduate and advanced degrees in metallurgical engineering from the Colorado School of Mines (CSM), Golden, Colo., Cross continued his involvement in the CSM welding program as an adjunct professor, accumulating more than eight years of teaching experience. He has given lectures and short courses worldwide and serves as a principal reviewer for the Welding Journal.

More recently, Cross spent one year as guest professor at the Universitat der Bundeswehr-Hamburg performing hyperbaric welding research on duplex stainless steel used in North Sea oil pipelines. Prior to joining Montana Tech, he spent two and one-half years at the Norwegian University of Science and Technology as a visiting scientist developing new high-strength welding consumables for use in the construction of aluminum fast ferries.

HOWARD E. ADKINS MEMORIAL INSTRUCTOR MEMBERSHIP AWARD

William L. Galvery, Jr., received a bachelor of vocational education degree from California State University, Long Beach, Calif., in 1999. He has more than 30 years of industrial welding experience and is an AWS Certified Welding Inspector and Certified Welding Educator.

Since 1993, Galvery has been associated with welding technology at the Orange Coast College in Costa Mesa, Calif., where he teaches structural and pipe welding in each of the welding processes along with advanced welding classes including training and preparation for the Los Angeles City written and physical exam. He is also involved with I-CAR training and test administration.

Galvery was recognized and hono-
K. Johnston
Y. Cho
S. Rhee
R. Menon
W. Beck
T. DebRoy

ored with an Excellence In Education Award by the University of Texas at Austin, nominated by the Orange County faculty and dean of technology as Outstanding Teacher of the Year, and has served as an officer for the AWS Long Beach/Orange County Section. In addition, Galvery is the author of "Welding Essentials: Questions and Answers and Welding Essentials: Questions and Answers, first revised edition.

HOWARD E. ADKINS MEMORIAL INSTRUCTOR MEMBERSHIP AWARD

Kevin D. Johnston holds an associate degree in electrical engineering and is working toward his bachelor degree in management. He is an adjunct professor at the Kansas City Metropolitan Community Colleges' Business and Technology Center.

Johnston is an AWS Certified Welding Inspector, a Certified Welding Educator, and a Senior Certified Welding Inspector. He is a member of the AWS Kansas City Section's executive board and serves as its first vice chairman. He is involved in all Section activities with special emphasis on educational activities for high school and postsecondary students.

ROBERT J. CONKLING MEMORIAL AWARD

First Place — High School Meridian Technical Center Stillwater, Oklahoma

First Place — Postsecondary Washtenaw Community College Ann Arbor, Michigan

A. F. DAVIS SILVER MEDAL AWARD

Machine Design

"Primary Circuit Dynamic Resistance Monitoring and Its Application to Quality Estimation during Resistance Spot Welding"

Yongjoon Cho received his Ph.D. in mechanical engineering from Hanyang University, Seoul, Korea. From 1993-2001, he was a graduate research assistant at the university's Laboratory of Welding Automatic Control System. In 2001, Cho joined the General Motors Collaborative Research Laboratory, University of Michigan in Ann Arbor, Mich. Cho is a recipient of Hanyang University's Outstanding Ph.D. Dissertation Award in 2000. He has coauthored more than 15 technical papers on the various applications of resistance welding and is a member of AWS and the Korean Welding Society.

Sehun Rhee earned his Ph.D. at University of Michigan in 1990. In 1994, Rhee joined Hanyang University in Korea as a professor in mechanical engineering. He has published 75 technical papers and 75 conference papers. In 1998, Rhee received the Best Paper Award from the Korean Welding Society (KWS) and, in 1999, the Best Researcher Award from the Korean Federation of Science and Technology Societies and the Best Professor Award from Hanyang University in 2002.

Rhee is a member of the American Welding Society, American Society of Mechanical Engineers, KWS, and Korean Society of Precision Engineering (KSPE). He is editor-in-chief for the "International Journal of the Korean Welding Society and serves on several national committees of professional societies and industrial advisory boards.

Maintenance and Surfacing

"Recent Advances in Gored Wires for Hardfacing"

Ravi Menon received his Ph.D. in metallurgical engineering with a specialty in welding metallurgy from the University of Tennessee (UT), Knoxville, Tenn.

Menon served as supervisor of welding research at UT until 1987, when he went to work for Teledyne McKay in York, Pa., as a senior research engineer. He was made director of research in 1989 and worked primarily in the development of stainless steel and nickel alloy welding consumables. He served as director of the Materials Group at Edison Welding Institute before joining the Stoody Company in 1994 as director of research.

Menon chairs the AWS ASG Subcommittee on Hardfacing Filler Metals and is a member of the A5 Filler Metal Committee. He has numerous publications to his credit and is currently the recipient of three U.S. patents pertaining to surfacing alloys and methods.

DALTON E. HAMILTON MEMORIAL CWI OF THE YEAR AWARD

William R. Beck is with the Project Management Construction Division of the Eastman Kodak Co., Rochester, N.Y. He began his welding career in 1967 while in the U.S. Navy, where he serviced and repaired nuclear and non-nuclear piping systems on nuclear submarines, performing pipelining, welding, and brazing.

Beck holds certifications as an AWS Certified Welding Inspector; a New York state DOT-Registered Inspector; ASNT Level II, visual testing; ASNT Level II, dye penetrant testing; and ASNT Level II, magnetic particle testing.

W. H. HOBART MEMORIAL AWARD

"Numerical Simulation of Sleeve Repair Welding of In-Service Gas Pipelines"

Authors: In-Wan Bang, Y.-P. Son, Kyu Hwan Oh, Y.-P. Kim, and W.-S. Kim

HONORARY MEMBERSHIP AWARD

Tarasankar DebRoy is professor of materials science and engineering at the Pennsylvania State University, University Park, Pa. He received his Ph.D. from the Indian Institute of Science, Bangalore, India, and completed postdoctoral work at the Imperial College of Science and Technology, Lon-
INTERNATIONAL INSTITUTE OF WELDING (IIW) for 23 years. He has served as U.S. Delegate to Commission IV and as a member of the Study Group on Welding Research and Collaboration. For six years, he was chair of the American Council and represented the U.S. as a member of the IIW Governing Council.

Ramsey spent most of his professional career with A. O. Smith Corp., where he was manager of welding and metallurgical R&D.

Ramsey was active in both local and national AWS affairs and served on the board of directors. He was president of the Society for the 1975-1976 term. From 1982-1987, he was on staff at AWS as executive director. A Fellow of AWS and ASM, Ramsey has been the recipient of several AWS awards including the R. D. Thomas Memorial Award. A Life Member of AIME, he also holds membership in ASME, SAE, SME, and the Welding Research Council. He has authored 16 technical papers and holds five patents.

WILLIAM IRRGANG MEMORIAL AWARD

James L. Jellison earned a Ph.D. in materials science from Rensselaer Polytechnic Institute, Troy, N.Y. He retired from Sandia National Laboratories, Albuquerque, N.Mex., in 2001, where, during his mid-career, he led the creation of Sandia's welding and R&D team.

From 1958 to 1967, while with General Electric, Jellison developed numerous metallurgical forming and joining processes, especially for nuclear reactor components. He joined Sandia National Laboratories in 1970. His early Sandia research was on micro-miniature solid state welding. Later, he performed and led R&D on a diverse number of welding processes, including soldering, brazing, diffusion welding, friction welding, arc welding, and laser beam welding. He was a pioneer in laser beam welding and was associated with the first commercial high pulse rate Nd:YAG laser to be applied to welding. Processes invented by Jellison while with GE and Sandia are the subject of numerous patents. Jellison is a Fellow of both AWS and ASM International.

HONORARY MEMBERSHIP AWARD

Michael L. Weller is president of Miller Electric Mfg. Co., an Illinois Tool Works company in Appleton, Wis. Weller received a bachelor's degree in economics from Ripon College in 1975. He joined Arps Division of Chromalloy, New Holstein, Wis., as director of human resources. Before joining Miller in 1993 as vice president of human resources, he was employed in various human resource assignments. From 1999 to 2001, he was Miller's vice president/general manager with areas of responsibility including sales, marketing, manufacturing, and finance.

INTERNATIONAL MERITORIOUS CERTIFICATE AWARD

Akira Matsunawa. See biography under Comfort Adams Lecture Award.

Stephen Liu is professor of metallurgical engineering at the Colorado School of Mines (CSM), Golden, Colo. He received his Ph.D. degree in metallurgical engineering from CSM. He joined the CSM faculty in 1987.

Liu has authored and coauthored more than 160 technical publications. He has received several prestigious AWS honors including the Adams Pulse Rate Nd:YAG Laser to be Applied to Welding. Processes invented by Jellison while with GE and Sandia are the subject of numerous patents. Jellison is a Fellow of both AWS and ASM International.

Memorial Membership Award, Distinguished Member, Robert L. Peaslee Brazing Award, District Meritorious Award, and Honorary Membership Award. He was elected AWS Fellow in 1996 and delivered the 1998 AWS Plummer Educational Lecture.

Liu received the ASME Special Achievement Award, the ASME-OMAE Special Achievement Award, the ASME-OMAE Achievement Award, and was elected Fellow of the ASME in 1999. He is a recipient of the SAE Teeter Educational Award in 1986. Liu is also an ASM Fellow (2001).

For his research work in underwater welding consumables development, Engineering News-Record selected Liu as one of the top 25 newsmakers in the world construction industries in 1996.

Liu is currently editor-in-chief of the ASME Journal of Offshore Mechanics and Arctic Engineering. He is a member of the American Welding Society, ASM International, the Metallurgical and Materials Society, American Society of Mechanical Engineers International, and the Japan Welding Society. He is also a Chartered Professional Engineer registered with the United Kingdom's Engineering Council.

Wesley Wang received his Ph.D. degree in metallurgical engineering and materials science from the Colorado School of Mines (CSM), Golden, Colo.

Wang is currently the country manager-China, SSD, with Global Industries, Ltd., Global Divers and Contractors, LLC. Previously, he was responsible for welding QA management, materials handling for pipeline projects, R&D projects, and field engineering. While earning his degrees, Wang was a graduate research assistant with the CSM.

PROFESSOR KOICHI MASABUCHI AWARD

Tracy W. Nelson received his Ph.D. degree from The Ohio State University in welding engineering. He joined the faculty at Brigham Young University (BYU) in 1995 and teaches courses in materials science, manufacturing, and joining processes. He is also the director of the Center for Advanced Joining of Materials at BYU.

Over the past five years, Nelson's research focus has been in the area of friction stir welding (FSW), including both fundamental and applied topics.

Nelson was the recipient of the Henry Granjon Award (1996) from the International Institute of Welding and the American Welding Society's Warren F. Savage Award. He presently serves on the AWS Chapter Committees on Welding Metallurgy and on Stainless and Heat-Resisting Steels and the Advisory Committee for AWS D17, Specification for Friction Stir Welding of Aluminum for Aerospace Applications.

NATIONAL MERITORIOUS AWARD

Richard Lyell Holdren began his professional welding career in 1973 after graduating from The Ohio State University with a B.S. in welding engineering.

In 1981, Holdren cofounded Welding Consultants, Inc., and served as its vice president and principal welding engineer until 1995. He then joined the Edison Welding Institute and served in various technical and marketing positions, including his current position as principal welding engineer.

Holdren is a registered Professional Engineer in Ohio and Indiana. He is an AWS Certified Welding Inspector and AWS Senior Certified Welding Inspector. He is certified as ASNT Level III in MT, PT, and UT.

Holdren has actively served in both local and national positions in various technical societies including ASNT and AWS. Locally, he served as chairman of both groups. Nationally, Holdren has served AWS through active involvement on numerous education and technical committees. He currently chairs the A2, A2B, and B1 Committees and is second vice chair of the Technical Activities Committee. Holdren is a Distinguished Member of AWS and an ASNT Fellow. He has received the AWS District Meritorious Award, the AWS Section and District CWI of the Year Award, and the IIW International Welding Engineer Award.

Holdren has made more than 50 technical presentations since 1980, several of which were published in the Welding Journal and other technical journals. He has served as both contributor and chapter chair for the 7th, 8th, and 9th editions of the Welding Handbook and has contributed to other committee publications. Additionally, Holdren authored the AWS training materials Welding Inspection Technology and Welding and Cutting Processes. He also revised and edited the latest edition of Certification Manual for Welding Inspectors.

Ronald C. Pierce earned his degree in mechanical engineering at Purdue University in 1955 and is a registered Professional Engineer in Alabama and Mississippi. He is president and CEO of Welding Engineering Supply Co., Inc., based in Prichard, Ala., and is chairman and trustee of the AWS Foundation.

Pierce is an AWS past president and a past member of the AWS board of directors, AWS Life Member, and a past and present member of various AWS Section and national committees. Pierce is a past member of the Welding Distributor Editorial Advisory Board and is presently affiliated with the Gases and Welding Distributors Association, Associated Builders and Contractors Association, and Associated General Contractors. He also serves on the welding advisory boards of Jefferson Davis Community College, North Baldwin Center for Technology, Bryant Area Vocational Center, and Jefferson Davis Community College.

ROBERT L. PEASLEE BRAZING AWARD

"The Development of New Silver-Free Brazing Alloys for Steel Tubular Assembly"

Anton Gales is senior project manager of welding and brazing technol-

Gale holds a teaching degree from the Technical High School at Deventer. He is currently working on a European project for replacing carbon steel with stainless steel in the metro car and train industry. Gale has published his findings in numerous technical journals and has lectured widely.

David Jacobson holds both academic and industrial appointments. He received his Ph.D. from the University of Sussex in 1972.

After working on brazing material development at Johnson Matthey Metals (U.K.), Jacobson joined the Hirst Research Centre of GEC-Marconi (U.K.) in 1981, heading the Materials Fabrication Division. He has conducted innovative research and development on solders for electronics, aluminum brazes and lightweight plasma interfaces for nuclear fusion reactors, and low-expansion alloys for electronics packaging. He is the author of more than 80 research papers and was named inventor on several patents in these fields.

For his contribution to aluminum joining technology, Jacobson was a recipient of the AWS Robert L. Peaslee Brazing Award and the Cook Prize from the Institute of Materials. He co-authored the textbook Principles of Soldering and Brazing with Giles Humphston (ASM, 1993).

P. S. Sangha received his graduate and postgraduate degrees in material science from Imperial College, London, U.K.

Sangha is currently with Astrium Ltd., where he has worked on various aspects of satellite manufacture including the design and manufacture of C-band and Ku-band electronic payload equipment. His prior projects include the European Union funded CRAFT project developing silver-free brazes for large gap brazing and the European Union funded BRITE/EURAM project dealing with the development of novel lightweight materials for microwave packaging based on high-silicon aluminum alloys.

From 1990 to 1994, Sangha worked on the development of low-temperature (550°C) aluminum brazes as a part of the European Union funded BRITE/EURAM program. He co-authored two award-winning publications on the subject and received the AWS Robert L. Peaslee Brazing Award and the award given by The Institute of Materials, London, for best publication for the years 1995 and 1996.

Sangha has coauthored more than 36 publications and conference presentations.

Eberhard Schmid studied metallurgical engineering at the University of Stuttgart, Germany, and, for one part of his thesis, he received ASM's Jacquet-Lucas Award for Excellence in Metallography. He earned his Ph.D. from the Max-Planck-Institut für Metallforschung, Stuttgart. Since 1996, he has been employed at the Berkenhoff GmbH (BedraTM) in Gießen. He is responsible for the research and development section of the welding/brazing business, and for the past three years, he has served as head of quality management.

From 1985 to 2000, Schmid was a member of the scientific group that critically evaluated publications dealing with ternary alloy constitution. From 1987 to 1995, he was the head of several international cooperative projects at the central laboratory of Metalgesellschaft AG in Frankfurt/Main. The industrial-oriented projects concerned powder metallurgy and casting developments for aerospace and automotive engineering components (i.e., pistons). Later, he was group leader of physical and metallographical examinations.

PLUMMER MEMORIAL EDUCATIONAL LECTURE AWARD

Glen Knight is welding training administrator for DaimlerChrysler's Advanced Technical Training, Manufacturing Group.

Knight began his career with Chrysler Corp. in 1976 in Detroit, Mich. He has held various positions in management and served as chief instructor and manager of the Weld Tech Welding Education Center, Chrysler Learning Inc., an accredited, licensed private vocational school.

Knight attended Macomb Community College, Lawrence Institute of Technology, and Central Michigan University. He is a member of AWS and is an AWS Certified Welding Inspector and Certified Welding Educator. Knight is a former AWS Detroit Section chairman (1991-1992) and is currently serving on the AWS National Education and Scholarship Committees and the Welding Handbook Subcommittee for Welding Tool & Die Steels.

Knight has been involved in the SkillsUSA/VICA Welding Competition for 25 years at the state level and has served on the International Weld Trials since 1989 and the National Committee for 5 years. He has helped design several challenging performance tasks for the Michigan State High School Competition and has acted as cochairman for the event.

PRIVATE SECTOR INSTRUCTOR MEMBERSHIP AWARD

In the early 1980s, William Campbell received a B.A. from the City University of New York, his New York City Welder License, New York City Welder Qualification Certificate, and a New York City Board of Education Evening School Substitute License.

Early in his career, Campbell was an apprentice with the Millwright Local Union #740 in New York. In 1980, he joined the New York City District Council of Carpenters Labor Technical College (NYCDCC) and trained millwright journeymen and apprentices in shielded metal arc welding. Since that time, the curriculum at the school has expanded to include beginning and advanced welding of plate and pipe using shielded metal arc, gas metal arc, and flux cored arc welding and GMAW, OFC, CAG, and PAC. Emphasis is placed upon welder qualification for a NYC Class 1 or Class 4 License and a NYC Department of Transportation Class 1 Qualification.

Campbell became an AWS Certification Welding Inspector in 1987. Having retired after 38 years of working in outside construction, he continues to perform welder qualification and inspection. He also continues to teach evening welding courses at the NYCDCC School, a Carpenter Minority Worker Pre-Apprentice Welding Program, and some apprentice day session programs in basic welding.
J. Grantham

J. Elmer

A. Landau

I. Maroef

PRIVATE SECTOR INSTRUCTOR MEMBERSHIP AWARD

Jesse A. Grantham earned M.S. and Ph.D. degrees in welding engineering from The Ohio State University in 1988 and 1992, respectively. He is a past instructor at The Ohio State University, Columbia Basin College, and adjunct professor at Washington State University. He is also an instructor for the National Board of Pressure Vessel Examiners, ASM International, and ASNT.

Grantham is a registered Professional Engineer in six states and an AWS Certified Welding Inspector, Certified Welding Educator, and ASNT Level III inspector. He manages the WJMG AWS Accredited Welder Test Facility and FAA Repair Station WOJR662Y, which conducts fusion welding and nondestructive testing. Grantham is an active member of several technical and professional societies and has held offices both locally and nationally. He is a member of the National Academy of Forensic Engineers (NAFE), an affiliate of NSPE, and is the current AWS District 20 director.

WARREN F. SAVAGE MEMORIAL AWARD

"Joining Depleted Uranium to High-Strength Aluminum Using an Explosively Clad Niobium Interlayer"

David G. Brasher completed his M.S. degree at the New Mexico Institute of Mining and Technology in 1984. Brasher is the co-owner and founder of High Energy Metals, Inc. (HEMI), a small explosive metal fabricating shop. Founded in 1997, the company specializes in unique dissimilar metal bonded joints. Prior to founding HEMI, Brasher was the vice president of Northwest Technical Industries, Inc., a manufacturer of explosively bonded and formed products. During his employment there, he specialized in developing new customers and research and development.

Brasher is the co-author of five publications.

Donald J. Butler received his B.S. in mechanical engineering from Tulane University in 1982. He is presently co-owner and co-founder of High Energy Metals, Inc., a small business specializing in explosive metal fabrication. Since 1997, High Energy Metals, Inc., has been at the cutting edge of the explosion bonding industry, joining many dissimilar metal combinations and machining the materials to provide a finished component.

Prior to founding High Energy Metals, Inc., Butler was senior project engineer at Northwest Technical Industries, Inc., a manufacturer of explosively bonded and formed products. He has written and received three Small Business Innovative Research (SBIR) Grants and managed their completion. Butler is the co-author of four published papers.

John W. Elmer earned his Sc.D. in metallurgy from the Massachusetts Institute of Technology in 1988. From 1982–1984, he worked as a welding metallurgist at Lawrence Livermore National Laboratories (LLNL) for a variety of defense-related programs. He returned to LLNL in 1989, where he is currently deputy program element leader for stockpile metallurgy and joining in the Materials Science and Technology Division.

Elmer is also the principal investigator for a DOE-Basic Energy Sciences program to study welding-induced phase transformations using synchrotron radiation. He is a Fellow of AWS, the recipient of AWS's Professor Masubuchi-Shinsho Corporation Award, William Spraragen Award, and A. F. Davis Silver Medal. He currently serves as adjunct professor at The Pennsylvania State University, is a member of numerous professional committees for AWS and ASM International, has published more than 70 articles and reports, and has received seven U.S. patents for his work in the field of welding.

Peter E. Terrill received his M.S. degree in mechanical engineering from Stanford University in 1997. Since then, he has worked as a research and design engineer at the Lawrence Livermore National Laboratory for a variety of defense-related programs. He is currently the flight test director for the Air Force Reentry Systems Group in the Defense Technology Engineering Division.

SILVER QUILL EDITORIAL ACHIEVEMENT AWARD

Stainless Steel World July/August 2002

"High Deposition of Welding of Francis Turbine Runners for the Three Gorges Dam Project"

WILLIAM SPRARAGEN MEMORIAL AWARD

"Retained Austenite as a Hydrogen Trap in Steel Welds"

Alex Landau received his Ph.D. in materials science from Ben-Gurion University of the Negev in Beer-Sheva, Israel. Currently, he teaches materials processing and welding theory at Ben-Gurion University and serves as a research group leader at the Israeli National Laboratory at Beer-Sheva. His expertise is in electron microscopy.

Landau performs research on the microstructural behavior of processed materials and on hydrogen management of welded alloys. In 1997, he spent a year as a visiting professor in the Center for Welding, Joining, and Coatings Research at the Department of Metallurgical and Materials Engineering at Colorado School of Mines in Golden, Colo.

Iman Soejadarma Maroef is a research associate at the Metallurgical and Materials Engineering Department, Colorado School of Mines, Golden, Colo. where, in 1999, he earned his Ph.D. His current metallurgical investigations include issues relevant to hydrogen cracking in high-strength steel weldments, weldability of superalloys, and failure analyses.

Maroef has a background in mechanical engineering with which he obtained several years of industrial experience in Indonesia before pursuing his graduate study.

David L. Olson received a Ph.D. in
materials science from Cornell University and has performed postdoctoral work at The Ohio State University. Currently, he is the John H. Moore Distinguished Professor of Physical Metallurgy at Colorado School of Mines, Golden, Colo.

Olson is a member of and has participated in a number of technical committees of professional societies and government organizations, including U.S.-sponsored visiting teams to India and Argentina. He is the recipient of numerous awards, honors, and recognitions from AWS and other professional societies and educational institutions and is an AWS and ASM Fellow. He received the 1999 TTCP Achievement Award from the U.S. Department of Defense, Washington, D.C., and the recognition of Foreign Member of the National Academy of Sciences (Materials Science) of Ukraine, Kiev.

Yeong-Do Park received his M.S. degree in metallurgical and materials engineering from Colorado School of Mines, Golden, Colo., in 1999 and is currently a Ph.D. candidate.

The topic of his master’s thesis was the role of retained austenite in the hydrogen management of high-strength steel welds. His research areas include hydrogen management of high-strength steel welds, hydrogen contents measurement by using thermoelectric power (TEP) for INVAR and bronze, and formability of Al-Au alloy (Purple Gold). The subject of Park’s Ph.D. thesis is the study of TEP to access the metallurgical and microstructural phase stability, including advanced diffusible hydrogen sensor, for welds using TEP.

