WELDING Journal

July 2003

AWS Welding Show Review

Pipe Clamps Handle Tough Jobs

Positioners: Make the Right Choice

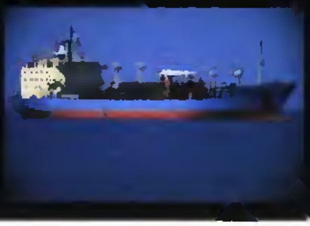
One-Sided Welding of Heavy Plate

PUBLISHED BY THE AMERICAN WELDING SOCIETY TO ADVANCE THE SCIENCE, TECHNOLOGY AND APPLICATION OF WELDING

Demanding Welding Applications. .

Demand Select-Arc Low Alloy Electrodes



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- Manganese - Molybdenum
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...in the cost of shielding gas.

Excellent arc characteristics with 100% CO_2, or 75% Ar + 25% CO_2

...in the cost of fabrication.

The self peeling slag and smooth weld finish minimize time of post weld clean-up.

...in the cost of rework.

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To ensure weld metal chemistry, all wires are made utilizing austenitic stainless steel sheaths and agglomerated flux infills. The wire reels are vacuum shrink-packed to preserve product freshness during shipping and storage.

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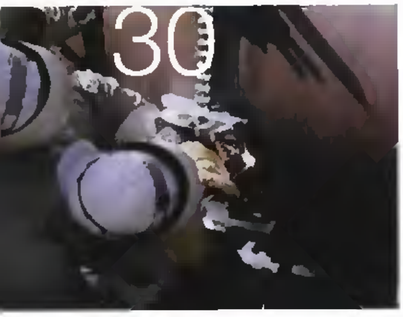

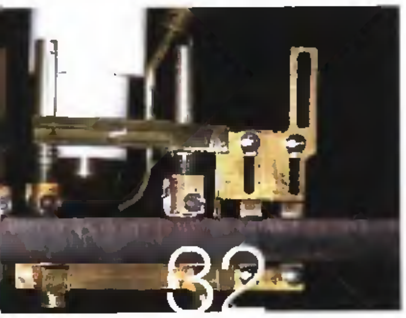

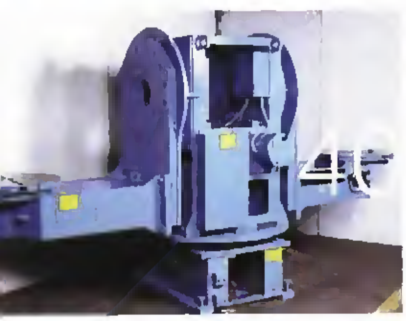

Features

Welding Research Supplement

AWS Web site *http://www.aws.org*

Departments

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PRESS TIME NEWS

Northrop Grumman Fiber Amplifier Achieves Record Laser Light Output Levels

Northrop Grumman Space Technology has developed a fiber amplifier that recently has produced an unprecedented output of 155 W from a slender optical glass thread. The energy emerges as infrared light with a single polarization. The fiber amplifier was developed under a contract with the Department of Defense's Joint Technology Office. Interest in fiber amplifiers is strong because of their high efficiency, which exceeds that of slab lasers. The optical efficiency reduces the amount of waste heat that has to be rejected in addition to providing power and weight savings.

"This demonstration is a big step forward in the scaling of fiber lasers to high power," said Jackie Gish, technology product area manager for Northrop Grumman Space Technology. "Our approach is scalable, and if you were to coherently combine a number of such fibers, as we're starting to do, you begin to reach significant laser power levels."

The company's fiber amplifier possesses two key technical properties. Its single-spatial-mode fiber ensures minimum diffraction of the light beam, delivering maximum power on target. In addition, the amplifier maintains a single polarization, which enables coherent combination of output from multiple fiber amplifiers, to deliver the highest energy on target.

"Our measured results are substantially higher than any previously reported power levels for single-mode, polarization-maintaining fiber amplifiers," Gish said.

Study Forecasts Improved Outlook for Construction Worldwide

A positive long-term picture is forecast for the global construction industry, according to a recently released study from Global Insight, Inc., Waltham, Mass. "Global Construction Study 2003" measures and forecasts out to 2025 construction industry spending in 55 of the world's largest construction markets. The study's three objectives were to size the market, forecast market growth, and determine construction-specific risk.

The study forecasts moderate global growth at 5% in construction investment through 2012, with India and China growing at considerably higher rates of 9.2% and 7.9%, respectively. Long-term, the United States is expected to grow to the global average of 4.8%; Western Europe will be slightly behind at 3.9%. In 2003, global construction activity is