R. D. THOMAS MEMORIAL AWARD

Craig Dallam is group leader, shielded metal arc welding (SMAW) consumables in the Consumable R&D Department of The Lincoln Electric Co. in Cleveland, Ohio.

Dallam’s research areas have included pipeline consumables, hydrogen-assisted cracking with pipeline consumables, alloy development for cellulosic electrodes, and manufacturing concerns for SMAW electrodes. His primary product development responsibilities have included pipeline consumables, both self-shielded flux cored consumables (FCAW-S) and SMAW.

Dallam earned a graduate degree from the Colorado School of Mines. He is a member of the API 1104 Committee (Welding of Pipelines and Related Facilities), IIW Commission XI (Pressure Vessels and Pipelines), and a principal reviewer for the Welding Journal’s Welding Research Supplement. He has contributed to the Metal Handbook and has published proceedings from several conferences in the Welding Journal.

ELIHU THOMSON RESISTANCE WELDING AWARD

T. James “Jim” Snow, Sr., is founder and chairman emeritus of T. J. Snow Co., Inc., Chattanooga, Tenn. He began his resistance welding career in the early 1950s as a salesman for the Jones-Sylar Supply Co. of Chattanooga, Tenn., the exclusive southeastern sales representative for the Taylor-Winfield Co. (T-W) of Warren, Ohio. After 12 years in the business, Snow founded the T. J. Snow Co.

T. J. Snow Co. employs two service engineers who are also private pilots. On call 24 hours a day, they regularly fly the company’s plane to the aid of customers with breakdowns, often literally “saving the day” of production.

After many years representing a succession of northern resistance welding machine manufacturers, including Progressive, Precision, LORS, and Berkeley-Davis (now Automation International), the time came for the company to expand into welding machine manufacturing. After taking trade-ins and attending auctions for several years, an inventory of used resistance welding machines had been acquired for resale. As the company was already well known for its ability to remanufacture and retool used resistance welding machines of all types, it was a natural fit.

Snow was this year’s recipient of the Elihu Thomson Resistance Welding Award. Snow is retired from the company as chairman emeritus.

GEORGE E. WILLIS AWARD

Walter J. Sperko is president of Sperko Engineering Services, Inc., which he founded in 1981. He has extensive experience in welding engineering, metallurgical engineering, design, failure analysis, and quality assurance with specialization in piping and pressure vessels. Sperko was awarded a B.A. and a B.S. in metallurgical engineering from the University of Notre Dame and is a Professional Engineer registered in North Carolina and other states. He has worked for Ebasco Services, ITT Grinnell Industrial Piping, and Richmond Engineering.

Sperko is vice chairman of ASME Boiler and Pressure Vessel Code Subcommittee IX, Welding and Brazing Qualifications; chairman of ASME Subcommittee B31.9, Building Services Piping; and chairman of the AWS International Standards Activities Committee. He has been an ISO Observer to CEN 121 SC1 since 1994 and SC2 since 1998.

Sperko teaches publicly offered courses in piping and ASME Section IX. He has published articles in various trade magazines and holds three U.S. patents.

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, Associate Editor, Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.

Reports can also be faxed to (305) 443-4704 or e-mailed to campbell@aws.org.
Sustaining Member Companies

Austin Mac Inc.
2739 6th Ave. S.
Seattle, WA 98134
(206) 624-7066
FAX: (206) 682-4442
e-mail: sales@teamafw.com
www.austinmacinc.com

Austin Mac Inc. is a manufacturer of conveyor equipment. The company offers screw conveyors ½ to 72 in. in diameter, from mild steel, stainless steel, AR235, T-1, and BHN 400/500. Surface treatments such as hard surface weld cladding, ceramic compound, and bonded tiles are provided. Austin Mac has engineers on staff to assist customers with their needs.

American Friction Welding, Inc.
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www.teamafw.com

American Friction Welding, Inc., is one of the largest and most modern full-service friction welding job shops in the United States. The company provides friction welding services and turnkey products manufactured complete per customer specifications. The company is dedicated to quality, service, and innovation.

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MACTEC Engineering and Consulting is a leader in the engineering, environmental, and remedial construction industries. Operating with more than 100 offices throughout the United States and 4000 employees with specialties in more than 50 scientific and engineering disciplines, MACTEC has the resources to perform virtually any scope of work, regardless of location, size, or complexity.

AWS Welcomes New Affiliate Member Companies

B.G. Brecke, Inc.
4140 F Ave. NW
Cedar Rapids, IA 52405

Blake's Custom Welding
221 South L Harder Rd.
Oak Harbor, OH 43449

Equipment Service Corporation USA
63 Kent Ave.
Warwick, RI 02886

International Library Service
734 S Hanover Dr.
Orem, UT 84058

K.I.T.S. Mfg., Inc.
10172 Bluemound Blvd.
Pratt, KS 67124-7711

L. N. Mohic Welding Service, Inc.
7829 Hamilton Ave.
Pittsburgh, PA 15208

Ritter Steel, Inc.
131 Stover Dr.
Carlisle, PA 17013

Rollins MetalWorks, Ltd.
1372 Shallcross Lake Rd.
Middletown, DE 19709

Sanitary Piping & Welding, Inc.
11930-D Old Stage Rd.
Chester, VA 23836

Universal Petroleum Services
15, The 48 Bldg.
Ras-Gharib
Red Sea, Egypt

AWS Welcomes New Supporting Companies

Arnold R. Burton Technology Center
1760 Boulevard
Salem, VA 24133

Brunswick High School
3920 Habersham St.
Brunswick, GA 31520

Camden County Technical Schools
343 Berlin-Cross Keys Rd.
Sicklerville, NJ 08081

Crest Senior High School
800 Old Boiling Springs Rd.
Shelby, NC 28152

Lee High School H.I.S.D.
6292 Beverly Hills Lane
Houston, TX 77057

Rowan-Cabarrus Community College
P.O. Box 1589
Salisbury, NC 28145

Valley Vocational Technical Center
49 Hornet Rd.
Fishersville, VA 22939

AWS Membership

Member As of Grades May 1, 2003
Sustaining Companies.................427
Supporting Companies.................206*
Educational Institutions..............319
Affiliate Companies....................109
Welding Distributor Companies........54
Total Corporate Members ...........1,115

* During the month of March, the Society launched the Welding Distributor Company Membership. Those Supporting Company Members identified as welding distributors were upgraded to this new corporate member category.

Individual Members..................44,106
Student Members.....................4,272
Total Members .....................48,378
SPECIAL OFFER (See reverse) – IT’S EASIER THAN EVER TO RECRUIT NEW AWS INDIVIDUAL MEMBERS

THE AWS ADVANTAGE
The 2002-2003
AWS Member-Get-A-Member
Campaign

AWS is nearly 50,000 members strong. Imagine how much stronger we would be if each one of our members looked just a few minutes to encourage one of their colleagues to join AWS. We could potentially boost our membership of nearly 100,000 – making us one of the largest associations in the world... and giving us the resources necessary to expand your benefits as an AWS Member.

Top Ten Reasons to be an AWS Member:

10. To encourage the next generation with AWS Scholarships awarded through the AWS Foundation and discounted student memberships.
9. To have a voice in a global community that promotes and takes pride in the materials joining industry.
8. For Members-only discounts on car rentals, insurance, and more!
7. To obtain valuable technical knowledge with 300+ publications available.
6. To experience the wave of the future through the world’s largest materials joining show by attending the AWS Welding Show.
5. For on-going training through AWS seminars and conferences.
4. To save hundreds of dollars with Members-only discounts on all AWS publications, conferences, seminars and certification programs.
3. Because your FREE annual subscription to the Welding Journal will provide you with valuable information to keep you at the forefront of the materials joining industry.
2. For career advancement through networking opportunities at local Section Meetings and by utilizing the AWS Website which includes AWS JobFind.

And the #1 reason to become an AWS Member...
Because of the savings, knowledge and prestige you’ll receive from the premier Society for materials joining professionals.

PRIZE CATEGORIES
President’s Honor Roll:
Recruit 1-5 new Individual Members and receive an American Welder™ T-shirt.

President’s Club:
Recruit 6-10 new Individual Members and receive an American Welder™ polo shirt.

President’s Roundtable:
Recruit 11-19 new Individual Members and receive an American Welder™ watch.

President’s Guild:
Recruit 20 or more new Individual Members and receive an American Welder™ watch, a one-year free AWS Membership, the 'Shelton Ritter Member Proposer Award' Certificate, and membership in the Winner’s Circle.

Winner’s Circle:
All Members who recruit 20 or more new Individual Members will receive annual recognition in the Welding Journal and will be honored at the AWS Welding Show.

SPECIAL PRIZES
Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2003).

Sponsor of the Year:
The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 2004 AWS Welding Show, and recognition at the AWS Awards Luncheon at the AWS Welding Show.

Student Sponsor Prize:
AWS Members who sponsor two or more Student Members will receive an American Welder™ T-shirt.

The AWS Member who sponsors the most Student Members will receive a free, one-year AWS Membership and an American Welder™ polo shirt.

International Sponsor Prize:
Any member residing outside the United States, Canada and Mexico who sponsors the most new Individual Members, will receive a complimentary AWS Membership renewal.

LUCK OF THE DRAW
For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2002, as well as in February, and June 2003.

Prizes Include:
• American Welder™ T-shirt
• Complimentary AWS Membership renewal
• American Welder™ polo shirt
• American Welder™ baseball cap

SUPER SECTION CHALLENGE
The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2003 deadline will receive special recognition in the Welding Journal and a District Membership Award.

The AWS Sections with the highest numerical increase and greatest net percentage increase in new Individual Members will each receive the Seitzel Membership Award.

American Welding Society
550 N.W. LeJeune Rd. • Miami, FL 33126
Visit our website http://www.aws.org
Mark Bell Elected to AWS Board

Mark D. Bell

Mark D. Bell was elected AWS director-at-large on April 7 at the AWS Annual Meeting in Detroit, Mich., to fulfill the remaining two years of Gerald D. Uttrachi’s term commencing June 1 when Uttrachi assumes the position of AWS vice president.

Currently, Bell is a senior welding engineer with MACTEC Engineering. Previously, he served as principal engineer for Preventive Metallurgy. He is a registered Professional Engineer, Metallurgical, in California and is certified in ASNT Level I, II (RT and UT), and III (MT, PT, and VT).

Accomplished in various aspects of training and education, Bell designed and taught a three-semester unit, engineering course on welding metallurgy at Michigan State University and presented a five-day welding processes class that included hands-on instruction with processes such as electron beam, laser, SMA, GTA, GMA, friction, explosion, and diffusion welding. He has expertise in procedure qualification, training of inspection and welding personnel, corrosion failures; SEM, optical microscopes, and mechanical testing; welding metallurgy and failure analysis. In addition, he has been an expert witness regarding failures of weldments, machinery failures, materials characterization, accident reconstruction, material standards, and codes for welding.

Bell received his bachelor of science degree in metallurgical engineering in 1978 from Cal Poly, San Luis Obispo, Calif.

An AWS member since 1978, Bell contributed to the Welding Handbook, 8th ed., in the Welding High Alloys chapter and is active on the National Scholarship Committee.

AWS Maine Section Hosts 2003 SkillsUSA/VICA Welding Competition

Judges from the 2003 AWS Maine Section, SkillsUSA Annual Welding Competition.

Fifteen students met at the Penobscot Job Corps Center on March 14 to take part in the 2003 SkillsUSA/VICA Welding Competition, American Welding Society (AWS) Maine Section and SkillsUSA/VICA Chairman Tom Cormier planned the contest.

Winning first place in the secondary category was Arthur Osborne, a student at Lincoln. St. Agatha’s Brian Ayotte won the silver medal; and Dustin Giles of Caribou received third place. In the postsecondary competition, Kenduskeag’s Ryan Leighton took first place; Graydon Spencer of Exeter won second, and third place was awarded to Shane Sapiel of Old Town.

The contest’s judges represented a cross section of the welding industry in Maine. They included Mike Brilliant (SMAW), Jamie Carter (SMAW), and Jeff Fields (testing) of Bath Iron Works; Maine Section Treasurer Greg Bushey (GMAW), and incoming AWS District 1 Director Russ Norris of Merriam-Graves; Tom Cormier (testing), Maine Section Secretary Scott Lee (GMAW), and Mike Gendron (GTAW) of Metso Paper; and Fran Piccirillo (GTAW) of Advantages Gases.

Welding materials for the contest were donated by Advantage Gases, Bath Iron Works, Hobart Brothers, Maine Oxy, Metso Paper, Merriam-Graves, and Victor Equipment. The Lincoln Electric Co. donated welding machines and prizes. Other companies donating prizes included Maine Oxy and Miriam-Graves.
AWS Indiana Section Sponsors Mid-West Team Welding Tournament

The Mid-West Team Welding Tournament's first-place team from Pike Central High School in Petersburg, Ind., with their trophies.

Each year, the American Welding Society's Indiana Section helps organize and sponsors the Mid-West Team Welding Tournament. This year's contest was held at the New Castle High School in New Castle, Ind. Richard Alley, associate executive director from AWS headquarters in Miami, attended the competition.

This was the twenty-fifth anniversary of the annual welding competition. One hundred thirteen students representing 15 high schools from Indiana and Kentucky competed. Each school was represented by at least one student in each of the following categories: theory (a 300 question test), flux cored arc (FCA), shielded metal arc (SMA), gas metal arc (GMA), and gas tungsten arc (GTA) welding. Students then competed for team points in the five areas of welding.

The weld tests were graded and judged for quality of appearance and structure. Twelve volunteers from industry participated in the three-day event as monitors, mentors, and judges. Local manufacturing plants and welding equipment manufacturers donated all the base materials and welding materials.

This year's winning teams and their instructors (names in parentheses) are, in first place, Pike Central High School, Petersburg, Ind. (Kevin Carter); second place, New Castle Vocational School, New Castle, Ind. (Mike Anderson); third place, Fountain Central High School, Veedersburg, Ind. (Chris Harrison); fourth place, Kentucky Tech, Nelson County, ‘A’ Team, Bardstown, Ky. (Joe Grider); and fifth place, Kentucky Tech “B” Team (Joe Grider).

Individual winners are, for theory, Brad Merkley, Pike Central High School; for SMAW, Jason Abrams, Kentucky Tech; for GMA, Wayne Shuman, Fountain Central High School; for FCAW, Austin Swain, New Castle Vocational School; and, for GTAW, Greg Vonderheide, Pike Central High School.

Each year, the AWS Indiana Section awards the George Knapp Memorial Student Attitude and Sportsmanship Award. This year, the award was presented to Daniel Witt of McKenzie Career Center, Larry Hensley, Jeffersonville High School, Jeffersonville, Ind., was presented with the Ivan Simmons Award and Lonnie Scott, J. Everett Light Career Center, Indianapolis, Ind., received the Dan Rayshick Award. Bob Richwine of Ivy Tech State College in Anderson, Ind., was honored with the AWS Professionalism Award, and The Lincoln Electric Co., Indianapolis, Ind., was given the Clifford Hunt Award.

The three-day tournament wrapped up with an awards banquet with Richard Alley as the keynote speaker.

Ford Technical Center Takes First Place in Welding Contest

Ford Technical Center students Mark Campbell, James Grygo, and Daron Cruickshank after winning first-place in the AWS Welding Show 2003 contest.

Mark Campbell, James Grygo, and Daron Cruickshank from the William D. Ford Career Technical Center in Westland, Mich., welded the winning project and earned their school $1000 in the welding contest sponsored by the Detroit Section of the American Welding Society.

In the weeks before the April 8–10 AWS Welding Show 2003, the students, guided by their instructor, Nick Regets, spent hours in class and after school to successfully complete their entry — a welded 2 x 2 x 2-ft structure of dissimilar metals that includes the letters A-W-S.

Regets proudly said, “Their persistence and dedication to accomplishing this AWS display was a pleasure to see. Despite any setbacks or difficulties, they continued to make their best efforts at every stage of this project.

The students, ranging in age from 16 to 18, plan to make welding a career after graduation. Their goals include underwater welding, joining the military as a welder, and owner/operator of a welding shop.

A second-place prize of $500 was awarded to Richard Hamilton, Ray Kennedy, and Chris Rohlig of Oakland Technical Center, Southwest Campus, in Wixom, Mich. The students spent approximately four weeks working on their winning project under the observation of instructor Bob Hughes. The prize money will go toward updating the class welding equipment.
MAINE
MARCH 14
Activity: The Section hosted the SkillsUSA/VICA Welding Competition. Section members acted as judges. (See page 71.)

BOSTON
APRIL 14
Speaker: Paul Gabriel, sales representative.
Affiliation: Olympus Industrial, Orangeburg, N.Y.
Topic: Borescope remote visual inspection technology.
Activity: Demonstrations were given of visual inspection of the inner bead surfaces of pipe welds.

LEHIGH VALLEY
MARCH 4
Speaker: Claudia Kaufman.
Affiliation: Fast AWS District 3 director.
Activity: Kaufman presented the District Director Award to Alan Pense for his work on the Section's Robert D. Stout Scholarship Program.

APRIL 8
Speaker: Rich Gallagher, technical representative.
Topic: Programmable pulsed gas metal arc and metal cored welding.

YORK-CENTRAL PENNSYLVANIA
APRIL 16
Speaker: Glen Washer.
Affiliation: Federal Highway Administration, Va.
Topic: Nondestructive testing of highway structures.
Activity: This was a joint meeting with the local ASNT Chapter.
Niagara Frontier Section Chairman Frank Schweers, third from left, and guest speaker Dennis Klingman, fourth from left, with members of the "Garage Guys," a local hot rod club, at the Section's March meeting.

SOUTH CAROLINA
MARCH 20
Speaker: Kenny Inabinette, production manager.
Affiliation: Division Five, Inc., Hollywood, S.C.
Topic: The Section received a tour of the Division Five plant.

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

NORTHERN NEW YORK
APRIL 1
Speaker: Jeff Zook, northeast regional sales manager.
Affiliation: Gullco International, Cleveland, Ohio.
Topic: Simplified automation and Ghana oil tanks.

NIAGARA FRONTIER
MARCH 20
Speaker: Dennis Klingman, director of technical training.
Affiliation: The Lincoln Electric Co., Cleveland, Ohio.
Topic: Motor sports welding.

JOHNSTOWN/ALTOONA
DECEMBER 4
Speaker: William Krupa, area manager.
Affiliation: Johnstown America Corp., Johnstown, Pa.
Activity: Members toured the Johnstown America Corp. aluminum coal car production line.
CINCINNATI
March 4
Speaker: Dennis Klingman, manager of technical training.
Affiliation: The Lincoln Electric Co., Cleveland, Ohio.
Topic: Motor sports welding.

DISTRICT 8
Director: Wallace E. Honey
Phone: (256) 332-3366

CHATTANOOGA
February 13
Activity: The Chattanooga Section Education Committee, in conjunction with Local Union #43 Plumbers and Steamfitters, held Student Night at the Plumbers and Steamfitters Union Hall in Chattanooga. The evening's activities included a tour of L.U. 43 Training and Apprenticeship programs and a demonstration of the narrow groove welding process. Guest speakers included Bob Rausch, project manager steam generator replacement, TVA; Bob Leonard, project manager, Bechtel; Mike Blevins, installation manager, Bechtel; Arnold Edwards, engineer, PCI; Briggs Smith, director of career and technical education, Hamilton County; and Doug Daily, union representative and apprenticeship coordinator. Door prizes for the evening were donated by local welding supply distributors.

March 20
Activity: Members toured the Aftek plant. Demonstration booths were set up for those who wished to weld with their products.

NORTHEAST MISSISSIPPI
March 20
Speaker: Judith Schneider, assistant professor.
Affiliation: Mississippi State University, Department of Mechanical Engineering.
Topic: The aluminum friction stir welding process.

HOLSTON VALLEY
April 1
Activity: Discussion on the upcoming District 8 Conference in Greeneville, Tenn.

NORTHEAST TENNESSEE
April 14, 15, and 16
Activity: The Tennessee SkillsUSA/VICA Welding Competition was held at the Tennessee Technology Center - Knoxville.

GREATER HUNTSVILLE
April 17
Activity: A meeting was held to discuss the District 8 Conference.

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

BATON ROUGE
November 11, 2002
Speaker: John Allgood, Level III NDE consultant
Affiliation: GCT, Houston, Tex.
Topic: Film interpretation.

NEW ORLEANS
March 18
Speaker: Anthony Nikodym, market manager.
Affiliation: Hobart Brothers, Troy, Ohio.
Topic: Understanding stainless steel coating types and ferrite.
Activities: The Section held Awards Night. Dr. G. W. Oyler received the Gold Member Award; Edward M. Gray, Jr., was presented with the Life Member Award; and Bruce A. Hallila, Dale D. Norman, William W. St. Cyr, and Paul T. Hickey received the Silver Member Award. It was also Student Night. Industrial Welding Supply hosted the evening and gave away $10 gift certificates and one $100 gift certificate.
Guest Speaker Anthony Nikodym, left, with Russ McClellan, center, and New Orleans First Vice Chairman David Foster at the March meeting.

Charles Hebert won the 50/50 raffle. Lloyd Lemle presented a $500 sponsorship check for the Annual Fishing Rodeo on behalf of Conoco/Phillips Refinery, Alliance, La.

**DISTRICT 12**
Directory: Michael D. Kersey
Phone: (262) 650-9364

Milwaukee Section Chairman Bob Schuster, right, and Vice Chairman John Kozieniak, left, presenting Dave Biddle of P&H Mining with a plaque honoring the company for its commitment to AWS members and functions.

**DISTRICT 11**
Directory: Efthios Siradakis
Phone: (989) 894-4101

Western Michigan
March 24
Speakers: Nate Hoffman, Joshua Goins, Bill Hunting, and Maxwell Payment, college welding engineering students.
Affiliation: Ferris State University, Big Rapids, Mich.
Topic: What each student's summer 2002 internship entailed.

**DISTRICT 13**
Directory: J. L. Hunter
Phone: (309) 888-8956

Peoria Section guest speakers Brad Walden, left, and Uwe Aschemeier during their March presentation.
CHICAGO
MARCH 19
Speakers: Dave Watson, regional sales manager, and Dave Vogeler, sales engineer.
Affiliation: LASAG Industrial Lasers.
Topic: The parameters, applications, and limitations of laser welding.

PEORIA
MARCH 19
Speaker: Uwe Aschemeier, senior welding engineer, and Brad Walden, supervisor of diving services.
Affiliation: H. C. Nutting Company.
Topic: Underwater welding.

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

TRI RIVER
NOVEMBER 13, 2002
Activities: Annual Student Night and Stump the Experts. Students tried to stump experts John Durhin, Ivy Tech State College Welding Department chairman, and Earl Young, QC manager for Industrial Contractors, for prizes.

MARCH 12
Speaker: Dennis Scott, electrical supervisor.
Affiliation: Industrial Contractors, Inc., Evansville, Ind.
Topic: The use of aluminum gas tungsten arc welding in electrical construction and maintenance.

MISSISSIPPI VALLEY
MARCH 19
Speaker: Kelly Campbell, official welder, for the International Hot Rod Association.

INDIANA
MARCH 19, 20, and 21
Speaker: Mike Anderson.
Affiliation: New Castle High School.
Activity: The 25th Annual Mid-West Team Welding Competition was held. Twenty-two welding teams participated from high schools in Indiana and Kentucky and competed for team and individual trophies. In addition to trophies, $3000 in prizes were given away to the winners. Welding instructors Larry Hensley and Jan Conway received the Ivan Simmons Award.

ST. LOUIS
MARCH 20
Activity: The Section toured the Tower Automotive Manufacturing facility in Granite City, Ill.

DISTRICT 15
Director: J. D. Heikkinen
Phone: (218) 741-9693

DISTRICT 16
Director: C. F. Burg
Phone: (515) 294-5428

NEBRASKA
MARCH 13
Activity: Jeff Rodenbarger guided members on a tour of the Drake Williams Steel plant in Omaha, Nebr.

KANSAS
MARCH 20
Speaker: John Stoll.
Affiliation: The Lincoln Electric Co.
Topic: Safety in the work environment.

EASTERN IOWA
MARCH
Activity: Plant Manager Tim Tompkins led members on a tour of the Sears Manufacturing plant.

DISTRICT 17
Director: Oren P. Reich
Phone: (254) 867-2203

TULSA
JANUARY 28
Speaker: William D. Underwood, manager of geoscience education.

Participants in the Indiana Section's 25th Annual Mid-West Team Welding Tournament at the Awards Banquet.
Kansas Section members pose for a photograph with guest speaker John Stoll, center holding plaque, from The Lincoln Electric Co.

Tulsa Section Chairman Jerry Knapp, right, with guest speaker Bill Underwood.

District 17 Director Oren Reich, right, with Tulsa Section Chairman Jerry Knapp at the Section's Ladies' Night social.

Activity: Members toured the society's Geoscience Resource Center Museum. The mission of the society is to educate students, teachers, and their families about the geosciences and their application in petroleum, mining, and the environment.

February 15
Speaker: Oren Reich.
Affiliation: AWS District 17 director.
Activity: Ladies' Night.

North Texas Section Chairman J. Jones, right, presenting guest speaker Trey Jenkins with a North Texas Section shirt in appreciation of arranging a tour of the Peterbilt Motors facility for Section members.

March 25
Speaker: Frank Babish, product manager - welding products.
Affiliation: Sandvik, Scranton, Pa.
Topic: Welding duplex stainless steel.

NORTH TEXAS
March
Activity: Trey Jenkins guided members on a tour of the Peterbilt Motors Company plant in Denton, Tex.

April 1
Speaker: Ernest Levert, senior staff engineer and AWS president.
Affiliation: Lockheed Martin Missiles and Fire Control.
Activity: Al Bernson was honored with the 5-Year Award and Larry Jeffus received his 25-Year Award. Jeffus made a donation of his book, Welding Principles and Applications, 5th ed., to the Section for its library section at the Dallas Public Library.

Lake Charles Section members learning about tube to tubesheet seal welding during their March tour of the Ohmstede-United Industrial Services tour.

Lake Charles
March
Activity: Section members toured the Ohmstede-United Industrial Services plant.

Sabine
March 18
Speaker: John Mendoza, District 18 director.
Affiliation: American Welding Society.
Topic: American Welding Society news and notes.
Activity: Mendoza presented awards during the meeting. Alton Wolf received the CWI of the Year Award, Ruel Riggs was given the District Director Award,
District 18 Director John Mendoza, left, with Sabine Section award winners, from right, Carey Wesley, Mark Clark, Alton Wolf, and Ruel Riggs.

District 19
**Director:** Phil Zammit  
**Phone:** (509) 468-2310 ext. 120

Puget Sound Section Chairman Ken Johnson, right, discussing metallurgical testing with guest speaker Blaine Maki.

Puget Sound
**March 6**  
**Speaker:** Blaine Maki, manager.  
**Affiliation:** METAL-TEST, Inc.  
**Topic:** The various types of metallurgical testing required on many welding procedures.  
**Activity:** The Section presented two welding scholarship checks to Lake Washington Technical College students.

Alaska
**March 28**  
**Speakers:** Dan Houghes and Joe Houghes.  
**Affiliation:** Arcos Industries, LLC.  
**Topic:** The thermal spray process and demonstration of a typical application.

District 22
**Director:** Kent S. Baucher  
**Phone:** (559) 276-9311

Guest speaker David Diaz, left, with Sacramento Valley Section First Vice Chairman Dale Flood.

Sacramento Valley
**April 16**  
**Speaker:** David Diaz.  
**Topic:** Weld Procedure (WPS) development.

International Section

Saudi Arabia
**April 13**  
**Activity:** The Section held an Executive Committee meeting. Discussed during the meeting were the objectives of the Section and the schedule for the 2003-2004 season. New Section officers were named, committees were formed, and members-at-large were identified.

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 the AWS Web site has for you, just visit [www.aws.org](http://www.aws.org).
Student Events

DISTRICT 13
Director: J. L. Hunter
Phone: (309) 888-8958

PEORIA
Illinois Central College
MARCH 1
Activity: The Student Chapter held an “Introduction to SCUBA” at the Bradley University pool. This gave students an opportunity to see if that part of underwater welding appealed to them.

MARCH 19
Activity: Students joined the Peoria Section for a meeting with two underwater welders from H. C. Nutting Company as guest speakers.

DISTRICT 20
Director: Jesse A. Grantham
Phone: (303) 451-6759

IDAHO
Brigham Young University
OCTOBER 30, 2002
Activity: The students toured the AMET facility.

DECEMBER 12, 2002
Speakers: Mark Miken, president, and Dean Park.
Affiliation: Miskin Scrap Works.
Activity: Members toured the Miskin Scrap Works plant in Idaho Falls, Idaho.
Four students from the Montana Tech AWS Student Chapter accompanied the Brigham Young Chapter members.

AWS Peoria Section Holds Its First Welding Contest

On March 19, the American Welding Society's Peoria Section held its first welding contest. The contest, which was held at Illinois Central College's (ICC) new welding lab, was coordinated by ICC Professor Richard Polanin.

The contest was split into four divisions: gas metal arc, shielded metal arc, gas tungsten arc, and combination welding. Thirty-seven students competed in the secondary and postsecondary categories. The contest was judged by five members with CWI certification.

All entrants received complementary safety glasses and welding gloves. Students placing first and second received prizes such as scholarships, AWS student memberships, autodarkening helmets, and welding jackets. Prizes were awarded the following week at the Awards Banquet.

Plans are already underway for the Second Annual Peoria Section Welding Contest.

Program Extends Deadline for Quality Certification

Profitability for more than 49,000 companies throughout North America depends on ISO 9001/2 certification. By December 15, these same companies must adhere to the 2000 edition of ISO's standards or risk losing their status as a certified corporation in the eyes of the International Accreditation Forum (IAF). IAF will not allow companies more time, so the International Accreditation Registry has conceived the "Phased Transition Program" to assist those companies unable to upgrade their certification so quickly.

Under the guidelines of the Phased Transition Program, IAR will honor the status of companies that meet the current standards until December 31, 2004, giving qualifying companies and certification bodies another 12 months to make the transition without risk of losing their quality certification status.

For more information on the program and the International Accreditation Registry, call Marisol Valenzuela at (305) 446-3894, e-mail mvalenzuela@iarinternational.org, or visit the Web site at www.iarinternational.org.
D1.2 Now Available

The American Welding Society (AWS) has published AWS D1.2/D1.2M:2003, Structural Welding Code — Aluminum. This first revision of D1.2 code since 1997 has been restructured to more closely resemble the format of the widely used and accepted AWS D1.1, Structural Welding Code — Steel. Users will benefit from a format that is easier to understand and apply. Both U.S. Customary and SI units are now used. AWS D1.2/D1.2M:2003 is unsurpassed in providing the specifications needed to ensure integrity of welded aluminum structures.

AWS D1.2/D1.2M:2003, Structural Welding Code — Aluminum contains the requirements for fabricating and erecting welded aluminum structures. The requirements include the design of welded connections, weld procedure and welder performance qualification, inspection procedures and acceptance criteria, stud welding procedures, and the repair and strengthening of existing structures.

AWS D1.2/D1.2M:2003 is 216 pages and contains 27 tables and 59 figures. The price for AWS members is $93; for nonmembers, the price is $124.

To Order AWS Publications

To order AWS publications, call Global Engineering Documents at (800) 854-7179 or, outside the United States, (303) 397-7956 or visit the AWS Web site at www.aws.org.

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 NW LeJeune Rd., Miami, FL 33126; FAX: (305) 443-7404; e-mail: campbell@aws.org.

Standard Notices

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, 25 West 43rd St., Fourth Fl., 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 NW LeJeune Rd., Miami, FL 33126; telephone (305) 443-9353 ext. 466, e-mail: adavis@aws.org. Otherwise, contact your national standards body.

ISO/DIS 17640-2, Non-destructive examination of welds — Ultrasonic examination of welded joints.


New Standards Approved by ANSI


International Brazing and Soldering Conference 2003 Proceedings Now Available

The American Welding Society (AWS) has just released the proceedings from the International Brazing and Soldering Conference (IBSC) 2003 on CD-ROM. The CD can be purchased for $79.00 by calling 1-800-854-7179 or online at www.global.ihs.com.

The documents included on the CD reflect the goal of the conference, which was to highlight technical advances in the areas of ceramic and metal joining, modeling and measurements, interfacial reactions and properties, materials and process development, process characterization, reliability and testing, and applications. This CD can be considered an excellent source for information in these areas.

The latest work in brazing and soldering science and technology from recognized international experts in the field is featured on the CD. Topics range from fundamental metallurgical research to practical engineering solutions.

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 NW LeJeune Rd., Miami, FL 33126; telephone: (305) 443-9353 or, outside the United States, (305) 443-9353.

June 3, D16 Committee on Robotic and Automatic Welding. Chicago, Ill. Standards preparation and general meeting. Staff contact: P. Howe, ext. 309.

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 NW LeJeune Rd., Miami, FL 33126, telephone, (305) 443-9353 ext. 244, FAX: (305) 443-7404, e-mail: campbell@aws.org.
2002-2003 Member-Get-A-Member Campaign

Listed below are the people participating in the 2002-2003 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**
M. Merzthal, Pensacola**
T. Skaff, Chicago, IL
J. Merzthal, Pensacola*
B. A. Mikolajko, Houston*
R. L. Peaslee, Detroit*
W. L. Shreve, Fox Valley*
G. Taylor, Pascagoula*
T. Weaver, Johnstown/Altoona*
G. Woomer, Johnstown/Altoona*
R. Wray, Nebraska*

*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, 2002, and May 31, 2003.)

G. Baum, Madison-Beloit
G. Huegin, Corpus Christi
S. Giese, Naples
W. Galvery, Jr, Long Beach/Orange County
G. Taylor, Pascagoula
T. Shirk, Corpus Christi
J. Smith, Corpus Christi
J. Compton, Corpus Christi
J. Ruiz-Castro, New Jersey
D. Scott, Peoria
K. Tebeau, Detroit
T. Tipton, Milwaukee
C. Wesley, NW Pennsylvania
P. Zamarin, Spokane
G. Atherton, Philadelphia
J. Biseggs, Rochester
F. Bonifati, International
C. Casey, Arizona
C. Daily, Puget Sound
A. Duschere, Long Island
T. Erichsen, Santa Clara Valley
E. Ezell, Mobile
M. Fedoruk, Maryland
R. Fitch, Southwest Virginia
N. Gool, Northwest Territory
S. Harville, Mobile
S. Hunt, Shreveport
W. Kilchron, East Texas
F. Langs, Central Mass./RI
D. Lockman, Alaska
A. Lynch, Pittsburgh
M. Marcum, Johnny Appleseed
D. Moulton, Saginaw Valley
F. Nguni, New Jersey
J. Norris, Iuernival
M. Perry, Tulsa
M. Powell, Lehigh Valley
D. Roskiewich, Philadelphia
G. Spengler, Chicago
R. Stobaugh, Jr, Carolina
J. Wells, Central Texas
B. Worley, Dayton

Student Sponsors
(AWS members sponsoring 3 or more new AWS Student Members between June 1, 2002, and May 31, 2003.)

D. Scott, Peoria
C. Wesley, Northwestern Pa.
W. Galvery, Jr, Long Beach/Orange County
A. Lynch, Pittsburgh
S. Caldera, Portland
B. Huff, Saginaw Valley
J. Sullivan, Mobile
T. Geisler, Pittsburgh
S. Sviskis, Maine
D. Combs, Santa Clara Valley
R. Grays, Kern
H. Browne, New Jersey
R. Durham, Cincinnati
F. Mong, Pittsburgh
J. Cox, Northern Plains
W. Harris, Pascagoula
K. Langdon, Johnny Appleseed
R. Boyer, Nevada
G. Woomer, Johnstown/Altoona
V. Hunter, Blackhawk
R. Robles, Corpus Christi
F. Juckem, Madison-Beloit
W. Kielhorn, East Texas
M. Anderson, Indiana
J. Hayes, Oklahoma City
D. Roskiewich, Philadelphia
F. Wernet, Lehigh Valley
S. Zwilling, Louisville
D. Davis, New Orleans
R. Fulmer, Twin Tiers
B. Lavallie, Northern New York
E. Soto Ruiz, Puerto Rico
A. Badeaux, Washington, D.C.
G. Euliano, NW Pennsylvania
C. Kipp, Lehigh Valley
F. Madrid, Arizona
R. Shrewsbury, Tri-State
R. Hilfy, Pittsburgh
T. Strickland, Arizona
D. Hatfield, Tulsa
C. Jones, Houston
K. Geist, Olympic
D. Ketter, Williamette Valley
J. Pelster, Southeast Nebraska
Z. Zabel, Southeast Nebraska
M. Pointer, Sierra Nevada
P. Walker, Ozark
J. Livesay, Nashville
R. Rux, Wyoming
D. Smith, Niagara Frontier
R. Tipta, Milwaukee
J. Boyer, Lancaster
J. Ciaramitaro, North Central Florida
S. Hoff, Saginaw Valley
A. Vidieck, Wyoming
R. Ledford, Jr, Birmingham
J. Smith, Mobile
P. Baldwin, Peoria
T. Buchanan, Mid-Ohio Valley
A. Honeycutt, LA/Inland Empire
T. Kienbaum, Colorado
D. Kowalski, Pittsburgh
R. Ledford, Jr, Birmingham
G. Menzer, LA/Inland Empire
E. Norman, Ozark
D. Parker, East Idaho/Montana
J. Smith, Great Hunsville
S. Strader, Portland
J. Yokum, South Florida
R. Brown, LA/Inland Empire
J. Compton, San Fernando Valley
A. DeMarco, New Orleans
R. Felix, Long Beach/Orange County
L. Frechette, San Francisco
J. Goodson, New Orleans
R. Hostun, Olympic
M. Kochler, Milwaukee
D. Marquis, Ozark
A. Mattix, Lexington
J. McCarty, St. Louis
W. Miller, Jr, New Jersey
F. Ramos, Sacramento
M. Rice, North Texas
H. Riviere, South Florida
T. Shirk, Tidewater
R. Vann, South Carolina

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GUIDE TO AWS SERVICES
550 NW LeJeune Rd., Miami, FL 33126
Phone (800) 443-9353; (888) WELDING
FAX (305) 443-7559; Internet: www.aws.org
Phone extensions appear in parentheses.
E-mail addresses available on the AWS Web site.

AWS PRESIDENT
Thomas M. Mustaleski
BWXT Y-12 LLC
P.O. Box 2009
Oak Ridge, TN 37831-8096

ADMINISTRATION
Executive Director
Ray W. Shook
(210)
Deputy Executive Directors
Jeffrey R. Hufsey
John F. McLaughlin
(264)
(235)

Corporate Director Volunteer Services
Debbie A. Cudavid
(222)

Corporate Director of Quality Management Systems and Human Resources Administration
Linda K. Henderson
(298)

Chief Financial Officer
Frank R. Barata
(252)

INFORMATION SERVICES
Corporate Director
Joe Cilli
(258)

HUMAN RESOURCES
Director
Luisa Hernandez
(266)

DATABASE ADMINISTRATION
Corporate Director of Database Administration
Jim Lankford
(214)

INTERNATIONAL INSTITUTE OF WELDING
Information
(294)

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

GOVERNMENT LIAISON SERVICES
Hugh K. Webster
Webster, Chamberlain & Bean
Washington, D.C.
(202) 466-2976
FAX (202) 855-0243

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)

WELDING INDUSTRY NETWORK (WIN)
Associate Executive Director
Richard L. Alley
(217)

CONVENTION & EXPOSITIONS
Exhibiting Information
(242, 295)
Associate Executive Director of Convention Sales
Richard L. Alley
(217)

Director of Convention & Expositions
John Osipin
(462)

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

PUBLICATION SERVICES
Department Information
(275)
Director
Andrew Cullison
(249)

WELDING JOURNAL
Publisher
Jeff Weber
(246)
Editor/Editorial Director
Andrew Cullison
(249)
National Sales Director
Rob Saffrin
(237)

WELDING HANDBOOK
Welding Handbook Editor
Annette O'Brien
(303)

Plants and coordinates marketing of AWS products and services. Responsible for print advertising, as well as design and print production of the Welding Journal, Inspection Trends, the annual Welding Show Program, and other AWS promotional publications.

MARKETING AND DESIGN
Corporate Director
Jeff Weber
(246)

Plans and coordinates marketing of AWS products and services. Responsible for print advertising, as well as design and print production of the Welding Journal, Inspection Trends, the annual Welding Show Program, and other AWS promotional publications.

MARKET RESEARCH AND DEVELOPMENT
Corporate Director
Deborah C. Weit
(482)

Investigates and/or proposes new products and services. Researches effectiveness of existing programs.

MEMBER SERVICES
Department Information
(450)
Associate Executive Director
Carole R. Burrell
(253)

Director
Rhema A. Mayo
(260)

Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and other activities of interest.

EDUCATIONAL PRODUCT DEVELOPMENT
Director
Christopher B. Pollock
(219)

Information on education products, projects, and programs. Responsible for the S.E.N.S.E. program for welding education, and dissemination of training and education information on the Web.

CONFERENCES & SEMINARS
Director
Gisele L. Hufsey
(278)

Responsibilities include planning and coordination of AWS conferences, workshops, seminars, and other events.

CERTIFICATION OPERATIONS
Managing Director
Wendy S. Reeves
(215)
Director
Terry Perez
(470)

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

INTERNATIONAL BUSINESS DEVELOPMENT
Director
Walter Herrara
(475)

Coordinates AWS awards and AWS Fellow and Counselor nominations.

TECHNICAL SERVICES
Department Information
(340)
Managing Director
Leonard P. Connor
(302)

Welding Qualification, Computerization, Technical Activities Committee
Andrew R. Davis
(466)
International Standards Program Manager
Welding in Marine Construction, Inspection, Mechanical Testing of Welds
Stephen P. Hedrick
(305)

Safety and Health Manager, Metric Practices, Friction Welding
John L. Gayler
(472)

Skeletal Welding, Personnel and Facilities Qualification
Rakesh Gupta
(301)

Filler Metals and Allied Products, Instrumentation for Welding, Sheet Metal Welding
Ed F. Mitchell
(254)

Thermal Spray, Iron Castings, Joining Plastics & Composites, Joining of Metals and Alloys, Railroad Welding
Harold P. Ellison
(259)

Resistance Welding, High-Energy Beam Welding and Cutting, Oxygen Fuel Gas Welding & Cutting, Automotive Welding, Aircraft and Aerospace
Peter Howe
(309)

Arc Welding & Cutting, Piping & Tubing, Machinery and Equipment, Robotics and Automatic Welding, Food Processing Equipment
Cynthia Jemper
(304)

Definitions & Symbols, Brazing & Soldering, Filler Metals for Brazing and Brazed Welds, Technical Editing
Rosalinda O'Neill
(451)

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. However, such opinions represent only the personal opinions of the individuals giving them. These oral opinions are not rendered on behalf of AWS. Only the standards and codes that are published in AWS standards contain interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

WEB SITE ADMINISTRATION
Director
Keith Thompson
(414)
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, must have been a member for at least one year, and should be of executive status in business or industry with experience in financial affairs.

Director-at-Large: To be eligible for election as a Director-at-Large, an individual shall have full rights of membership.

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 Richard L. Arr, Chairman, National Nominating Committee, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126.

The next meeting of the National Nominating Committee is currently scheduled for April 2004. The terms of office for candidates nominated at this meeting will commence June 1, 2005.

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 Exposition 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 NW LeJeune Rd., Miami, FL 33126.

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

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

International Meritorious Certificate Award: This award is given in recognition of the candidate's significant contribution 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 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.
## American Welding Society

**Founded in 1919 to Advance the Science, Technology and Application of Welding**

### AWS Certification is the welding industry's most respected sign of approval.

### AWS’ Authoritative Seminars

prepare you for the CWI or CWE examination.

### Seminar and Exam Schedule for August 2003 Through October 2003

<table>
<thead>
<tr>
<th>AUGUST 2003</th>
<th>SEMINAR DATES</th>
<th>EXAM DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque, NM</td>
<td>8/3-8</td>
<td>8/9/2003</td>
</tr>
<tr>
<td>Columbus, OH</td>
<td>8/4-8 at NBBPV</td>
<td>8/9/2003</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>8/10-15</td>
<td>8/16/2003</td>
</tr>
<tr>
<td>Memphis, TN</td>
<td>8/10-15</td>
<td>8/16/2003</td>
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<tr>
<td>Indianapolis, IN</td>
<td>8/17-22</td>
<td>8/23/2003</td>
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<td>Houston, TX</td>
<td>8/17-22</td>
<td>8/23/2003</td>
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<tr>
<td>Charlotte, NC</td>
<td>8/24-29</td>
<td>8/30/2003</td>
</tr>
<tr>
<td>Rochester, NY</td>
<td>8/24-29</td>
<td>8/30/2003</td>
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<table>
<thead>
<tr>
<th>SEPTEMBER 2003</th>
<th>SEMINAR DATES</th>
<th>EXAM DATES</th>
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<tbody>
<tr>
<td>Anchorage, AK</td>
<td>9/7-12</td>
<td>9/13/2003</td>
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<tr>
<td>New Orleans, LA</td>
<td>9/7-12</td>
<td>9/13/2003</td>
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<tr>
<td>Minneapolis, MN</td>
<td>9/14-19</td>
<td>9/20/2003</td>
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<tr>
<td>San Diego, CA</td>
<td>9/14-19</td>
<td>9/20/2003</td>
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<tr>
<td>Dallas, TX</td>
<td>9/21-26</td>
<td>9/27/2003</td>
</tr>
<tr>
<td>Detroit, MI</td>
<td>9/21-26</td>
<td>9/27/2003</td>
</tr>
<tr>
<td>Milwaukee, WI</td>
<td>9/28-10/3</td>
<td>10/4/2003</td>
</tr>
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</table>

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<thead>
<tr>
<th>OCTOBER 2003</th>
<th>SEMINAR DATES</th>
<th>EXAM DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver, CO</td>
<td>10/5-10</td>
<td>10/11/2003</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>10/12-17</td>
<td>10/18/2003</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>10/19-24</td>
<td>10/25/2003</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>10/19-24</td>
<td>10/25/2003</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>10/26-31</td>
<td>11/1/2003</td>
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<tr>
<td>Atlanta, GA</td>
<td>10/26-31</td>
<td>11/1/2003</td>
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### Seminar and Exam Schedule

<table>
<thead>
<tr>
<th>Course</th>
<th>Schedule</th>
</tr>
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<tbody>
<tr>
<td>D1.1 Code Clinic</td>
<td>Sunday; 1 p.m. - 5 p.m.</td>
</tr>
<tr>
<td>API 1104 Code Clinic</td>
<td>Monday; 8 a.m. - Noon</td>
</tr>
<tr>
<td>Welding Inspection Technology</td>
<td>Tuesday-Thursday; 8 a.m. - 5 p.m.</td>
</tr>
<tr>
<td>Visual Inspection Workshop</td>
<td>Friday; 8 a.m. - 5 p.m.</td>
</tr>
<tr>
<td>Exam</td>
<td>Saturday; report for exam at 7:30 a.m.</td>
</tr>
</tbody>
</table>

To register or for more information on an exam prep course, call (800) 443-9353, ext. 226; to request an application for CWI exam qualification, call ext 273.

To find out about AWS Customized In-House Training and Quality Assurance Programs for your company, call AWS, toll-free at 1-800-443-9353, ext. 482, or check the box on the registration form.

Visit our website [www.aws.org](http://www.aws.org) for additional dates.

AWS reserves the right to cancel or change the published date of an exam preparation seminar listed if insufficient number of registrations are received. Prices are subject to change without notice.
Catalog Lists Hundreds of Automation Sensors

The catalog contains inductive, photo-electric, and capacitive sensor products and accessories for industrial uses, such as assembly processes, cylinders and valves, and remote systems.

Bailuff Inc.
8125 Holton Dr., Florence, KY 41042

Replacement Plasma Cutting Torches Featured in Brochure

The six-page brochure features selection guidelines for "Torch" models SL60™ (light/medium duty) and SL100™ (medium/heavy duty) hand torches, which can be used as replacements with most plasma cutting power supplies.

Thermal Dynamics Corp.
16032 Swingley Ridge Rd., Ste. 300, St. Louis, MO 63017

Steel Building Seismic Standards Published

The 2002 AISC Seismic Provisions for Structural Steel Buildings (ANSI/AISC 341-02) is now available in print and electronic form. The publication is a revision of the 1997 version and addresses the design and construction of structural steel and steel-reinforced building systems for seismic demands. The printed document costs $30 ($20 for AISc members) and the electronic version is available for free download at www.aisc.org.

American Institute of Steel Construction
One East Wacker Dr., Ste. 3100, Chicago, IL 60601-2001

Catalog Describes Power Tools and Abrasives

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Correction

The April 2003 Welding Journal's Learning Track column on page 113 contained an error regarding Alfred State College's AOS (Associates in Occupational Studies) degree in welding technology. The article stated students must take additional liberal arts courses to earn an AOS degree. This is incorrect. To earn an AOS degree, students need only complete technical courses in the welding program, which includes no liberal arts courses.*
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TRUMPF Announces President/CEO

TRUMPF Inc., Farmington, Conn., has announced Rolf Biekert will serve as president and CEO of TRUMPF Inc., the North American subsidiary of the TRUMPF Group. Biekert will succeed Peter Leibinger, who is returning to Germany to serve as president of TRUMPF Laser GmbH and Co. KG, Schramberg, Germany. Leibinger will remain on the TRUMPF Group board of directors, continuing to oversee North American operations, and will assume responsibility for the laser business unit.

Biekert, who will assume his new position effective July 1, has been with the company for more than 17 years. During that time, he has held a number of professional and managerial positions both in Germany and the United States.

Leibinger will replace Paul Seiler, who retires in June. He remains on the board of directors of the holding company, serving as executive vice president.

Jackson Products Names President/CEO

Jackson Products, Inc., St. Louis, Mo., has named David Gilchrist as president and chief executive officer. Gilchrist has more than 30 years of management experience in several industries, including building products, automotive, electronics, medical, consumer products, and fabricated metals. He joined the company from VP Buildings, Memphis, Tenn., where he served as president and chief executive officer since 1995. Gilchrist has a bachelor's degree in mechanical engineering from the United States Naval Academy and an M.B.A. from St. Francis College.

St. Louis Metallizing Announces Promotions

St. Louis Metallizing Co., St. Louis, Mo., recently announced the following promotions:

Todd Degitz, formerly sales manager, was promoted to vice president of sales. Degitz, who received a M.B.A. from Lindenwood University, began his career at the company in 1989 as a sales engineer.

Les Nappier was named vice president of operations. Previously plant superintendent, Nappier graduated from the Washington University EMBA program geared toward manufacturing management.

PCI Makes Staff Changes

PCI Energy Services LLC, Lake Bluff, Ill., has announced the following personnel changes.
John Stringer has been named vice president of marketing and sales. Stringer most recently served as operations director for Ocean State Technical Services.

Jim LaFortune has been appointed director, support operations. LaFortune has been with the company for 18 years. His past positions include purchasing agent and director of purchasing.

Tim Grubbs has been named general manager, steam generator replacement and special projects. Grubbs has held positions of increasing authority during his 15 years with the company including quality assurance engineer NDE III, quality assurance manager, and vice president of quality and safety.

Bill Reinhardt has been named southeast regional account manager. He has been with the company for six years. He holds a bachelor's degree from the College of William and Mary, Williamsburg, Va.

Mike Petersen has been appointed southwest/west regional account manager. Petersen, who has been with the company for 17 years, previously held the positions of field supervisor, thermal operations manager, and midwest regional account manager.

Steve Sirianni [AWS] has been named midwest regional account manager. He brings more than 15 years of experience in the field services industry to the company. Sirianni's previous employers include ComEd (Exelon) at Lasalle County Nuclear Station, Continental Field Machining, and Welding Services, Inc.

Hypertherm Appoints Sales Manager

Hypertherm, Inc., Hanover, N.H., has appointed Sergio Ferrero [AWS] sales manager for South America. Most recently, Ferrero served as South American contract manager for the company. Previously, he was employed as sales and marketing manager with Buenos Aires Welding. Ferrero holds an industrial engineering degree from the National University of Buenos Aires and an electronics technician degree from the National School of Technical Education.

ITW Hobart Brothers Announces New Regional Manager

ITW Hobart Brothers Company, Troy, Ohio, has announced the promotion of Raddy Thompson to southeast regional manager of its filler metal products. Thompson joined the company in 1998 as a district manager. Prior to joining the company, he was employed by Drake Atwood Industrial Tool and Supply.

Lincoln Names Manager

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has named Steven Sumner global product manager. Prior to his promotion, Sumner, who joined the company in 1987 as a mechanical engineer, served as manager of product development. He is a graduate of Cornell University, where he earned a bachelor of science degree in mechanical engineering, and Weatherhead School of Management at Case-Western Reserve University, where he received a M.B.A. in marketing.

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Preco Laser Systems Adds Engineer

Steve Llewellyn has joined Preco Laser Systems, LLC, Somerset, Wis., as a field sales engineer. Llewellyn brings to the job more than 20 years of industrial laser experience.

Advanced Fabricating Machinery Appoints Manufacturing Reps

Nick Grose of Industrial Manufacturing Solutions, Oshkosh, Wis., has been appointed the exclusive manufacturer’s representative for Advanced Fabricating Machinery in Minnesota, Wisconsin, and Illinois.

Grose has more than 20 years’ experience in the fabricating equipment industry.

Matt Mangulis of M & T Marketing, Centirburg, Ohio, has been named the exclusive manufacturer’s representative for Advanced Fabricating Machinery in Ohio, West Virginia, and northern Kentucky.

Genesis Systems Group Hires Engineer

Genesis Systems Group (GSG), Davenport, Iowa, has hired Roger Christensen as tooling design engineer for New Dimensions Tooling, a GSG business unit. Before joining the company, Christensen worked for Reynolds Manufacturing Co., Rock Island, Ill., as a tooling manager.

Grose has more than 20 years’ experience in the fabricating equipment industry.

Matt Mangulis of M & T Marketing, Centirburg, Ohio, has been named the exclusive manufacturer’s representative for Advanced Fabricating Machinery in Ohio, West Virginia, and northern Kentucky.

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Obituary

Boris A. Bernstein

Boris A. Bernstein [AWS], founding chairman of the AWS Puerto Rico Section, died on January 27 in Puerto Rico.

Bernstein was the owner of Servicios Profesionales de Inspección (SPIN-X) in the Dominican Republic, which his sons, David and Ronald, continue to operate. He had also owned Techniweld Lab, Dorado, Puerto Rico. Previously, he was quality assurance manager at Goodyear and Uniroyal, both in Venezuela. Bernstein became an AWS Certified Welding Inspector in 1990 and attained Senior Certified Welding Inspector status in 1997. In addition, he was certified by ASNT-Level III in RT, MT, and PT since 1994.

Bernstein had been an active member of the American Welding Society since 1980. He had served on the AWS board of directors as District 5 director and as a director-at-large. While serving on the AWS board, Bernstein worked to fulfill his goal of bringing Puerto Rico and the rest of the Caribbean, as well as North, Central, and South America together in welding excellence. In 1996, Bernstein received the AWS Dalton E. Hamilton CWI of the Year Award from both the Puerto Rico Section and District 5.

Bernstein is survived by his wife, Tere, and sons, David and Ronald.

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The American Welding Society announces a Call for Papers for the 2004 Professional Program to be held as part of Welding Show 2004 on April 6–8, 2004, in Chicago, Ill.

Submissions should fall into one of the following three categories and will be accepted only in a specific format. Individuals interested in participating should contact Dorcas Troche, Manager, Conferences and Seminars via e-mail at dorcas@aws.org for specific details. Deadline for submission of papers is Thursday, July 31, 2003.

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

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

**Education**
- Welding education at all levels.
- Emphasis is on education/training methods and their successes.
- Papers should address overall relevance to the welding industry.
Microstructural Evolution and Weldability of Dissimilar Welds between a Super Austenitic Stainless Steel and Nickel-Based Alloys

The influence of filler metal composition and dilution on fusion zone microstructure and solidification cracking susceptibility is evaluated for AL-6XN welded to IN622 and IN625

BY J. N. DUPONT, S. W. BANOVIĆ, AND A. R. MARDER

ABSTRACT. Microstructural evolution and solidification cracking susceptibility of dissimilar metal welds between AL-6XN super austenitic stainless steel and two nickel-based alloys, IN625 and IN622, were studied using a combination of electron microscopy, differential thermal analysis, and Varestraint testing techniques. Welds were prepared over the entire dilution range (where dilution was determined with respect to AL-6XN as the base metal). The effect of processing parameters and filler metal chemistry on the fusion zone composition, microstructure, and resultant weldability was investigated.

Iron additions to the weld (which occur with increasing dilution) increased the segregation potential of Mo and Nb. This behavior was attributed to a reduction in the solubility of Mo and Nb in austenite with increasing iron additions, as inferred from available binary phase diagrams. Welds prepared with IN625 formed a single interdendritic \( \sigma \) phase at the end of solidification, and the amount of this secondary phase was not sensitive to changes in dilution. The \( \sigma \) phase formed at a relatively high temperature and led to a relatively narrow solidification temperature range for welds prepared with IN625. In contrast, welds prepared with IN625 exhibited \( \text{NbC} \) and Laves phases in the interdendritic regions, and the total amount of secondary phase decreased with increasing dilution. Solidification of welds prepared with IN625 terminated with formation of the Laves constituent at relatively low temperature and, thus, the solidification temperature range of welds involving IN625 was relatively wide.

The solidification cracking sensitivity of welds prepared with IN622 was relatively low and independent of weld metal dilution level, while the cracking susceptibility of welds produced with IN625 was relatively high and increased with decreasing dilution. The dilution/cracking relation is controlled by the solidification temperature range and amount of secondary phase that forms at the terminal stages of solidification. The good cracking resistance of welds prepared with IN622 is attributed to the small amount of secondary phase and narrow solidification temperature range. The relatively poor cracking resistance of welds prepared with IN625 is attributed to a wide solidification temperature range and increasing amount of secondary phase that forms with decreasing dilution.

Introduction

Super austenitic stainless steels such as AL-6XN are used extensively in applications requiring good resistance to aqueous corrosion. These relatively high-nickel stainless steels contain Mo additions (~6-7 wt-%) for improved corrosion resistance. However, during solidification of the weld, Mo segregates preferentially to the liquid due to the low solubility of Mo in the austenite phase and leaves the first solid to form depleted in Mo (Ref. 1). In addition, the low diffusion rate of Mo in \( \gamma \) does not allow for Mo to diffuse back toward the dendrite cores to eliminate the concentration gradient. This can lead to poor corrosion resistance of the weld metal. Previous research has shown that the depleted dendrite cores are susceptible to preferential corrosion due to the low, localized Mo concentrations (Refs. 2-5). To compensate for this effect, high-Mo, nickel-based filler metals such as IN625 (~9 wt-% Mo) and IN622 (~14 wt-% Mo) are often utilized during fusion welding of these alloys (Ref. 5). While these filler metals do not eliminate microsegregation of Mo, the dendrite core compositions in the fusion zone are increased relative to those in autogenous welds, and this helps to minimize preferential attack at the dendrite cores.

With this approach, the final distribution of Mo (and other alloying elements)
Thus, the objective of this research was to characterize the microstructures and weldability of fusion welds in AL-6XN stainless steel as a function of filler metal composition (using IN625 and IN622) and welding parameters. The results of this study will be useful for ultimately minimizing solidification cracking in welds of this alloy.

**Experimental Procedure**

Welds were produced between AL-6XN stainless steel and nickel-based alloys IN622 and IN625 over the entire dilution range using the gas tungsten arc welding (GTAW) process. With the GTAW process, the volumetric filler metal feed rate and arc power can be independently controlled, thus easily changing the dilution levels. The starting substrate materials were approximately 0.64 cm thick, 2.54 cm wide, and 15.25 cm in length. The samples were held flush to the welding table in order to maintain a constant and reproducible heat sink, with the table being at room temperature before beginning each deposit. The travel speed was fixed at 2.0 mm/s with a 2.5-mm arc length, which produced a voltage of 14 ± 1.3 V.

Commercially pure argon was used as the shielding gas.

The materials used were AL-6XN and IN625 both in plate and filler metal form. A small heat of IN622 filler metal was obtained while C-22 (compositional equivalent for IN622) was used in plate form. Table 1 shows the respective compositions of all the materials. In order to produce dilution levels from 0 to 100%, with respect to AL-6XN as the base metal, IN625 and IN622 filler metal were deposited on AL-6XN for high dilution levels, typically above 50% dilution. For the lower values, the materials were reversed with AL-6XN filler metal being deposited onto IN625 and C-22 base metals.

Samples were removed from the welds, mounted in cold setting epoxy, and polished to a 0.04-μm finish using colloidal silica. Higher dilution level samples were electrolytically etched in a mixture of nitric acid (HNO₃) and water (H₂O) in the proportions of 60/40 using a platinum cathode at a preset voltage of 5 V. For the lower dilution levels, 10% oxalic acid was used under the same conditions. Microstructural characterization was performed using electron microscopy techniques. Dilution levels were determined by two methods: chemical analysis and geometric dilution calculations. For the former, quantitative chemical information was obtained through use of an electron probe microanalyzer (EPMA). A JFOL 733 SuperProbe EPMA, equipped with wavelength dispersive spectrometers, was operated at an accelerating voltage and probe current of 15 kV and 20 nA, respectively. Sample areas were approximately 1500 μm², large enough to avoid

---

**Table 1 — Compositions for Raw Materials (wt-%)**

<table>
<thead>
<tr>
<th></th>
<th>Filler Metal Diameter</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Nb</th>
<th>Mn</th>
<th>Si</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>0.064</td>
<td>47.6</td>
<td>23.9</td>
<td>21.3</td>
<td>6.4</td>
<td>0.0</td>
<td>0.2</td>
<td>0.3</td>
<td>0.032</td>
</tr>
<tr>
<td>IN625</td>
<td>0.035</td>
<td>47.0</td>
<td>24.4</td>
<td>20.9</td>
<td>6.3</td>
<td>0.0</td>
<td>0.2</td>
<td>0.3</td>
<td>0.029</td>
</tr>
<tr>
<td>Plate</td>
<td>0.035</td>
<td>0.6</td>
<td>64.6</td>
<td>21.7</td>
<td>8.9</td>
<td>3.5</td>
<td>0.0</td>
<td>0.1</td>
<td>0.010</td>
</tr>
<tr>
<td>IN622</td>
<td>0.035</td>
<td>4.5</td>
<td>60.8</td>
<td>20.8</td>
<td>8.7</td>
<td>3.5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.080</td>
</tr>
<tr>
<td>Plate</td>
<td>0.035</td>
<td>2.4</td>
<td>59.0</td>
<td>20.5</td>
<td>14.3</td>
<td>0.0</td>
<td>0.2</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>C-22</td>
<td>0.035</td>
<td>3.6</td>
<td>56.7</td>
<td>21.3</td>
<td>13.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

---

**Fig. 1** — Experimental matrix of fusion welds produced where AL-6XN was the substrate and IN625 was the filler metal. Numbers to the right signify the dilution level with respect to AL-6XN as the substrate.

**Fig. 2** — Comparison plot of dilution levels as determined through both geometric measurements and chemical analysis showing good agreement between the two methods.
any deviations that may be encountered
due to microsegregation. X-ray counts
were converted to weight percentages
using a ZAF correction scheme (Ref. 6).
EPMA traces were also conducted in spot
mode (i.e., with no beam raster) in order
to investigate microsegregation patterns
from solidification.

In the fully mixed fusion zone, the final
weld composition will simply be a mixture
of the substrate and filler metal and is
given by

$$C_{Fe} = C_{fm}(1-D) + C_{s}(D)$$  \hspace{1cm} (1)

where $C_{Fe}$, $C_{fm}$, and $C_{s}$ are the elemental
compositions of the fusion zone, filler
metal, and substrate, respectively, and $D$
is the dilution level. Thus, when $C_{Fe}$, $C_{fm}$,
and $C_{s}$ are all known, the dilution level is sim-
ply determined by

$$D = \frac{C_{Fe} - C_{fm}}{C_{s} - C_{fm}}$$  \hspace{1cm} (2)

The values for the major constituents of
Fe and Ni were used and averaged to get
the final dilution level of the weld. Dilu-
tion levels were also determined using
metallographic methods to measure the
individual geometric cross-sectional areas
of the deposited filler metal and melted
substrate. The ratio of the melted sub-
strate ($A_s$) to the total melted cross-
sectional area from the filler metal and
substrate ($A_s + A_{fm}$) is the dilution level

$$D = \frac{A_s}{A_s + A_{fm}}$$  \hspace{1cm} (3)

Solidification cracking susceptibility
was determined using Varestraint testing
with subsize specimens (165 x 25 x 3.2
mm). The crown of each weld deposit was
first machined flush with the top surface
of the plate. The back side of the surface was
then machined to obtain the final 3.2-mm
thickness. This process for making Vare-
straint samples from dissimilar welds was
described previously in more detail (Ref.
1). A welding current of 100 A and 12 V
was chosen for Varestraint testing so that
the material melted during the autoge-
nous Varestraint pass resided entirely
within the homogeneous portion of the
original dissimilar metal weld fusion zone.
(In this work, the “homogeneous portion”
of the fusion zone refers to the fully mixed
fusion zone where, on a macroscopic
scale, the composition is uniform. In other
words, the partially melted and partially
mixed zones were avoided.) The travel
crack for each sample, while the total crack length was the addition of all the crack lengths per sample.

Differential thermal analysis (DTA) was conducted on selected samples carefully sectioned out of the homogeneous portion of the fusion zone of the dissimilar metal welds. Samples were heated to 10°C above their liquidus temperatures at 5°C/min and cooled at 20°C/min to room temperature. This procedure was conducted under flowing argon to avoid oxidation of the sample. The amount of second phase in each weld was measured by Quantitative Image Analysis on at least 20 fields for each dilution level, and the standard deviation for the 95% confidence interval was determined from the measurements.

Results and Discussion

Information on fusion zone compositions, microsegregation, and secondary phase formation are presented below. Detailed descriptions of these results have been provided in Refs. 7 and 8. The information is briefly summarized here, as it forms a basis for interpreting the weldability results, which are the main focus of this article.

Fusion Zone Compositions

The relation between dilution and welding parameters for these dissimilar welds has already been described in quantitative detail through process modeling in Ref. 7. The results will only be briefly summarized here to support the remaining sections on microstructural evolution and weldability. Welds were produced to obtain the full range of dilution levels for both sets of dissimilar metal welds between AL-6XN and IN625 or IN622. Volumetric filler metal feed rates between 0 and ~80 mm³/s were used while the current was varied between 250 and 325 A in 25-A increments and voltages averaged 14 V ± 1.3 V. This produced a range of arc power (VI) from 3475 to 4520 W. Figure 1 displays a typical experimental matrix produced for samples where AL-6XN was the substrate and IN625 was the filler metal. Each data point represents a weld deposited at the specified volumetric filler metal feed rate and arc power. The numbers located to the right of the symbols signify the resultant weld metal compositions.

Attempts were made to decrease the dilution to lower levels using AL-6XN as the substrate. However, a point was reached where the filler metal was not being completely melted and exited the weld pool still in solid form. Therefore, the full range of dilution and resultant weld metal com-
position was obtained by reversing the materials during the process and depositing AL-6XN filler metal onto the nickel-based substrates. Relatively good agreement can be seen over the entire range of samples between the two methods used to calculate the dilution levels, as shown in Fig. 2. More detail on these results can be found in Ref. 7.

Secondary Phase Formation and Microsegregation

Figure 3 shows SEM photomicrographs of the typical phases observed in autogeneous welds of AL-6XN (Fig. 3A) and welds prepared with IN622 — Fig. 3B. In these welds, an interdendritic phase was observed with a globular morphology. DTA samples from welds prepared with IN622 showed identical results. The interdendritic phase in the DTA samples was larger because of the slower cooling rates and could be analyzed by EPMA. Typical results are shown in Table 2. The composition of this phase is consistent with the sigma (σ) phase commonly observed in welds of both AL-6XN (Ref. 9) and IN622 (Ref. 10). As this phase is commonly found in welds of both AL-6XN and IN622, it is not surprising to find it in this set of dissimilar welds. Note that the sigma phase is very high in Cr and Mo.

Figure 4 shows SEM photomicrographs of the typical phase morphologies observed in welds prepared with IN625. There were two types of phases observed in these welds: one often referred to in the literature as a “Chinese script” morphology (Fig. 4A), and one with a eutectic-type morphology (Fig. 4B) (Refs. 11-14). Typical EDS spectra collected from the phase with the “Chinese script” and eutectic-type morphology are shown in Figs. 5A and 5B.

Table 2 — Composition of Second Phase

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Nb</th>
<th>Mn</th>
<th>Si</th>
</tr>
</thead>
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<tr>
<td>wt%</td>
<td>31.1</td>
<td>14.9</td>
<td>25.5</td>
<td>25.9</td>
<td>0.0</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.3</td>
<td>1.1</td>
<td>2.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

(a) Found within the interdendritic region of dissimilar metal weld samples prepared with IN622 after DTA testing. Compositions determined by EPMA, with all values reported in weight percent. Values under reported compositions represent standard deviations.
respectively. Note the "Chinese script" phase is very high in Nb. It has been well established that Nb-bearing superalloys terminate solidification by the formation of a NbC phase with this Chinese script morphology and a γ-Laves constituent that exhibits a eutectic-type morphology (Refs. 11–14). This is consistent with the SEM photomicrographs and EDS spectra shown in Figs. 4 and 5. Quantitative image analysis was used to measure the total amount of secondary phases that formed in each weld, and the results are shown in Fig. 6. The volume percent of secondary phase formed in welds prepared with IN625 decreased with increasing dilution levels. In contrast, the amount of secondary phase that formed in welds prepared with the IN622 filler metal was essentially insensitive to changes in dilution.

EPMA traces were conducted across the dendritic substructures found within the fusion zone of the welds and across the large cells of the DTA microstructures to investigate the segregation patterns that occurred upon solidification. Figure 7 shows a typical EPMA trace and the corresponding area that was analyzed. In all cases, the dendrite cores were depleted in Mo and Nb (the latter for alloys with IN625 only) and enriched in Fe and Ni. In general, Cr had a slight tendency to segregate to the liquid. Similar results were obtained for traces across the structures observed within the DTA samples.

EPMA traces were also conducted across the dendritic substructures in the unmixed zone of the dissimilar metal welds. In these areas of the fusion zone, the presence of the dendrite substructure was a direct indication that melting occurred, but EPMA traces showed the nominal Mo content was identical to the base metal, and thus no mixing with the filler metal occurred. On welds prepared with the AL-6XN base metal, EPMA scans showed the Mo concentration in the dendrite core in the unmixed zone was identical to the Mo dendrite core concentration in the fusion zone of an autogenous weld on AL-6XN. This is an important observation that indicates, regardless of the filler metal composition, an unmixed zone will always exist that contains dendrite core concentrations equivalent to that of an autogenous weld. Thus, it is not possible to increase the core composition of the dendrites in the unmixed zone. The formation of unmixed zones in AL-6XN has been investigated previously (Ref. 5) and will not be described here further.

The amount of Mo and Nb in the dendrite cores for all the welds and DTA samples, as well as those for the nominal composition of the fusion zone, is plotted as a function of dilution level in Figs. 8 and 9. For both sets of data, as the dilution level increased, the amount of Mo and Nb were found to decrease in both the nominal and dendrite core compositions. It is interesting to note that, although the DTA samples were solidified at a rate of only

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**Table 3 — Partition Coefficient Values for Dissimilar Metal Welds with IN622**

<table>
<thead>
<tr>
<th>Dilution Level</th>
<th>100%</th>
<th>81%</th>
<th>67%</th>
<th>46%</th>
<th>32%</th>
<th>20%</th>
<th>12%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1.06</td>
<td>1.09</td>
<td>1.17</td>
<td>1.16</td>
<td>1.09</td>
<td>1.04</td>
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<tr>
<td>Ni</td>
<td>1.02</td>
<td>1.06</td>
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<td>1.02</td>
<td>1.07</td>
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<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.99</td>
<td>0.91</td>
<td>0.92</td>
<td>0.91</td>
<td>0.94</td>
<td>0.89</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td>Mo</td>
<td>0.65</td>
<td>0.76</td>
<td>0.76</td>
<td>0.75</td>
<td>0.74</td>
<td>0.79</td>
<td>0.79</td>
<td>0.82</td>
</tr>
<tr>
<td>Mn</td>
<td>0.76</td>
<td>0.74</td>
<td>0.87</td>
<td>0.87</td>
<td>0.80</td>
<td>0.86</td>
<td>0.84</td>
<td>0.82</td>
</tr>
</tbody>
</table>

**Table 4 — Partition Coefficient Values for Dissimilar Metal Welds with IN625**

<table>
<thead>
<tr>
<th>Dilution Level</th>
<th>87%</th>
<th>74%</th>
<th>49%</th>
<th>46%</th>
<th>40%</th>
<th>16%</th>
<th>9%</th>
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<td>Fe</td>
<td>1.08</td>
<td>1.10</td>
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<td>1.10</td>
<td>1.15</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>1.03</td>
<td>1.04</td>
<td>1.07</td>
<td>1.06</td>
<td>1.05</td>
<td>1.05</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.91</td>
<td>0.90</td>
<td>0.84</td>
<td>0.90</td>
<td>0.91</td>
<td>0.90</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td>Mo</td>
<td>0.77</td>
<td>0.75</td>
<td>0.77</td>
<td>0.79</td>
<td>0.79</td>
<td>0.85</td>
<td>0.85</td>
<td>0.86</td>
</tr>
<tr>
<td>Nb</td>
<td>0.20</td>
<td>0.15</td>
<td>0.32</td>
<td>0.32</td>
<td>0.40</td>
<td>0.45</td>
<td>0.39</td>
<td>0.45</td>
</tr>
<tr>
<td>Mn</td>
<td>0.89</td>
<td>0.84</td>
<td>0.83</td>
<td>0.87</td>
<td>0.85</td>
<td>0.77</td>
<td>0.83</td>
<td>0.81</td>
</tr>
</tbody>
</table>

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Fig. 9 — Nominal and dendrite core Nb compositions for the as-welded structures and DTA samples plotted as a function of dilution level for welds with IN625.

Fig. 10 — Mo partition coefficient as a function of dilution level for both sets of welds.
The k-values for Mo are relatively low and span the range from 0.65 to 0.86. These values are in good agreement with other reported k_Mo values in similar alloy systems (Refs. 12, 13). As shown in Fig. 10, the Mo partition coefficient decreases as the iron content in the weld increases (i.e., as the dilution level increases). A similar trend is observed for Nb, as shown in Fig. 11. These effects are controlled by the influence of Fe on the solubility of Mo and Nb in austenite and can be explained by consulting the phase diagrams for the Ni-Mo, Fe-Mo, Ni-Nb, and Fe-Nb systems (Ref. 15). These diagrams indicate that the maximum solid solubility of Mo in γ-Ni is 35 wt-% (at 1200°C), while a maximum of only 2.9 wt-% Mo can be dissolved in γ-Fe (at −1150°C). A similar trend is observed with Nb, where the maximum solid solubility of Nb in γ-Ni is 18.2 wt-% (at 1286°C), while it is only 1.3 wt-% at a similar temperature (1210°C) in γ-Fe. Based upon these observations, Fe additions to nickel-based alloys will decrease the solubility of Mo and Nb in austenite. Thus, as the Fe-rich dendrites form, the decreased solubility will lower the amount of Mo and Nb dissolved in the first solid, and increased segregation to the liquid will occur. The general trend of decreasing k-values for Mo and Nb with increasing Fe (Figs. 10 and 11) confirms this. Therefore, the segregation potential of Mo and Nb is a function of the nominal composition of the weld metal. Since the fusion zone composition depends on the arc power and volumetric filler metal feed speed, the segregation potential of Mo and Nb will be indirectly affected by the welding parameters.

The information presented above can be used to understand the microstructural evolution of welds prepared with each filler metal. In the case of welds made on "pure" AL-6XN and welds prepared with IN622 (each of which contain no Nb), Mo segregated from the solid to the liquid and the Mo-rich sigma (σ) phase formed at the terminal stages of solidification. Thus, solidification initiates by a L → γ (austenite)
primary reaction, in which the γ dendrites reject Mo into the interdendritic liquid. As solidification progresses, the γ dendrites become richer in Mo at the solid/liquid interface until the maximum solid solubility of Mo in austenite is reached at the edge of the γ dendrites. At this point, solidification goes to completion by a $L \rightarrow (\gamma + \sigma)$ reaction, where the $\sigma$ phase forms in order to dissolve the Mo in the interdendritic liquid. This solidification reaction sequence accounts for the γ dendrites that exhibit a concentration gradient and Mo-rich interdendritic $\sigma$ phase. The terminal solidification reactions that occur in welds prepared with IN625 are different due to the presence of Nb. It is well established that Nb is a very strong segregant that controls the terminal solidification reactions in Nb-bearing superalloys (Refs. 10–14). Direct evidence to this end is provided in this work by the low $k$ values for Nb reported in Fig. 11. The primary solidification reaction for welds prepared with IN625 is similar and involves the $L \rightarrow \gamma$ reaction. However, both Mo and Nb segregate to the liquid, and solidification goes to completion by two terminal eutectic-type reactions that involve Nb-rich phases: $L \rightarrow (\gamma + NbC)$ followed by $(L \rightarrow \gamma +$ Laves). More details of the segregation behavior and resultant solidification sequences can be found in Ref. 8.

Weldability

It is well known that solidification cracking susceptibility of austenitic alloys depends on the solidification temperature range and amount/distribution of solute rich liquid that exists at the terminal stages of solidification (Refs. 1, 11, 14). A larger solidification temperature range increases the size of the crack-susceptible two-phase solid/liquid zone that trails the liquid weld pool, thus increasing cracking susceptibility. In fact, correlations have been made between the maximum crack length and solidification temperature range (Ref. 11). The amount of terminal solute-rich liquid that forms can be directly assessed by examining the amount of secondary interdendritic phases, since these secondary phases form from the solute-rich liquid. It is generally known (Refs. 11, 13) that solidification cracking susceptibility increases with increasing amount of sec-

Fig. 13 — DTA traces obtained on AL-6XN base metal. A — During heating; B — during cooling.

Fig. 14 — DTA traces obtained on weld made with IN622 at 46% dilution. A — During heating; B — during cooling.
ordinary constituent up to approximately 10 vol-%, at which point cracking susceptibility begins to decrease with increasing secondary phase amount. The initial increase in cracking susceptibility occurs because the solute-rich liquid wets the grain boundaries and interdendritic regions. Under this condition, shrinkage strains that develop across these partially solidified boundaries cannot be accommodated and cracks form due to boundary separation. With increasing secondary phase amount (above approximately 10 vol-%) the excess solute-rich liquid can lead to back filling of the solidification cracks, thus providing crack healing and reducing cracking susceptibility. The weldability results are provided below and interpreted based on the solidification temperature range (determined from DTA testing) and secondary phase formation.

Figure 12 shows both the maximum and total crack lengths for both sets of samples as a function of dilution level. As previously noted, three samples of each dilution level were tested at an augmented strain of 3.75%, which was determined to be the saturation strain from preliminary experiments. A 316L stainless steel sample, tested under identical conditions, was also added for comparison since this alloy is known to exhibit excellent weldability. The data point for the 316L alloy is located at 50% dilution level simply for convenience. Average and standard deviation values were determined from at least three samples. The AL-6XN alloy and welds prepared with the nickel-based alloys solidify in a purely austenitic primary mode, and cracking susceptibility is thus relatively higher. Welds prepared with IN625 had the poorest resistance to hot cracking, and the cracking susceptibility increased with increasing dilution. In contrast, welds prepared with IN622 were more resistant to solidification cracking, and cracking susceptibility is not particularly sensitive to the dilution level.

Table 5 shows the solidification behavior on cooling. Solidification initiates at 1410°C, which represents the liquidus temperature of the alloy. Figure 13B shows the solidification behavior on cooling. Solidification initiates at 1403°C after 7°C of undercooling and terminates at 1354°C by a secondary reaction. The as-solidified microstructure exhibited γ dendrites as the major phase and smaller amounts of interdendritic secondary γ phase. Thus, the large peak initiating at 1403°C is associated with formation of the γ dendrites, and the small secondary peak at 1354°C is associated with the L → (γ + σ) reaction. The solidification temperature range of the weld metal is best represented from DTA data by using the liquidus temperature from the heating trace.

![Fig. 15 -- DTA traces obtained on weld made with IN625 at 46% dilution. A -- During heating; B -- during cooling.](image-url)
and the lowest terminal reaction temperature from the cooling trace. The heating trace best represents the liquidus temperature of the weld because solidification in the fusion zone occurs by epitaxial growth off of existing base metal grains and requires no undercooling (Ref. 16). Thus, use of the heating trace avoids the undercooling associated with nucleation in the cooling trace. However, the microsegregation that occurs under the nonequilibrium solidification conditions during cooling of the fusion zone leads to the buildup of solute-rich liquid and formation of secondary phases at low temperature that are best represented by the cooling portion of the DTA trace. Thus, the solidification temperature range of autogeneous welds on AL-6XN is 1410°C - 1354°C = 56°C.

Figures 14 and 15 show the DTA traces of fusion welds prepared with IN622 (Fig. 14) and IN625 (Fig. 15). Each of these welds were prepared at identical dilution levels (46%). Since these traces were conducted on samples extracted from the fusion zone, secondary interdendritic phases are present from the onset of the test, and evidence for liquation of these minor phases is evident in each DTA heating trace. The σ phase liquates at 1304°C in the weld prepared with IN622 — Fig. 14A. The heating trace for the weld prepared with the IN625 displays only one small endothermic peak, but two minor constituents are present in the microstructure (NbC and Laves). Of these two constituents, it is well established that NbC forms at higher temperatures (on the order of 1350°C) and its presence can typically only be detected by DTA techniques in higher carbon alloys, which form relatively large amounts of the NbC constituent (Refs. 11, 12). In contrast, Laves usually forms in higher quantities (and is therefore easier to detect with DTA techniques), and it forms in the temperature range of 1150 to 1200°C. Thus, the minor liquation reaction observed at 1195°C for the weld prepared with IN625 (Fig. 15A) can be linked to the Laves constituent. The liquidus temperatures are 1383 and 1368°C for the welds prepared with IN622 and IN625, respectively. During cooling, the L → (γ + σ) reaction occurs at 1305°C for the weld prepared with IN622, and the solidification temperature range is 78°C. For the weld prepared with the IN625, solidification terminates with the L → (γ + Laves) reaction at 1172°C, and the solidification temperature range is 196°C. Table 5 summarizes the DTA results. Included in this data are liquidus and terminal reaction temperatures previously reported for IN622 (Ref. 17) and IN625 alloys (Ref. 13). Thus, the data presented in Table 5 bound the possible range of behavior expected for dissimilar welds on AL-6XN made with IN622 and IN625. This data, along with the quantitative image analysis data shown in Fig. 6, can be used to understand the weldability behavior.

First, the results presented above show that the autogeneous welds on the AL-6XN base metal solidify over a relatively narrow temperature range of 56°C. The IN622 alloy exhibits a similar reaction sequence and solidifies over a larger temperature range of 108°C. The weld between the AL-6XN and IN622 exhibits the same reaction sequence as the "end members," and exhibits an intermediate solidification temperature range of 78°C. This change in solidification temperature range can primarily be attributed to the increase in the L → (γ + σ) reaction temperature, which occurs as the iron content of the weld increases. This influence from iron has also been observed for the L → (γ + Laves) reaction in welds prepared with IN625 and has been documented in other work as well (Ref. 12). However, the general solidification behavior of fusion welds made with the IN625 is significantly different. In this case, the addition of Nb leads to the formation of Laves at low temperatures and results in a significant widening of the solidification temperature range. This difference in reaction sequence and solidification temperature range accounts, in part, for the observed differences in weldability between the welds prepared with IN622 and IN625.

The data presented in Table 5 does not explain, however, the observed dependence of total and maximum crack length on dilution displayed in Fig. 12. The details of this dependence can be understood by considering the relationship between weld metal dilution and secondary phase formation shown in Fig. 6. As previously discussed, increasing amounts of solute rich liquid (which transforms to secondary phase) lead to increased solidification cracking susceptibility because it interferes with the formation of solid/solid boundaries, thus preventing accommodation of shrinkage strain across the boundaries. Figure 16 shows the direct relation between crack length (both total and maximum) and volume-percent of secondary phase for all the dilution levels. Note that the data for the welds prepared with IN622 are grouped at the lower left portion of the plots where low amounts of secondary phase correspond to low crack lengths (good weldability). It is also interesting to note that, although a wide range of welds were investigated with different compositions, there is a smooth transition.
between the data represented by the welds prepared with IN622 and IN625.

In summary, then, the weldability behavior can be interpreted as follows: The solidification cracking resistance of autogenous AL-6XN welds and welds prepared with IN622 is consistently better than welds prepared with IN625 because the terminal L → (γ + σ) reaction temperature in welds prepared with IN622 is significantly higher than the L → (γ + Laves) reaction temperature that occurs in welds prepared with IN625. This effectively leads to smaller solidification temperature ranges for autogenous AL-6XN welds and welds prepared with IN622. The L → (γ + Laves) reaction is promoted by the Nb additions to IN625. The amount of secondary phase that forms in welds prepared with IN622 is not very sensitive to changes in weld metal composition (dilution) and, thus, solidification cracking resistance is also not a strong function of dilution. (Discussion on the reason for this insensitivity of secondary phase amount on dilution is beyond the scope of the current article and will be the subject of a future article on solidification modeling.) In contrast, the amount of secondary phase that forms in welds made with IN625 depends on the dilution level and, as a result, the weldability also depends on dilution level. In this case, higher dilutions are favored in order to reduce the risk of solidification cracking in the fusion zone. Unfortunately, the higher dilution levels also have reduced nominal and dendrite core Mo concentrations, and are not optimal from a corrosion perspective. Thus, IN622 filler metal is generally favored over IN625 because the weldability is insensitive to dilution.

Conclusions

A study was conducted on microstructural evolution and weldability of dissimilar metal welds between AL-6XN super austenitic stainless steel and two nickel-based alloys, IN625 and IN622. The effect of processing parameters and filler metal chemistry on the final fusion zone composition and microstructure was investigated. These results were related to Varestraint weldability tests. The following conclusions can be drawn from these results:

1) Iron additions to the weld (which occur with increasing dilution) decrease the distribution coefficient of Mo and Nb. This, in turn, produces lower dendrite core concentrations with increasing dilution.

2) Welds prepared with IN622 exhibit a two-step solidification reaction sequence consisting of L → γ followed by L → (γ + σ). Welds prepared with IN625 exhibit a three-step solidification sequence consisting of L → γ, L → (γ + NbC), and L → (γ + Laves). The L → (γ + σ) reaction temperature in AL-6XN/IN622 welds depends on dilution level and ranges from 1354°C for “pure” AL-6XN to 1285°C for “pure” IN622. In contrast, the terminal L → (γ + Laves) reaction temperature in AL-6XN/IN625 welds is considerably lower (approximately 1150°C to 1170°C) and less dependent on weld metal dilution. Thus, welds produced with IN625 have an appreciably wider solidification temperature range.

3) The total amount of secondary phase that forms in welds prepared with IN622 is generally less than about 2 vol-% and does not depend on dilution level. The total amount of secondary phase that forms in welds prepared with IN625 varies from about 7 vol-% at 0% dilution to approximately 2 vol-% at 8% dilution.

4) Welds produced with IN626 exhibit better resistance to solidification cracking than those prepared with IN625. The solidification cracking sensitivity of welds prepared with IN626 is essentially independent of weld metal dilution level, while welds produced with IN625 filler metal exhibit increased cracking susceptibility with decreasing weld metal dilution. The dilution/cracking relation is controlled by the solidification temperature range and amount of secondary phase that forms at the terminal stages of solidification. The good cracking resistance of welds prepared with IN626 is attributed to the small amount of secondary phase and narrow solidification temperature range. The relatively poor cracking resistance of welds prepared with IN625 is attributed to a wide solidification temperature range and increasing amount of secondary phase that forms with decreasing dilution.

Acknowledgments

The authors gratefully acknowledge helpful discussions with Dr. George Yoder from the Office of Naval Research. Financial support for this work was provided by the Office of Naval Research under Contract No. N00014-99-1-0887. Special thanks go to Matthew Perricone of Lehigh University for conducting the DTA tests. The AL-6XN material was provided from Allegheny Ludlum by Dr. John Grubb and Ronald Daily and is also appreciated.

References


WELDING RESEARCH

Effect of Welding Parameters and H₂S Partial Pressure on the Susceptibility of Welded HSLA Steels to Sulfide Stress Cracking

A standard controlling usage of welded high-strength, low-alloy steels in sour envoiriments is assessed

BY G. M. OMWEG, G. S. FRANKEL, W. A. BRUCE, J. E. RAMIREZ, AND G. KOCH

ABSTRACT. The susceptibility of welded API 5L X70 and X80 steels to sulfide stress cracking (SSC) was investigated using two applied stresses and three H₂S concentrations. The effect of peak weld hardness was examined by using three welding conditions. Weld hardness was characterized with Rockwell C and Vickers (HV) 10-kg hardness mapping. Hardness mapping revealed the inadequacy of Rockwell C hardness (HRC) measurements, which is specified by the National Association of Corrosion Engineers (NACE) MR0175 standard, for testing narrow heat-affected zone (HAZ) regions because of the size of the indenters. Several welds meeting the HRC 22 requirement failed by SSC. Several weld conditions containing hardness exceeding 248 HV, which is equivalent to HRC 22, were resistant to SSC at low H₂S concentrations, suggesting that cap hardness levels exceeding 248 HV are suitable for sour service. Hardness level dictated the performance of the X70 material, while the X80 was more susceptible at lower hardness due to localized plastic deformation in intercritically reheated HAZ regions. The centerline segregation region (CSR) in the X70 material was exposed to the corrosive environment at the sample surface as an artifact of the sample preparation, and played an important role in the susceptibility to both SSC and hydrogen-induced cracking (HIC).

Introduction

The hardness of carbon steels currently determines their fitness for sour (aqueous and H₂S-containing) environments according to National Association of Corrosion Engineers (NACE) MR0175, which requires that carbon steel and its weldments not exceed a Rockwell C hardness (HRC) of 22 for these applications (Ref. 1). Steels exceeding the HRC 22 threshold are more susceptible to sulfide stress cracking (SSC), a form of hydrogen embrittlement (HE) (Refs. 2–4). The suitable sour service materials listed by NACE MR0175 are based on their resistance to SSC either in actual field applications or in laboratory testing using the NACE TM0177 test method, which is a severe, accelerated exposure test (Ref. 5). The HRC 22 hardness requirement precludes the use of many high-strength low-alloy (HSLA) steels, especially in the as-welded condition, due to either high base material hardness or to the formation of localized high-hardness regions in the weld heat-affected zone (HAZ). HAZ regions have shown heightened susceptibility to SSC in both service and laboratory environments (Ref. 3). The NACE MR0175 requirement may be overly conservative for HSLA steels due to their low carbon contents and high toughness.

The oil and gas industries have increasing need for the use of HSLA steels due to the cost savings they afford, especially in long piping systems that transport crude oil or natural gas. Transport conditions, however, are becoming increasingly sour (higher H₂S concentrations) and the use of higher strength HSLA grades is prevented where NACE MR0175 is employed as a governmental regulation. Of particular importance is the performance of pipeline girth welds used to connect pipe segments in the field. Circumferential girth welds are typically multipass welds, in which subsequent welds temper underlying hard HAZ regions, leaving the hardest HAZ regions in the final untempered cap passes. The cap passes are on the exterior of the pipeline girth weld and thus are exposed to lower hydrogen concentrations than weld regions in contact with the sour environment within the pipe. Because SSC is a HE mechanism, higher hardness values (exceeding HRC 22) should be tolerable in hard weld cap regions, which are exposed to relatively low hydrogen concentrations. Testing performed at TWI showed that, in fact, hard external weld regions exceeding a Vickers hardness (HV) of 300 (248 HV = HRC 22) were resistant to SSC in a stressed pipe containing the NACE test solution (Ref. 6). This investigation was aimed at assessing the conservatism of the NACE requirements for HSLA weldments, with focus on weld hardness requirements and extrapolation to service conditions. Many of the corrosion and embrittlement aspects of this work are described elsewhere (Refs. 7, 8).

Experimental

The materials investigated were API 5L X70 and X80 spiral-welded high-strength low-alloy (HSLA) line pipe materials. Table 1 lists the steel compositions, the values of carbon equivalent CE (IIW), cracking parameter, Pₐₙ, and the pertinent pipe dimensions, including outer diameter (OD) and wall thickness (t). The X80 was very low in carbon, just above saturation in ferrite (0.022 wt-% C). Both alloys are low-sulfur steels (Ref. 9). The primary carbo-nitride-forming elements in the X70 and X80 are vanadium and niobium, respectively. The Pₐₙ values are more relevant measures of the hardenability of these alloys than the CE values. The X70 has a higher susceptibility to hydrogen cracking (higher Pₐₙ value), pri-
were tack welded to a 2-in.-thick steel plate to provide the necessary constraint during cooling. A small carbon steel 3/4 in. x 1 in. backing bar was incorporated into the joint to facilitate the deposition of the root passes. The mock-up weld geometry appears in Fig. 4. The joint geometry was chosen to duplicate a typical GMAW girth weld joint: a 0.25-in. root opening with a 12-deg included angle. All root passes were deposited using low arc energy (15.1 kJ/in.) and the weld interpass temperature was measured using a contact thermocouple. The subsequent fill passes created the gauge material isolated in the tensile specimen for SSC testing. The fill pass weld preheat and input energy were varied to achieve three desired ranges in specimen peak hardness for each pipe steel. These parameters were chosen based on the results of preliminary weld trials. The parameters used for the fill passes in each weld condition appear in Table 2. Condition I, II, and III welds correspond to hard, medium, and soft gauge regions, respectively, in the final simulated girth welds.

The weld cap passes were all performed utilizing the low heat input and a room temperature (RT) preheat in order to minimize tempering effects, thus improving the predictability of the peak hardness from preliminary bead-on-plate weld data. Low heat input weld cap passes were omitted from the Condition I welds for both base materials in order to prevent localized hard spots in these soft weld conditions. The welds were performed at Edison Welding Institute (EWI) using an automated GMAW station, which allowed for accurate control of the weld travel speed. Each weld pass was visually inspected for undercutting, incomplete fusion, and slag. The pertinent welding process conditions common to all welds (both X70 and X80) appear in Table 3. The typical composition for the ER70S-3 filler wire is 0.08% C, 1.1% Mn, and 0.6% Si. The joined material was milled flat on the upper and lower surfaces and screened for defects using X-ray radiography. Transverse weld tensile specimens were machined in accordance with the specifications in NACE TM0177-A. The machined tensile specimens contained a weld centered in the gauge length.

Fig. 1 — X70 long transverse section, 2% Nital etch. A — Fine-grained ferrite; B — centerline segregation region. F=ferrite; P=pearlite.

In order to systematically quantify both the peak weld hardness and hardness distribution in each tensile sample, weld hardness mapping was performed. Metallographic sections were isolated from each weld condition. These sections were taken from regions of the milled weld plates that were adjacent to the material machined for the NACE TM0177-A samples. Each weld was mounted, polished, and etched with 2% Nital. The approximate weld centerline was then scribed across the etched surface as it provided a reference point for the hardness mapping grid and also aided sample alignment on the hardness testing stage. Hardness mapping was performed using both a Rockwell C indenter and a Vickers 10-kg indenter — Fig. 5. One half of each prepared weld was mapped using a grid of approximately 140 Vickers indents. The opposite half of each prepared weld was mapped using the Rockwell C test method. The hardness map did not span the entire plate thickness, because the tensile sample gauge could only be isolated from the center region of the plate. In fact, the map extended into the wall 0.09 in. (2.3 mm) from both the inner and outer machined plate surfaces, as this distance is the average difference between the gauge and shank radii, or half the difference in diameters: (D_s - D_t)/2 — Fig. 5. It is clear in Fig. 5 that the tensile bar specified by NACE TM0177 and the chosen weld geometry did not allow for isolation of actual weld cap regions in the gauge sections.

### Table 1 — API 5L Steel Pipeline Base Alloy Compositions (wt-%) and Pipe Dimensions

<table>
<thead>
<tr>
<th>Alloy</th>
<th>X70</th>
<th>X80</th>
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<tbody>
<tr>
<td>C</td>
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<td>0.029</td>
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<tr>
<td>Mn</td>
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<td>1.66</td>
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<tr>
<td>P</td>
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<td>0.008</td>
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<tr>
<td>S</td>
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<td>0.003</td>
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<tr>
<td>Si</td>
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<td>0.35</td>
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<tr>
<td>Ni</td>
<td>&lt;0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Cr</td>
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<td>0.16</td>
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<tr>
<td>Mo</td>
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</tr>
<tr>
<td>Cu</td>
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<td>V</td>
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<tr>
<td>Al</td>
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<td>0.03</td>
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<tr>
<td>Ti</td>
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<tr>
<td>Nb</td>
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<tr>
<td>CE</td>
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<tr>
<td>Pmax</td>
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<td>0.170</td>
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<tr>
<td>OD</td>
<td>34.75 in.</td>
<td>42 in.</td>
</tr>
<tr>
<td>t</td>
<td>0.75 in.</td>
<td>0.55 in.</td>
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Fig. 2 — X80 LT section, 2% Nital etch.

<table>
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<tr>
<th>Composition</th>
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<th>X80</th>
</tr>
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<tbody>
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<td>Ti</td>
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<td>0.22</td>
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<tr>
<td>Cu</td>
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<td>0.35</td>
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<td>Si</td>
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<tr>
<td>S</td>
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<td>Cu</td>
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<td>Al</td>
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<td>Pmax</td>
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<td>OD</td>
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<table>
<thead>
<tr>
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<th>X80</th>
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<td>Condition III</td>
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Table 2 -- Welding Parameters and Hardness Mapping Results

<table>
<thead>
<tr>
<th>Weld Condition</th>
<th>Relative Peak Hardness</th>
<th>Voltage (Volts)</th>
<th>Current (Amps)</th>
<th>Travel Speed (in./min)</th>
<th>Energy Input (kJ/in.)</th>
<th>Preheat (°F)</th>
<th>Hardness Range (HV 10-kg)</th>
<th>Peak Hardness (HV 10-kg)</th>
<th>Peak Hardness (HRC)</th>
<th>Peak HV Converted to HRC</th>
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<td>15.7</td>
<td>15.1</td>
<td>Room Temp.</td>
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<td>295</td>
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<td>29.1</td>
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<td>15.7</td>
<td>15.1</td>
<td>250</td>
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<tr>
<td>X70 Condition III</td>
<td>Low</td>
<td>33</td>
<td>300</td>
<td>14.6</td>
<td>40.7</td>
<td>250</td>
<td>154-236</td>
<td>236</td>
<td>&lt;20</td>
<td>19.8</td>
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<td>X80 Condition I</td>
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<td>23</td>
<td>172</td>
<td>15.7</td>
<td>15.1</td>
<td>Room Temp.</td>
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<td>X80 Condition II</td>
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<td>15.7</td>
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<td>250</td>
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<tr>
<td>X80 Condition III</td>
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<td>33</td>
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<td>179-247</td>
<td>247</td>
<td>&lt;20</td>
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A test matrix was employed to examine the effects of weld hardness, applied stress, and H2S concentration on the SSC performance of the X70 and X80 welded samples. The three weld conditions produced a range in specimen peak weld hardness. Two applied stresses, 80% and 100% of the specified minimum base yield, were used in the test matrix. These high stresses were applied in order to duplicate the high residual tensile stresses encountered in non-postweld-heat-treated in-service weldments (Ref. 11). The NACE TM0177-A solution (Ref. 5) was used as a base solution: 5.0 wt-% NaCl + 0.5 wt-% glacial acetic acid in deionized H2O. A range in H2S concentration was achieved by bubbling the solution with 100%, 30%, or 10% H2S (balance N2) gas mixtures. The use of 100% H2S exactly reproduced the standard test method, but the H2S-N2 mixtures created a major modification. The H2S testing was performed in a special lab at CC Technologies. Proving rings were used for static load application and nitrogen was used for solution deaeration. All testing procedures outlined in NACE TM0177 were followed, except for the fact that diluted H2S gas mixtures were used for several testing schedules.

After specimen removal, each specimen was examined optically at 10X in order to reveal any apparent surface cracking, as per the NACE TM0177-A standard. Cracking observed at 10X was sectioned and metallographically prepared to determine if SSC was the cause. In addition to the NACE failure criterion, a more detailed cracking investigation was performed. Even samples that passed the NACE criteria were examined for internal flaws. Details of the failure investigation procedure and results are given elsewhere (Ref. 7).

Results

Figure 6 displays the Rockwell C hardness results for the L and LT sections of each base material. The HV 10-kg measurements were converted to equivalent HRC values, and are included in Fig. 6 for comparison (X70 L CONV and X80 L CONV). The X80 converted HV measurements indicate that HRC 22 was exceeded in both the inner and outer peak hardness bands. Actual HRC test results show that neither material exceeded the HRC 22 threshold. In fact, the X70 measurements were well below HRC 20, which is the lower limit for reporting HRC values. The highest Rockwell reading in the X80 material was HRC 22. Comparison between the actual HRC readings and the converted Vickers hardness reveals that the HV technique slightly overestimates hardness, even where there is not a steep hardness gradient, such as in the middle of the plate. However, there is no way to determine which hardness scale provides the more accurate readings. The HRC measurements may very well underestimate hardness in this case. In general, due to the indentation size produced in each hardness scale, Vickers hardness is able to detect localized hard spots and HRC hardness provides an average reading of the tested area.

The multipass welding employed for the welds created complex HAZ subregions that have been discussed in the literature (Ref. 12). These HAZ regions include the coarse-grained HAZ (CGHAZ), the grain-refined HAZ (GRHAZ), the intercritical HAZ (ICHAZ), the subcritical HAZ (SCHAZ),
the intercritically reheated coarse-grained HAZ (IRCG) and the subcritically reheated coarse-grained HAZ (SRCG). The latter regions were investigated at higher magnification to characterize the transformations that occurred. Figure 7 displays micrographs from the CGHAZ regions of both the X70 and X80 Condition I final welds. The Condition I weld produced the hardest overall weld microstructures, which were located in the CGHAZ. The X70 CGHAZ contained upper bainite (ferrite sideplates + interplate carbides) and lower bainite (carbides within ferrite plates), whereas the X80 CGHAZ contained only upper bainite. The ferrite portion of the upper bainite adopted a Widmanstätten “basket weave” that nucleated at a preferred orientation relative to the prior austenite grain boundaries (Kurdjumov-Sachs relationship) (Ref. 13). The CGHAZ grain size was very large relative to the base material grain size and exhibited large variability with position in each weld. Figure 8 displays the CGHAZ regions in the X70 and X80 Condition III welds, which had considerably higher heat inputs (40 kJ/in. vs. 15.1 kJ/in.) and a high weld preheat (250°F) that produced substantially lower CGHAZ cooling rates. The lower cooling rates produced a coarser ferrite side plate structure. The GRHAZ (not shown) in both alloys was characterized by grain refinement compared to the original base grain size. However, the X70 ICCHAZ was evidenced by the “fuzzy pearlite” microstructure — Fig. 9. The intercritical HAZ (ICHAZ) in the X80 was virtually indistinguishable from the adjacent GRHAZ. Figure 10 displays the intercritically reheated coarse-grained HAZ (IRCG) microstructure encountered in both X70 and X80 multipass welds. Austenite islands nucleated in the CGHAZ grain boundaries, and also in the grain interiors during reheating from an overlay weld pass (Ref. 14). Upon cooling, the austenite islands can transform into twinned martensite (Ref. 14). A hardness map of the X70 Condition I sample appears in Fig. 11. The peak hardness measured in the X70 Condition 1 weld was 295 HV. Relatively high hardness regions were encountered deep within the weldment. The hardness data generated from the six hardness maps is summarized in Table 2. There is a general reduction in peak sample hardness from Condition I to Condition III in both materials, indicating that the change in welding parameters had the desired effect. Peak HV 10-kg hardness measurements were located in the CGHAZ, close to the fusion boundary, in all welds. It was difficult to accurately center HRC measurements on the CGHAZ due to the indent size and sample manipulation. The Vick-
Vickers hardness measurements in each respective weld region were tabulated from inspection of the hardness maps. The mean hardness values for each weld region in both the X70 and X80 welds are given in Figs. 12 and 13, respectively. The X80 Condition III (Fig. 13) weld exhibited considerable softening in the ICHAZ and IRCG regions such that measured hardness values were lower than the minimum base metal hardness. A significantly lower strength can be expected in these regions. This softening has been reported in the HAZ of TMCP steels (Ref. 15). While the Condition III welding parameters produced a relatively soft ICHAZ and SCHAZ microstructures in the X70 material, these regions remained within the base metal hardness range.

The results of the sulfide stress cracking tests are given in Table 5. The failures are distinguished in Table 5 according to the nature of the failure. NACE failures were observed at 10X, and complete double-ended fractures (DEF) or samples that experienced complete separation are denoted. The crack initiation region is denoted for each DEF. Internal failures were found solely by either scanning electron microscope (SEM) investigation or metallographic cross-sectioning. Base metal failures are distinguished from the typical weld metal (WM) or heat-affected zone (HAZ) failures. Repeat tests were performed on each weld condition at 100% YS and 100% H2S, and are discussed elsewhere (Ref. 7).

The SSC testing revealed that the X70 Condition I welds were not suitable for sour service, failing even when exposed to lower H2S concentrations, despite being below HRC 22. The peak HRC hardness values for all welds were below HRC 22, and the peak HV 10-kg values are included for each weld condition in Table 5. Post-exposure hardness testing around an internal crack indicated that the X70 I welds contained higher hardness than determined with the hardness mapping (310 HV vs. 295 HV). Ignoring the base metal failures (since the high applied stresses were meant to duplicate weld residual stress), the X70 II, X80 I, and X80 II welds exhibited SSC resistance at lower H2S concentrations despite their high hardness (> 248 HV). Surprisingly, the soft X80 III welds were highly susceptible to complete, double-ended SSC fracture. The X70 and X80 Condition III welds failed at 100% YS, at all concentrations of H2S. The applied stress seemed to dictate SSC resistance in the Condition III welds, as these welds were resistant at 80% YS. Metallographic examination and SEM fractography indicated that brittle SSC crack propagation was typically associated with the CGHAZ and IRCG in the double-ended...
fractures. The base metal failures in the X70 were associated with the centerline segregation region (CSR). In some samples, SSC was observed in the CSR if and when it intersected the sample surface. An example of cracks formed at the intersection of the CSR with the surface is given in Fig. 14A. Internal SSC cracking was also observed if the CSR intersected the ICHAZ, rather than emerging on the sample surface — Fig. 14B. The X70 III welds failed in this manner.

Discussion

NACE MR0175 requires that carbon steels and their weldments utilized in sour service conditions not exceed HRC 22 (Ref. 1), thereby placing importance on the predictive capabilities of the Rockwell C test method. However, HSLA weld hardness testing is typically performed using the Vickers hardness measurement technique (Refs. 16, 17) because of the difficulty of measuring narrow HAZ regions in low heat input welds. The relatively large HRC indenter senses an average of the hardness of a narrow heat-affected zone (Ref. 18). This difference in size between the Vickers and HRC indents is portrayed accurately in the X70 Condition I hardness map in Fig. 11. The inability of the HRC test method to test narrow HAZ regions is evidenced by the disparity between the HRC and Vickers testing results produced by this study. The HRC weld measurements were consistently lower than converted Vickers measurements. This difference was also exhibited in the base metal hardness traverses. However, there was a systematic difference between the measured base metal HRC values and the converted HV values. The converted HV values overestimated the measured HRC values by about 2-3 HRC points in the base metal. On the other hand, the difference between the converted HV weld measurements and the HRC weld measurements varied by as much as 9 HRC points (X80 I, Table 2). This deviation cannot be attributed to the error in the hardness conversion equation alone. Rather, it implicates the averaging effect of the HRC indenter. Figure 15 shows individual Vickers hardness traverses from each X70 weld hardness map (Conditions I, II, and III). Very steep gradients in hardness are seen in the HAZ, especially in the Condition I weld. The X70 Condition I weld exhibited a change in hardness of about 60 HV over a distance of 0.03 in. This distance is comparable to the diameter of the HRC indenter, which ranged from 0.034 to 0.038 in. in these materials. The same averaging effect was also found in the X80 welds. In short, the HRC technique does not have the appropriate hardness resolution required for characterizing low heat input weld HAZs.

The comparison between the HRC and HV test methods has strong implications on the conservatism of both the NACE MR0175 and BS4515 materials requirements when considering sour service welding applications. Because the HRC test method cannot accurately test narrow HAZ regions, the HRC requirement is not conservative when applied to low heat input welds. This view is based on the fact that hardness depends on the microstructure, which, in turn, reflects susceptibility to sulfide stress cracking (Ref. 19). If very hard regions (more susceptible) exist in a weldment that cannot be characterized with the HRC method, then any standard based on this measurement would not be conservative.

The results of the hardness testing in this work also have implications on the comparison between the NACE MR0175 requirements (<HRC 22) and the relaxation in weld hardness afforded by the BS4515 standard. As of July 1989, BS4515 has permitted weld cap hardness values up to 275 HV (HRC 26) (Ref. 20). This relaxation was based on work performed by Robinson on as-welded X60 pipe, in which he suggested that average hardness as high as 370 HV (HRC 38) was permissible under similar hydrogen absorption conditions without externally applied stress (Ref. 20). Later work by Walker led to further relaxation in the BS4515 requirement, allowing peak cap hardness of 300 HV (HRC 30) in outer cap regions in stressed pipes (Refs. 20, 21). However, caution should be exercised when applying Walker's HRC results, as these values were determined by conversion of measured HV values, not by direct measurement (Ref. 20). The HRC 22 limit was recommended for weld regions exposed directly to sour environments by both Robinson and Walker, and adopted by BS4515 (Refs. 20-22). However, this value was based on test results involving welds characterized only with the HV test method (Ref. 20). Hardness mapping in this work showed that welds containing hard regions on the order of 295 HV only registered peak HRC readings of 20-21. Presumably, welds with HV readings in excess of 300 HV would still only register HRC 22 or less, depending on the width of the HAZ. Therefore, there may not be a
WELDING RESEARCH

Fig. 12 — Mean hardness for different regions in X70 welds.

Fig. 13 — Mean hardness for different regions in X80 welds.

large difference between the NACE MR0175 and BS4515 standards when qualifying low heat input welds in HSLA materials.

The results of the SSC testing portion of this work and extrapolation to service are discussed in more detail elsewhere (Ref. 8). In general, the X70 welds (excluding base material failures) exhibited an increase in SSC susceptibility with increased weld peak hardness, as would be expected based on the long-standing correlation between hardness and SSC susceptibility (Ref. 1). The X70 I weld was produced without preheat and generated the highest hardness measurement (310 HV). The high hardness coarse-grained heat-affected zone (CGHAZ) was predominantly implicated in both complete fractures and terminal cracking. Generally, post-test hardness testing showed good agreement with the hardness mapping results other than the X70 I welds as discussed above and the X80 III welds as discussed below. The X70 II welds (15.1 kJ/in., 250°F), which contained hard regions exceeding 248 HV (HRC 22), failed in the standard TM0177 tests (100% H2S) at both applied stresses, yet exhibited resistance with lower H2S concentrations (10%, 30% H2S). The failures that did occur in the X70 II welds were in the base metal and fusion zone. The X70 III welds (<248 HV) exhibited no susceptibility with the lower applied stress (80% YS), yet failed under the more aggressive testing conditions with the high applied stress (100% YS). The failures in the X70 III welds were either associated with weld inclusions or SSC at the IRCG/CSR interface. The X70 II and III welds were, to some degree, resistant to SSC, whereas the X70 I weld was determined not to be suitable for sour service, with a peak sample hardness of 310 HV (10kg).

The X80 welds exhibited very interesting trends when considering only those failures that occurred in welded regions (not base metal failures). Increasing hardness tended to increase resistance to SSC, especially at the applied stress equivalent to 100% of the specified minimum yield of the base material (80 ksi). The Condition I X80 weld exhibited poor resistance to the modified NACE TM0177 testing conditions (100%, 30% H2S). The Condition II weld was more susceptible under more severe testing conditions, and failed at 100% YS, 30% H2S, where the Condition I weld did not. The X80 Condition III (Peak HV = 247 HV) weld exhibited poor performance at 100% YS. The applied stress level dominated the SCC susceptibility.

Fracture analyses implicated not only the influence of the high-hardness CGHAZ on cracking and complete failure, but also the importance of the intercritically reheated heat-affected zone (IRCG) and, in the X70 samples, the IRCG/CSR intersection. The deleterious effect of the CGHAZ, ICHAZ, and IRCGHAZ regions on SSC performance has been reported by several investigators. One property shared by each of these regions is that they all have shown the potential to contain martensite-austenite (MA) constituent (Refs. 14, 23, 24). The volume-fraction of MA constituent has been linked to a lack of toughness (Ref. 10). Not only is the MA constituent brittle itself, it creates stress concentrations in the surrounding matrix (Ref. 14). Double thermal cycling of the CGHAZ during multipass welding creates the IRCG. The CGHAZ and IRCGHAZ weld regions were implicated either in crack initiation or propagation in most of the welds tested. The upper bainite CGHAZ is recognized as a low toughness microstructure (Refs. 12, 24). Heat treatment has not been shown to improve the low toughness of this region (Ref. 24). The CGHAZ and IRCG zones may be susceptible to SSC cracking due to MA constituent, which can comprise the carbide phase in upper bainite (CGHAZ) or decorate the prior austenite grain boundaries in the IRCG (Refs. 12, 23). MA constituent has been shown to reduce toughness of the ICHAZ substantially (Ref. 24), and promote interand transgranular cracking (depending on location) (Ref. 24).

In the X80 Condition III welds, the IRCG zone was particularly susceptible to crack initiation and propagation, especially at applied stresses of 80 ksi. The X70 Condition III weld did not exhibit this same high susceptibility to either complete fracture or terminal cracking, despite the use of the same welding parameters (40 kJ/in., 250°F preheat).

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IRCG and ICHAZ were softened considerably when compared to the base metal — Fig. 13. It is reasonable to assume that, due to the localized softening, strain localization occurred predominantly in these softened zones during loading. Therefore, plasticity was introduced into the X80 III samples and possibly the X80 II samples. This preferential straining in softened weld regions is mentioned by Pargeter and Gooch, who attributed SSC cracking in the ICHAZ of a welded TMCP steel to this phenomenon (Ref. 19). Localized deformation in this region may also account for the higher post-test HV hardness values in the X80 III IRCG relative to the as-welded values reported in the hardness maps. In the X70 welds, SSC susceptibility decreased with lower hardness and the same degree of softening exhibited in the X80 III welds was not observed in the IRCG and ICHAZ regions. The mean hardness values of these regions in all weld conditions were within the base metal hardness range. High heat input welds are not recommended for these types of steels, but were used in this study in order to examine the effect of low weld hardness.

Presumably, the X70 Condition I weld is more susceptible to SSC than the X80 I weld because of its higher carbon content (0.16 vs. 0.029 wt-%). Higher carbon equivalents and higher carbon content are directly related to higher hardness and the amount of MA constituent (Ref. 10). It has been established that extra-low carbon steels are more resistant to SSC in as-welded conditions, due to the absence of highly susceptible martensite (Ref. 25). The higher manganese and low sulfur would promote higher hardenability of CGHAZ and IRCG in the X80, as the low phosphorus and carbon content in each alloy probably dominates the toughness response (Refs. 10, 19, 26, 27). Mn and S segregate in the grain boundaries, the former promoting the formation of martensite and the latter promoting ferrite formation. The effect of austenite island (MA precursor) hardenability on ICHAZ toughness was shown by Fairchild et al. (Ref. 12).

The X80 Condition I weld HAZ was much more resistant to SSC than the X70 Condition I HAZ, especially considering the values of the absolute stresses impressed on this region in the respective alloys. Failures were focused in the CGHAZ and IRCG in these conditions. The thermomechanical history of the alloy is essentially erased in the CGHAZ due to the high austenitizing temperatures and the CGHAZ is typically the hardest (strongest) weld region, so the base metal yield strength means little in this weld region. The IRCG results from reheating of the CGHAZ, so its microstructure is independent of thermomechanical history of the alloy. The X80 Condition I CGHAZ/IRCG was resistant to SSC (at lower H2S concentrations) at applied stresses equivalent to 80 ksi (100% base YS), while the X70 failed under similar conditions at applied stresses of 57 ksi (80% base YS). This may be a result of the deleterious effects that increasing carbon content has on weld performance. Normally, comparison of steel susceptibility to SSC based on absolute stresses is not meaningful. On the other hand, as the strength of the steel (UTS) increases, the susceptibility to SSC is expected to increase.

Alternatively, low carbon martensite formation (on a larger scale than in the MA constituent) in the X70 CGHAZ may have produced the high susceptibility to cracking observed in the X70 I Condition. The presence of martensite was not confirmed with optical or SEM methods. However, the tempering response observed in this weld region upon comparison of the peak cap CGHAZ hardness to underlying CGHAZ hardness values may suggest the formation of low carbon martensite. Further characterization would be required to affirm its presence.

**Conclusions**

- The Rockwell C hardness test method does not accurately characterize hardness in narrow heat-affected zones (HAZ) due to an averaging effect produced by the large indenter size.
- The HRC 22 threshold hardness is a nonconservative criterion for weldments in sour service carbon steels because of averaging effects in narrow HAZ regions.
- The HV 10-kg technique is recommended for characterizing peak weld hardness with the low heat input welds investigated in this study (~15 kJ/in.), and is warranted as an alternative to the Rockwell C method on carbon steel welds in conjunction with the NACE MR0175 requirements.
- A maximum hardness of 248 HV should be maintained for carbon steel
base materials and regions of carbon steel weldments that are in direct contact with sour service environments.

- The Rockwell C method did not reproduce the high HAZ hardness values measured using the HV 10-kg technique in narrow heat-affected zones. Therefore, the relaxation in allowable hardness afforded by BS 4515 should only be used in context with the appropriate Vickers measurements, as the relaxation recommendation was based on testing of welds characterized using actual HV measurements, not actual HRC measurements.

- The martensite-austenite (MA) microconstituent that has been attributed to low HAZ toughness contributed to low SSC resistance in the HAZ.

- The low-carbon (≤0.03 wt-% C) X80 steel was subject to HAZ softening relative to the base metal, which increased SSC susceptibility due to strain localization. A minimum HAZ hardness may be justified for these types of steels.

- The low-carbon (≤0.03 wt-% C) X80 steel was more resistant to SSC in the as-welded condition and tolerated much higher absolute tensile stresses than the as-welded X70. In general, based on experimental observations (Table 5), X80 pipe steel was more resistant than X70. However, X70 steel was more resistant in Condition III than X80.

- SSC experiments showed that the centerline segregated region (CSR) in control rolled steels is susceptible to SSC, and may dictate both alloy and weld susceptibility.

- The NACE failure criteria were not adequate for detecting internal SSC cracking associated with the CSR/weld intersection. A more detailed metalographic evaluation is recommended for carbon steel weldments in which the base metal contains a CSR. Otherwise, the NACE criteria were adequate for detecting weldment failures.

Acknowledgments

This project was funded by Edison Welding Institute Cooperative Research Program 43564-IRP. We would like to acknowledge personal contributions from Charlie Ribardo (formerly at EWI) and Gary Todd (CC Technologies). CC Technologies donated the use of its laboratory facility for H2S testing performed in this study.

References

1. MR0175 materials requirement standard: Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment. Houston, Tex.: NACE.
5. TM0175 Test Method Standard: Laboratory Testing of Metals for Resistance to Specific Forms of Environmental Cracking in H2S Environments. Houston, Tex.: NACE.
ABSTRACT. Long-term isothermal solution heat treatments were conducted to simulate multiple weld repair/postweld heat treatment cycles in Alloy 718 wrought plate. These heat treatments resulted in extensive precipitation of needle- and plate-shaped δ phase in the γ-nickel matrix. δ-phase accumulation represents the principal metallurgical damage from simulated multiple repair/postweld heat treatment cycles in Alloy 718. Grain size did not increase during this exposure due to the grain boundary pinning effect of the δ phase. Simulated weld heat-affected zone thermal cycles resulted in a variety of microstructural changes to the heat treated material, including δ-phase dissolution-promoted liquation, boron carbide constitutional liquation, and segregation-induced grain boundary liquation. The effect of these liquation phenomena on the weldability degradation of Alloy 718 is discussed.

Introduction

Weld repair of aircraft gas turbine engine components has become increasingly prevalent as a means of extending engine life and reducing the costs associated with component replacement. As part of the repair welding process, the precipitation-hardened superalloys must undergo postweld heat treatment (PWHT) to restore their mechanical properties. Because components are subject to multiple repairs over their lifetimes, they will also be exposed to multiple cycles of PWHT. It has been observed that the weldability of some superalloys degrades after an accumulation of repair/PWHT cycles (Refs. 1–5), making further repair difficult. Heat-affected zone (HAZ) liquation cracking is the root cause of this difficulty, which occurs in the partially melted region of the HAZ. Such cracking has been shown to be associated with local or partial melting of grain boundaries, causing a short time high temperature grain boundary (GB) weakening (Ref. 6). Preliminary investigations on the effect of multiple PWHT cycles on repair weldability have been conducted for Alloy 718 (Refs. 2–5, 7). A direct result of the multiple PWHT is the accumulated, abundant δ-phase (Ni, Nb, orthorhombic) precipitation in the nickel matrix, constituting the metallurgical “damage” that degrades the weldability of Alloy 718. The δ-phase dissolution during weld thermal cycles was reported to be a factor resulting in grain boundary liquation (Ref. 7) by promoting GB segregation of Nb, a melting point depressant (Ref. 1). The purpose of this paper is to elucidate the effect of liquation phenomena on the weldability degradation in the Alloy 718 due to multiple repair/PWHT cycles.

Experimental Procedure

The material used in this study was Alloy 718 in the form of wrought plate. The composition of this material, based upon an independent analysis, is shown in Table 1. The plate microstructure in the as-received condition is shown in Fig. 1. There are fine deformed grains surrounding the “normal” grains and some δ phase is present in the γ-nickel matrix. Simulation of multiple PWHT cycles was accomplished through metallurgical-equivalent long-term isothermal heat treatments. This technique has previously been shown to yield microstructures and properties similar to those achieved through multiple thermal cycles for equivalent times (Ref. 6). A normal PWHT for Alloy 718 would be 954°C for 0.5–2 h. Two isothermal treatments were performed to simulate multiple PWHT cycles: 954°C/40 h and 954°C/100 h. The isothermal treatments were conducted in air in a box furnace with air cooling. Subsequently, Gleeble hot ductility specimens were machined from the bulk materials after heat treatment.

Gleeble hot ductility testing was conducted to evaluate and compare the susceptibility of Alloy 718 to HAZ liquation cracking in three different conditions: 1) as-received, 2) 954°C/40 h, and 3) 954°C/100 h. The specimens are 6.35 mm in diameter, 100 mm in length, taken longitudinally along the rolling direction in the plate. The hot ductility testing follows conventional procedures as have been reported previously (Refs. 2–7). A heating rate of 111°C/s, hold time at test temperature of 0.5 s, cooling rate of 43°C/s (for on-cooling tests), and stroke rate of 25 mm/s were used. All testing was conducted under an argon atmosphere. Figure 2 schematically shows the procedure for determining critical values of nil-strength temperature (NST), nil-ductility temperature (NDT), and ductility-recovery temperature (DRT). Initially, the nil-strength temperature (NST) was determined by heating the specimen under a small static load (approximate 10 kg) until failure occurred. On-heating hot ductility tests were conducted by heating samples to various test temperatures, and pulling them to failure at the stroke rate reported, until NDT was achieved. On-cooling tests were performed after heating to a peak temperature (Tp) between the NDT and NST, and then cooling to a desired temperature, and pulling to failure to identify the DRT.

Metallographic samples were examined using both an optical microscope and a Phillips XL-30 scanning electron microscope (SEM) equipped with an energy-dispersive spectrometer (EDS). Electrolytic etching with 10% aqueous chromic acid was generally used to reveal

KEY WORDS

Alloy 718
Weld Repair
δ-Phase Precipitation
Boron Carbide Constitutional Liquation
Liquation Cracking
Intergranular Fracture

M. QIAN and J. C. LIPPOLD are with the Welding and Joining Metallurgy Group at The Ohio State University, Columbus, Ohio.
Fig. 1 — Microstructure of as-received Alloy 718 base metal: A — distribution of fine deformed grains at grain boundaries; B — short bar-shaped intra- and intergranular δ phase.

Table 1 — Chemical Composition of Alloy 718 Wrought Plate

<table>
<thead>
<tr>
<th>Element</th>
<th>wt-%</th>
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<tbody>
<tr>
<td>Cr</td>
<td>18.42</td>
</tr>
<tr>
<td>Mn</td>
<td>0.09</td>
</tr>
<tr>
<td>Co</td>
<td>0.2</td>
</tr>
<tr>
<td>V</td>
<td>0.022</td>
</tr>
<tr>
<td>Al</td>
<td>0.5</td>
</tr>
<tr>
<td>C</td>
<td>0.033</td>
</tr>
<tr>
<td>Ti</td>
<td>1.03</td>
</tr>
<tr>
<td>B</td>
<td>0.0018</td>
</tr>
<tr>
<td>Mo</td>
<td>3.03</td>
</tr>
<tr>
<td>Si</td>
<td>0.1</td>
</tr>
<tr>
<td>S</td>
<td>0.0005</td>
</tr>
<tr>
<td>Fe</td>
<td>17.58</td>
</tr>
<tr>
<td>P</td>
<td>0.012</td>
</tr>
<tr>
<td>W</td>
<td>0.029</td>
</tr>
<tr>
<td>Mg</td>
<td>0.011</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
<td>0.006</td>
</tr>
<tr>
<td>Ni</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Fig. 2 — Schematic of Gleeble hot ductility test procedure.

Table 2 — The Effect of Heat Treatment on Grain Size of Alloy 718

<table>
<thead>
<tr>
<th>HT Condition</th>
<th>Grain Size (d_f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-received</td>
<td>79±40.6 μm</td>
</tr>
<tr>
<td>954°C (1750°F)/40 h</td>
<td>83±27 μm</td>
</tr>
<tr>
<td>954°C (1750°F)/100 h</td>
<td>83±34 μm</td>
</tr>
</tbody>
</table>

Results and Discussions

The principal microstructural feature in long-term isothermally treated Alloy 718 is the high fraction of precipitated δ phase relative to that of the as-received material. The as-received base metal had relatively little δ phase and the size of intra- and intergranular bar-shaped δ phase is comparable — Fig. 1. In contrast, the fraction of both intra- and intergranular (IG) δ phase in the long-term, isothermally treated material increased dramatically, as shown in Fig. 3. The intergranular δ phase becomes essentially continuous as a result of the long-term isothermal treatment, and some bar-shaped δ phase along twin boundaries also became continuous. The morphology of the intragranular δ phase appears as fine needles that intercrossed compactly — Fig. 3B. There was no evidence of gamma double-prime (γ') observed in this structure since the heat treatment temperature is above the precipitation range for γ' and none would be expected to form upon rapid cooling to room temperature. In addition, the rapid formation of the δ phase depletes the matrix of niobium, further reducing the possibility of γ'.

The grain size remained essentially constant after the long-term isothermal heat treatment at 954°C, as shown in Table 2. This is due to the pinning effect of the γ' phase on grain boundaries. The bulky angular phases in the nickel matrix (Fig. 3B) are carbides that are distributed as stringers in the rolling direction of the wrought plate.

Gleeble hot ductility testing revealed HAZ liquation cracking susceptibility increases with the increase in hold time at 954°C, as determined by the liquation temperature range (LTR), which is the difference between NST and DRT (Table 3). Noticeably, the increase of LTR is consis-
Fig. 3 — High fraction of needle-shaped intragranular and bulky continuous, intergranular δ phase from long-term isothermal treatment. A — 954°C/40 h; B — 954°C/100 h.

Fig. 4 — δ-phase dissolution during simulated HAZ thermal cycles in Alloy 718. A — δ-phase thickening at NDT of the as-received material; B — dissolving δ-phase network at NDT of 954°C/40 h treated material; C — δ-phase “rounding” at NST of the as-received material (liquated boron carbide is indicated); D — interconnected cluster of B- and Nb-rich eutectic constituents from dissolved δ-phase along grain boundaries at NST of 954°C/100 h-treated material.

Microstructural evaluation revealed that δ-phase dissolution-promoted liquation occurs during the on-heating thermal cycle and persists to the NST. δ phase has an orthorhombic structure with composition of Ni5Nb. In Alloy 718, its precipitation temperature range is from 650 to 1050°C (Refs. 9, 10). δ phase will dissolve above the upper temperature limit. Upon dissolution, the surrounding γ-nickel matrix is enriched in Nb, both intra- and intergranularly depending on the δ-phase distribution. Since Nb forms two eutectics with Ni as (Ni+Ni3Nb) at 1282°C (23 wt-% Nb) and (Ni3Nb+Ni6Nb7) at 1175°C (52 wt-% Nb), Nb acts as a melting point depressant element in Ni (Refs. 11, 12). With regard to Alloy 718, it is expected that the dissolution of δ phase will result...
in formation of Nb-rich eutectic constituents, as has been observed in the current research.

Figure 4 shows microstructural evidence of δ-phase dissolution and associated liquation. The dissolution of the δ phase results in Nb enrichment at the grain boundary that gives rise to the different etching characteristic of the boundary. The Nb-enriched boundary varied as a function of the peak temperature reached during the hot ductility test and is manifested microstructurally by different morphologies. At the NDT, the microstructure appears as δ-phase needle "thickening," as shown in the as-received material — Fig. 4A. Note that the "holes" along the GBs are sites of eutectic, δ-phase dissolution products that have etched out of the structure. Fracture surface analysis in the SEM revealed additional details of the liquation process, including apparent constitutional liquation of boron carbides.

Typical intergranular features are shown in Fig. 6, where liquated particles and evidence of liquid films on the fracture surface can be seen. Note the angular but slightly rounded particles and holes where particles have dropped out of the fracture surface — Fig. 6A and B. EDS analysis revealed that the particles are complex boron carbides containing Cr, Ti, and some Nb. The presence of round holes accommodating the rounded boron carbides suggests that boron carbide-related constitutional liquation has occurred along the GBs. Heating of the densely distributed δ phase in 954°C-treated samples to the NDT produced more extensive, dissolving δ phase networks — Fig. 4B. As the test temperature was raised to the NST, δ-phase dissolution became more pronounced. The once-thickened, intragranular δ-phase needles began "rounding" (Fig. 4C and D), indicating a more accelerated Nb dissolution rate. Some adjacent dissolved δ phase near or along GBs interconnected to form B- and Nb-rich eutectic constituents — Fig. 4D. These low-melting eutectic liquids along GBs will result in GB weaken-
more evident, appearing as terraced ripple patterns. At the center of concentric ripples, a liquated particle in a hole was identified as a Nb-rich boron carbide, as shown in Fig. 7B and C. Similar but smaller particles can also be differentiated in the same micrograph. The angular particle at the upper right has not liquated and was identified as TiC. More GB liquation associated with ripple patterns can be seen in Fig. 7D.

Figure 8 presents secondary electron (SE) and back-scattered-electron (BSE) micrographs that clearly show the morphology of boron carbides (lighter bulky phase) and MC carbides (dark phases), where boron carbide has apparently decomposed from its periphery. A similar case can be seen in Fig. 4C (arrow) and is probably due to constitutional liquation. Based on the above results, it can be concluded that δ-phase dissolution-promoted liquation plays a major role in influencing the susceptibility to liquation cracking in Alloy 718 subjected to long-term heat treatments at 954°C. Segregation of B and Nb as well as other melting-point depressants also contribute to the localized melting of the GB.

Interstitial elements, such as boron, are well known to have the propensity to segregate to GBs. Nb from the dissolution of δ phases could preferentially segregate to GB through either diffusion (Refs. 13, 14) or a segregation mechanism (Ref. 7), by which Nb could be swept by mobile GBs once the pinning effect of δ phase was reduced by dissolution. Nb-containing boron carbide liquation also contributed to the Nb segregation to GBs, though this is expected to account for only a small fraction of the liquid present, since the fraction of boron carbides is much less than the δ phase. In addition, boron carbide liquation produces a low-melting eutectic, an extra low melting point constituent that further aggravates the liquation.

In summary, the effect of liquation phenomena on the susceptibility to liquation cracking of Alloy 718 that has been exposed to multiple PWHT cycles that result in a high fraction of δ phase can be explained as follows. As the number of weld repair cycles accumulates, δ-phase precipitation becomes more extensive. Upon re-
heating in the weld HAZ, rapid δ-phase dissolution occurs. δ-phase dissolution-promoted liquation, possibly combined with boron carbide constitutional liquation, results in extensive grain boundary liquation that then leads to cracking if restraint levels are sufficient. This explains why the buildup of δ-phase in Alloy 718 increases the susceptibility to HAZ liquation as the number of repair/PWHT cycles increases.

Conclusions

1) Simulated multiple PWHT cycles using equivalent long-term isothermal heat treatments (954°C/40-100 h) resulted in extensive precipitation of needle- and plate-shaped δ-phase in the γ-nickel matrix, which is the major metallurgical change relative to the starting plate material. Grain size did not change appreciably during these heat treatments due to grain boundary pinning by the δ-phase.

2) Gleeble hot ductility testing showed weldability (resistance to HAZ liquation cracking) of Alloy 718 degraded as a consequence of the simulated multiple PWHT cycles.

3) The degradation of weldability results from grain boundary liquation resulting primarily from the δ-phase dissolution and associated Nb enrichment of the grain boundary. Constitutional liquation of boron-rich carbides was also observed and may contribute to the grain boundary liquation.

Acknowledgment

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8. ImageTool program developed at the University of Texas Health Science Center at San Antonio, Tex., and available from the Internet by anonymous FTP from ftp://maxrad6.uthscsa.edu.


Laser Beam Weld Bonding of AA5754 for Automobile Structures

There are benefits in both static and dynamic mechanical properties when welding is combined with adhesive bonding

BY R. W. MESSLER, JR., J. BELL, AND O. CRAIGUE

ABSTRACT. Combining spot welding with bonding using a structural adhesive in the hybrid process of weld bonding is known to result in synergistic benefits in joint static and, especially, dynamic mechanical properties. Here, a laser beam source was substituted for a more traditionally used resistance welding source to produce spot welds either through the adhesive or in gaps in the adhesive in a study of the weld-bonding of AA5754 for application in the assembly of automobile body and underbody structure. Static shear, coach (T-coupon) peel, and shear fatigue were all assessed in various combinations of sheet thickness, pretreated (i.e., dry lubricant coated or uncoated) conditions, and testing temperatures.

Introduction

In response to pressure from the Environmental Protection Agency (EPA), as well as consumers, for more fuel-efficient and environmentally friendly automobiles, manufacturers are looking at alternative materials of construction to reduce vehicle weight. Weight is the key to fuel savings because a 10% reduction of weight yields a 6-8% improvement in fuel economy (Ref. 1). Aluminum alloys are leading candidates because of their inherently low density and superior corrosion resistance (compared to steels), greater design flexibility due to ease of forming and diversity of forming processes (compared to reinforced plastics), aesthetic appeal (at least when unpainted), and 100% recyclability (offering environmental friendliness at a premium scrap value) (Ref. 1). The one-third density of aluminum alloys vs. steel (i.e., 2.8 vs. 7.8-7.9 g/cm³) has been purported to afford as much as a 40% “body-in-white” (BIW) weight savings (Ref. 2). However, to replace steel, the current “workhorse” material of construction for automobiles, aluminum alloys have to be equally amenable to modern automobile production methods, including assembly while traveling along a production transfer line with many assembly operations being automated, frequently using robots. With speed and efficiency being critical to production economy, a fast, reproducible, and reliable method for joining is as essential as joints that provide structural integrity under a complex combination of static and dynamic loads.

The Challenges of Joining Aluminum Structures

As is so often the case in life, the attractive properties of aluminum alloys as a structural material are accompanied by their special challenges to automated automobile assembly, especially to traditional welding methods (e.g., resistance spot welding) long used by the industry. Aluminum and its alloys are extremely reactive with air and quickly form a tenacious, highly refractory oxide (Al₂O₃) outer layer on all exposed surfaces. Pure aluminum has a melting point of about 660°C (1200°F), while its oxide has a melting point of about 1650°C (3000°F), thereby persisting even in the melt. Furthermore, aluminum’s oxide is both electrically and thermally insulative. Hence, it presents a barrier that must be penetrated before the base metal can melt during welding to achieve the metal-to-metal (part-to-part) continuity that is required to produce a weld (Ref. 3).

Resistance welding, the process that predominates in vehicle assembly throughout the automobile industry, becomes particularly difficult with aluminum alloys (Ref. 4). Passing current into the aluminum alloy parts to join them with the desired spot weld at part-to-part interfaces becomes very difficult without careful, time-consuming, and expensive chemical and mechanical cleaning reasonably soon (ideally, just) before welding to prevent reoxidation/recontamination. High contact resistance between the copper (or copper-alloy or composite) welding electrodes and the oxidized aluminum alloy, together with aluminum oxide’s high melting point compared to copper’s (i.e., 1600°C or 3000°F compared to 1035°C or 1985°F, respectively), leads to unwanted melting at the electrode-to-weldment interface while current is applied to slowly break through the insulative oxide.

While new Cu-based electrode compositions show promise of dramatically extending electrode life in the laboratory or under controlled tests, this is not the case in production. Controlled tests tend to employ flat, close-fitting lap joints, the shorter welding cycles allowed by such joints, and electrodes that are optimally sized for each particular combination of joint element gauges and desired spot size. All of these factors allow the welding heat to be minimized and extend electrode life to thousands of welding cycles or spot welds before electrode change-out, even without periodic tip dressing. Welding in actual production, on the other hand, generally results in electrode life of hundreds of welding cycles or spot welds, at best, with built-in automatic dressing of electrode tips often occurring every 20 weld-

KEY WORDS
Weld Bonding
Laser Beam Welding
Adhesive Bonding
Aluminum Alloys
Static and Dynamic Properties
Automobile Assembly
ing cycles or so. Less-tight-fitting lap joints between formed sheet metal parts, often with complex curvatures, and the need for larger electrodes to enable multiple gauge combinations (typical of most vehicle assembly) to be handled without changes, demand higher welding currents and longer welding cycles; both of which combine to increase heat at the electrode-to-aluminum workpiece interface. The result of these production realities leads to 1) electrode sticking and 2) accelerated wear, as well as 3) Cu-contamination of the aluminum alloy (with possible cracking) (Ref. 5). At the part-to-part interface, the resulting spot weld also frequently contains porosity from absorbed moisture typically associated with the oxide, and brittle (and embrittling) inclusions of the oxide itself.

Another issue with welding aluminum alloys is their high thermal conductivity. Heat is quickly dissipated through the metal, causing difficulties with localized melting and a tendency for cracking upon solidification, which always takes place more rapidly than in less thermally conductive metals. When attempting to weld aluminum alloys, additional heat must be added to achieve melting, and cooling after welding must be controlled, typically using preheating and postheating techniques in the form of added current pulses during resistance spot welding (Ref. 6).

As a result of all of the above, the resistance spot welding process found so amenable to welding steel automobiles poses challenges that are, from a practical, even if not theoretical, standpoint, insurmountable for the automobile industry at large. Fortunately, there are other viable ways to join aluminum and its alloys.

**Weld-Bonding as an Alternative for Joining Aluminum**

Extensive experience in the aerospace industry over several decades has shown that aluminum alloys are especially suited to joining by adhesive bonding (Ref. 7). Adhesive bonding is the process of employing substances (i.e., chemical agents) capable of holding materials together by surface attachment forces (Ref. 8). Adhesive bonding offers a number of advantages, including 1) excellent strength in shear (due to both the viscoelastic nature of most adhesives), 2) uniform distribution (i.e., spreading) of loads and softening of stress concentrations (compared to fastened or spot welded joints), 3) excellent fatigue resistance (largely due to the viscoelastic nature of most adhesives, and attendant self-healing of cracks, as well as reduced stress concentrations from load spreading), and 4) good energy absorption (from impact and/or vibrations). Other associated (secondary or designed in) properties can include sealing (against fluid leakage), and thermal and electrical insulation, elasticity, and smoothing of contours (especially in joint areas) (Refs. 8-10).

Despite these numerous advantages, there are shortcomings, if not disadvantages, to the adhesive bonding process. These include 1) low peel strength under out-of-plane loads (largely due to the low inherent strength of adhesion between adhesive and adherend or substrate), 2) limited tolerance of low (generally much below 0°C) or even moderately high (generally above 200°C) temperatures, 3) short shelf life, 4) short working life, and 5) tendency of fumes/odors to be toxic, beyond just being unpleasant (Refs. 8, 10).

As stated at the beginning of this section, there are many different and diverse adhesives that work well with aluminum and its alloys including, but not limited to (Refs. 8, 10), modified epoxies, modified phenolics, epoxy-phenolics, neoprene-phenolics, second-generation acrylates, cyanoacrylates, silicone rubbers, nitro-phenolics, vinyl-epoxies, and polyurethanes.

Such a wide choice offers opportunities to achieve desired properties and performance for a wide variety of loading, environmental, and production manufacturing conditions. It also offers considerable challenges to both design and process engineers.

An attractive, compromise joining process for the assembly of aluminum structures in automobiles is weld bonding. Weld bonding is defined as “a spot welding process variation in which the spot weld strength is augmented by adhesive at the faying surfaces” (Ref. 9). In general...
terms, it is the combination of adhesive bonding with a welding process to gain advantages of each joining method (in the form of a hybrid method), and, ideally, some unique advantages through a synergetic effect (Ref. 11).

Alcan (Aluminum Company of Canada) has explored the weld-bonding process for an automobile production line with its ASVT process — Fig. 1. First, adhesive is applied to preformed, chemically pretreated aluminum panels. The panels are then spot welded together with the spot welds acting as "clamps" or "tacks" for the joints, preventing the panels from shifting throughout further production processing. Finally the heat-activated adhesive is thermally cured in an oven at the end of the production line (Ref. 2). The adhesive provides shear strength, while the weld protects the joint from out-of-plane loads.

There are several particularly interesting potential benefits for weld-bonding. The static shear strength of the joint can be reasonably expected to increase along with the peel strength; with spot welds carrying out-of-plane loads to protect the adhesive from peeling. Fatigue life of the joint can be expected to increase because of the presence of the adhesive; with the adhesive spreading the loading around the spot welds to soften stress concentrations. Synergistic effects between the adhesive and the weld can thus be present. Load transfer is vastly improved throughout the joint. The adhesive also provides energy absorption (which improves crash worthiness), sealing and corrosion resistance (which extends vehicle life in the face of environmental factors), vibration damping (which contributes to improved ride quality by reducing harshness and noise), and smooth contours (which contributes to appearance/aesthetics) (Refs. 8, 12).

Overall, weld-bonding could allow the automobile industry to optimally join aluminum alloys, which are inherently much more difficult to spot weld than steels, but relatively easy to adhesive bond. The purpose of this study was to assess the use of laser (spot) weld-bonding, because of numerous attractive characteristics and qualities of laser beam welding, including 1) precise control of energy input level and weld placement, 2) suitability for use in a normal production plant environment (i.e., open air), 3) amenability to automation using fiber-optic delivery with robotic end-effectors, and 4) use of a central power source and beam splitting (Ref. 3).

Experimental Procedure

Test Coupon Preparation

Aluminum alloy AA5754, provided by Alcan in 4- x 1-ft (i.e., 120- x 30-cm) panels mechanically sheared from larger sheets, was used throughout the study. Tables 1 and 2 give the alloy's composition and mechanical properties, respectively. A proprietary water-soluble dry lubricant designed especially for use with adhesives was preapplied to the aluminum alloy sheet at Alcan. Two thicknesses of 2.08 mm, referred to as "thick," and 1.03 mm, referred to as "thin," were used for three different mechanical property tests: 1) single-lap static tensile shear (Fig. 2) to ASTM D1002-99, 2) coach (T-coupon) peel (Fig. 2) to ASTM D1876-99, and 3) single-lap tensile shear fatigue to ASTM D3166-99. The purpose of single-lap static tensile shear testing is to assess joint strength under static in-plane loading, while the purpose of single-lap tensile shear fatigue testing is to assess joint strength (or life at a given stress level) under cyclic loading. The purpose of coach (T-coupon) peel testing is to assess out-of-plane (peel) strength, and to give an indication of the joint's ability to absorb energy upon impact, say during a crash.

For all three tests, appropriate-sized sheared blanks were laser beam spot welded only; adhesive bonded only; or

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1. All blanks were 38.1 mm (1.5 in.) long, with static tensile shear and tensile shear fatigue coupons overlapped at opposite ends of the two pieces making up the coupon, and coach peel coupons stacked as pairs face-to-face. Overlap was chosen to ensure failure occurred in shear in the joint, not by overload in the base metal. Figures 2A and 2B show the two specimen designs.
Comparison of Lubricated and Nondub¢lcated Weld-bonded Shear Strength

![Graph showing lubricant effect on weld-bonded test results of static shear strength.](image)

![Graph showing temperature effect on weld-only static shear strength.](image)

**Table 3A — Full Test Matrix for the Study; Part A, Static Tensile Shear**

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Orientation</th>
<th>Overlap (mm)</th>
<th>No. at RT</th>
<th>No. at 100 °C</th>
<th>No. Extra</th>
<th>No. Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive, lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>thin thick</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Adhesive, no lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, no lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, through adhesive lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, through adhesive, no lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, gap in adhesive, lubricant</td>
<td>thick thick</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Weld, gap in adhesive, no lubricant</td>
<td>thick thin</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>thin thin</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

No. of thick pieces: 140.
No. with 4.625 in. to hole: 76.
No. with 4.4865 in. to hole: 34.
No. of thin pieces: 126.
All with 4.3865 in. to hole.

Laser (spot) weld-bonded in thin-to-thick, thin-to-thick, and thick-to-thick combinations, with the producer-applied lubricant (designated "lubricant") or with that lubricant removed by washing in clean warm water (designated "no lubricant"). Some tests (e.g., static tensile shear and coach peel) were performed at room temperature and others at 100°C to test for the effect of temperature on the joints in inherently warmer structures (e.g., around the engine compartment). Table 3, consisting of Parts A, B, and C, gives the full test matrix for the study.

**Welded-Only Test Specimen Preparation**

Combinations of thin-to-thin, thin-to-thick, and thick-to-thick blanks in lubricant and no-lubricant conditions were spot welded using a 1700-W Convergent-Prime Arrow Ultimate CO₂ laser operating in the continuous (vs. pulsed) mode. The same parameters were used for specimens that were welded only, welded through, and welded through a gap in the adhesive. The goal in parameter selection was to obtain a 5-mm-diameter weld spot or nugget at the interface of the thick-to-thick blanks and a 3-mm-diameter weld spot or nugget at the interface of thin-to-thin and thin-to-thick blanks. Parameters of beam power, beam-on time, and any beam movement (actually, CNC table movement) to increase spot weld size by circle generation were not changed from weld-only to weld-bonded joints because it was assumed spot size would not change much with the different types of samples. Final laser welding parameters are given in Table 4.

**Adhesive Bonded-Only Test Specimen Preparation**

For all test coupons involving adhesive bonding, whether alone or in combination with subsequent laser spot welding, regions to receive adhesive were left open, while regions not to receive adhesive were covered by masking tape. For weld-bonded specimens in which the spot welds

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2. For the thin-to-thick combination, laser spot welding was always performed from the thin side to produce the spot weld by a melt-in (or conduction) mode into the thick back piece.

3. The masking tape could be left on single-lap shear specimens until after the adhesive was cured (or until supplemental laser spot welding) as it was outside the overlap area and could be removed. For coach (T-coupon) peel specimens, the masking tape, while not accessible (being fully sandwiched between blanks), could be left in place without affecting test results.
would be made in openings (or gaps) in the adhesive (so as not to have to weld through the adhesive with whatever problems that might cause) an additional (second), transverse strip of masking tape approximately 8.5 mm (3.38 in.) wide was applied to create a small (approximately 8 mm square or rectangular gap at the coupon overlap midpoint. After masking, adhesive was spread evenly over the unmasked region and 20-50 glass beads measuring 0.25 mm (0.010 in.) in diameter were sprinkled on. These nondeformable beads fixed the bond-line thickness (which is a variable needing to be controlled in adhesive bonding).

Betamate 4601 adhesive, produced by Essex Specialty Products, Inc. (a division of Dow Chemical Co.), is a one-part, high-performance heat-curing (or heat-activated) structural epoxy adhesive (Ref. 13). It was allegedly designed specifically for use on pretreated aluminum and aluminum alloys, and comes as a paste that can be dispensed manually or automatically/robotically. This adhesive is widely used in the automobile industry for structural assembly. Table 5A and B gives the adhesive's cured physical properties and performance properties in joints.

The cure cycle used was 30 minutes at 175°C, with a ramp up from room temperature at no more than 5°C per minute.

Weld-Bonded Test Specimen Preparation

The weld-bonded test specimens were of two types to assess alternative approaches for laser welding through the adhesive or only through gaps within the adhesive. Welding of both specimen types was performed as described above under the heading “Welded-Only Test Specimen Preparation.” The adhesive application was performed as described above under the heading “Adhesive Bonded-Only Test Specimen Preparation.” The only change was that preliminary weld-bonding trials (involving the development of laser beam spot welding parameters) showed the heat of the laser spot welds caused the uncured adhesive to soften and flow outside masked areas. Welding trials with precured coupons showed no improvement in laser beam/adhesive interaction, so coupons were left in the uncured condition during all welding of test coupons to allow the adhesive to flow back around newly made spot welds (for maximum effect on softening stress concentrations at the spot welds).

Property Testing

All single-lap static tensile shear testing and coach peel testing were performed on an Instron 4204 machine with a 50-kN (11,240-lb) load cell and 1.5-in.-wide (38-mm-wide) wedge grips. Except where noted, testing was performed at room temperature, with the other testing occurring at 100°C (as noted). Three repeat tests were performed for each and every condition of paired-coupon (blank) thickness, lubricant or no lubricant, and laser (spot) weld only, adhesive bonding only, and combined weld bonding either welding through the adhesive or into openings (gaps) in the adhesive, with the average value being plotted.

Single-lap tensile shear testing
was performed initially at Rensselaer Polytechnic Institute (RPI), but then predominately at Winona State University (WSU) using an Instron Model 1331 Load Frame with Instron Series 8500 Controller, with 1-in. Instron Hydraulic Wedge Grips (with a 21-MPa gripping pressure), and a 50-kip (about 250-kN) load cell at RPI and a 10-kip (about 50-kN) load cell at WSU operating at 20-22 Hz.

In all cases, five to seven specimens (of each joint condition) were run at various stress levels to develop a stress vs. number of cycles (S-N) graph for each condition. (Later on, results were plotted as maximum load vs. number of cycles due to inherent difficulties of calculating stress, as will be described below.) One million (10^6) cycles was set as the maximum life for the tests to determine fatigue strength (or fatigue limit). The specimens were run with a fully reversing (R = -1.0) sinusoidal waveform at a frequency of 20-22 Hz. All testing was performed at room temperature under normal atmosphere.

Table 4—Final Laser Welding Parameters Used throughout the Study

<table>
<thead>
<tr>
<th>Joint Condition</th>
<th>Power</th>
<th>Speed</th>
<th>Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin to thin (weld only)</td>
<td>865 W</td>
<td>50 in./min</td>
<td>R c.</td>
</tr>
<tr>
<td>Thin to thick (weld only and WB)</td>
<td>1200 W</td>
<td>50 in./min</td>
<td>R c.</td>
</tr>
<tr>
<td>Thick to thick (weld only and WB)</td>
<td>1600 W</td>
<td>15 in./min</td>
<td>R c.</td>
</tr>
<tr>
<td>Thin to thin (WB)</td>
<td>915 W</td>
<td>50 in./min</td>
<td>R c.</td>
</tr>
</tbody>
</table>

Table 5—Properties for Betamate 4601 Structural Adhesive

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Cure</td>
<td>15 minutes @ 175°C</td>
</tr>
<tr>
<td>Modulus Tensile</td>
<td>76 MPa</td>
</tr>
<tr>
<td>Elongation at break (23°C)</td>
<td>11.5%</td>
</tr>
<tr>
<td>Performance Properties</td>
<td></td>
</tr>
<tr>
<td>Test Substrate</td>
<td>2-mm-thick Alcan 5754 alloy aluminum, PT2 pretreatment</td>
</tr>
<tr>
<td>Bondline Thickness</td>
<td>0.254 mm (0.010 in.)</td>
</tr>
<tr>
<td>Lap Shear</td>
<td>23°C 23.3 MPa (3380 psi)</td>
</tr>
<tr>
<td>-40°C 23.7 MPa</td>
<td></td>
</tr>
<tr>
<td>Pecl</td>
<td>3 m/s</td>
</tr>
<tr>
<td>ISO 11343 Dynamic Resistance to Cleavage</td>
<td>15100 (75)</td>
</tr>
<tr>
<td>23°C 730 Newtons</td>
<td></td>
</tr>
<tr>
<td>40°C 220 Newtons</td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

Single-Lap Tensile Shear Test Results

For the adhesive bonded-only tests, there was an insignificant difference between lubricant and no-lubricant results (Fig. 3), confirming that the Betamate 4601 adhesive was, indeed, designed to work with the dry lubricant. For weld-only tests, the no-lubricant specimens exhibited higher shear strengths than lubricant specimens (Fig. 4), indicating that the dry lubricant has adverse effects on the laser spot welds, even if not on the beam-metal interaction. Weld-bonded tests exhibited an insignificant difference between lubricant and no-lubricant specimens (Fig. 5); suggesting any possible adverse effect of lubricant is overshadowed by the general adverse effect of the adhesive itself on the quality of the laser spot weld due to violent outgassing, molten metal expulsion (leading to hollow spot welds), and charring due to the laser's interaction with the polymeric adhesive.

Joint thickness had no noticeable effect on adhesive-only samples, but did have an effect on weld-only and weld-bonded samples (Figs. 3–5). These results are consistent with the fact the load-carrying ability of an adhesive bonded joint is dependent on the amount of surface area bonded and the inherent strength of the adhesive, with material (i.e., adherend) thickness having a secondary effect, at least as long as thickness differences do not result in significant degrees of joint rotation under eccentric loads in single-lap specimens (Ref. 8). However, the thickness of joint elements does have an effect on a welding process, including laser beam spot welding. The thick-to-thick combination posed the greatest problem for laser spot welding, requiring more beam energy to melt through the 2-mm-thick aluminum alloy sheet on the beam entry side with less penetration into the backing sheet, resulting in inferior weld strength. (This could be overcome by refining welding parameters for this thickness combination.) With the thin-to-thick and thin-to-thin combinations, the laser beam only had to penetrate a 1-mm-thick sheet of aluminum alloy on the entry side (in each case) to produce greater penetration into the backing sheet and a stronger weld. Between these two, the thin-to-thick combination (actually the most common joint found in vehicles) exhibited the superior strength, possibly attributable to the thicker backing sheet providing a larger heat sink and less thermal damage to the adhesive.
Testing temperature had no effect on the weld-only results (Fig. 6), as would be expected for such a low temperature (100°C) for an alloy with a melting point near 600°C. However, joint static shear strength was adversely affected in both the adhesive-only (Fig. 7) and weld-bonded (Fig. 8) tests by even modestly elevated temperatures (i.e., 100°C). This is, without question, the direct result of the polymeric adhesive softening upon heating (as do most viscoelastic materials), thereby having a reduced ability to carry (shear) loads.

The weld-bonding data are quite interesting. Static shear stress data for weld-bonded specimens were considered two ways: 1) a stress was calculated (in the conventional manner) by dividing the peak load (sustained) by the combined areas of the adhesive as well as of the weld, while 2) an "expected load" was also determined by multiplying the area of adhesive bond by the measured value of shear strength (stress) for the adhesive only and adding the product of the area of the spot weld and the measured value of shear strength (stress) for the weld only. The stress used to determine what level of load could be carried came directly from the average stress from an adhesive-only and a weld-only test of the same joint geometry (due to differences in stress based on joint geometry). The expected load was then compared to the actual load as a percentage of the difference between the two values divided by the expected load. It reads: the actual load is x percent greater than what was expected, if x is positive, and the actual load is x percent lower than what was expected, if x is negative. By this technique there appears to be a positive (synergistic) effect in the thick-to-thick, a marginally positive (synergistic) effect in the thin-to-thick, and a negative (degradation) effect in the thin-to-thin joints. One reason for the apparent degradation in the thin-to-thin joints could be due to differences in the shear strengths (stresses) of adhesive-only joints that are thin-to-thin vs. thin-to-thick. Only further testing will resolve this question. This effect is shown in Fig. 9.

**Coach (T-Coupon) Peel Results**

The customary way to measure the peel strength of an adhesive is by using the average peel force. It is common to measure the strength of welds (especially, spot welds) by looking at the maximum force. It was determined in this study that in order to see if there is, in fact, any synergistic benefit of combined weld bonding, bond energy would have been used. The two main reasons for this were 1) the spot welds break 19 mm (0.75 in.) after the adhesive starts peeling (due to the way the coupon peels) and 2) high peel forces can exist for very short periods of time and actually absorb less energy than if a lower peeling force were required to be applied but for a much longer time. In other words, it is the area under force-displacement curves for weld-bonded specimens that is important in energy absorption. If
there is a synergistic effect of weld-bonding, the area under the force-displacement curve for a weld-bonded specimen should be greater than the sum of the areas for a weld-only and an adhesive-only curve, correcting for the areas of each in the weld-bonded specimen.

When comparing the energies for the thin-to-thick specimens, it is evident there is a synergistic effect of weld bonding, averaging about 25% higher than expected by simple additive effects. This is shown in Fig. 10.

Single-Lap Tensile Shear Fatigue Test Results

Six specimens each of lubricant and no-lubricant thick-to-thick adhesive bonded-only samples were tested at RPI to establish a uniform testing procedure and to determine broad life-vs.-load behavior. The starting fatigue load level was taken as approximately 50% of the maximum static load required to cause static tensile fracture. This load level resulted in a fatigue life of approximately 100,000 cycles for both conditions. From this “base point,” higher and lower loads (as a percentage of the maximum static load to cause fracture) were applied in order to generate a stress vs. number of loading cycles to failure (S-N) curve. At approximately 65% of the maximum static fracture load, fatigue specimens survived only 1000-4000 loading cycles. This was taken as the maximum load level for fatigue testing, as any load above this would have resulted in life of very little interest. A fatigue life of 500,000 cycles was obtained with load levels between 40 and 45%. The sought-after 1,000,000 (10^6) cycle maximum life (or fatigue limit) was predetermined from regression analysis to occur at a load level of 38-40% and, in fact, this load level did result in 10^6 cycles life.

Figure 11 shows there is virtually no difference in the fatigue behavior of lubricant and no-lubricant specimens for adhesive bonded only, thick-to-thick condition. Within expected error from various sources, the regression lines lie on top of one another.

Using this same general testing procedure, all remaining fatigue testing was performed at Winona State University using the system described previously under the heading “Property Testing.”

First, thin-to-thick and then thin-to-thin combinations of adhesive bonded-only samples were tested. Again, no effect (positive or negative) of dry lubricant was found, although there was an effect of adherend (or joint element) thicknesses. Thin-to-thick samples showed an upward shift of the S-N curve compared to thick-to-thick samples, and thin-thin samples showed an upward shift even to the thin-to-thick S-N curve. No particular explanation can be given for this behavior except that fatigue is a surface-related phenomenon, and the relative surface area (to volume ratio) is greater for thin-to-thick than thick-to-thick, and greatest of all for thin-to-thin joint combinations.

Results of fatigue testing of weld-only specimens showed lower life at a stress level, or, alternatively, a lower tolerable stress for any particular required life — Fig. 12. This result is expected, given that applied shear stress tends to concentrate discrete (spot) welds, thereby lowering resistance to fatigue near such welds.

The last samples to be tested were the weld-bonded samples in which laser spot welds were made at points where there was an intentional gap in the preapplied adhesive. Gaps were necessary since the laser beam interacted violently with the polymeric adhesive, causing severe outgassing of volatiles, and due to inherent thermal decomposition of the polymer itself, with attendant expulsion of molten aluminum from newly formed molten spots, large voids and carbonaceous residue from pyrolysis were left. Both thin-to-thick and thin-to-thin joint combinations were tested, with no real effect from the dry lubricant. The possible synergistic effect of weld bonding on fatigue life is more difficult to determine.

The difficulty of trying to determine whether there is any synergistic benefit of combining (laser) spot welding and adhesive bonding is trying to account for the individual effect of each joining process alone and then seeing if the weld-bonding combination results in more than an additive effect. If only one particular joining process is being considered, it is obvious that doubling the number of spot welds (or, actually, total spot weld area) would greatly increase the fatigue life by halving the stress in each weld. Likewise, if the area of adhesive bonding is doubled, the stress in the adhesive is halved, and the fatigue life is increased considerably. However, when spot welds and adhesive are combined, it is more difficult to determine what the stress is in each, as they are different since the inherent stiffness (as measured by modulus of elasticity) is so different for the metal spot welds and polymeric adhesive.

In an attempt to compare actual results to see if there is greater than an additive effect (of spots plus adhesive), a “theoretical” S-N curve for the weld-bonded data was calculated and then compared to the experimentally determined S-N curve. Only results for no-lubricant thin-to-thick samples were analyzed because lubricant had an adverse effect on spot welding and because the thin-to-thick point combination is the most popular in automobile structure assembly.

Fatigue S-N curves were plotted for adhesive bonded only and spot welded only
joints, as can be seen in Fig. 13. A trend regression line was computed for each of these test conditions data sets and the equations for these lines were used to calculate theoretical load components for the weld-bonded samples. The components (for adhesive only and weld only) were added together and then plotted as load vs. number of cycles of life to give a P-N curve. The experimental and theoretical P-N curves, along with the component curves, are shown in Fig. 14. It can be seen that the experimental P-N curve starts out above the theoretical curve, suggesting some synergistic effect, but then appears to simply overlie (overlap) the theoretical curve area 6,000,000 cycles of life. This seems to indicate weld-bonded specimens (joints) equal or exceed the theoretically predicted, purely additive effects of adhesive bonding and spot welding alone.

Conclusions and Future Directions

Laser beam weld bonding offers improvements in in-plane static tensile shear strength, out-of-plane peel strength (and, especially, energy absorption), and fatigue performance (i.e., at any life, life to 10^6 cycles) that appear to be the result of a synergistic effect between the two processes in combination. Problems encountered when the laser beam interacts with the polymeric adhesive that degrade the quality of the spot weld in the aluminum alloy need to be overcome to realize full potential of the hybrid process of weld bonding. Further testing is required in each peel and fatigue to conclusively demonstrate any synergistic benefit of combined spot welding and adhesive bonding.

Future work will address several ways of practicing laser beam spot welding in a way in which the beam will (1) have to interact with the temperature-sensitive, volatile polymeric adhesive and (2) assure that the adhesive back-fills around newly made spot welds to maximize stress concentration "softening" effects.

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References


IIW Annual Assembly Convenes in Romania

The 56th Annual Assembly of the International Institute of Welding (IIW) will be hosted by ISIM, the Romanian National Research and Development Institute for Welding and Materials Testing, at the Bucharest Marriott Grand Hotel, Bucharest, Romania, July 6-11, 2003.

The IIW is the global body in the science and application of joining technology providing networking and knowledge exchange. Its technical field encompasses the joining, cutting, and surface treatment of metallic and nonmetallic materials by such processes as welding, brazing, soldering, thermal cutting, thermal spraying, adhesive bonding, and microjoining and embraces allied fields including quality assurance, nondestructive testing, standardization, inspection, health and safety, education, training, qualification, design, and fabrication.

The United States will be represented by members of The American Council of the IIW, which is the United States' national committee for the IIW. As a comprehensive forum for professional cooperation through interaction with representatives of the other 41 member countries, the IIW provides a unique opportunity for sharing technological innovations and can be an important avenue for international trade.

For further information on the IIW and membership on The American Council, please contact Andrew Davis, International Standards Program Manager, at adavis@aws.org, (305) 443-9353, ext. 466; or Gricelda Manalich, IIW Coordinator, at gricelda@aws.org, (305) 443-9353, ext. 294. Further information, including registration forms, can also be obtained from the IIW Secretariat in Paris, France, at www.iiw-iis.org.
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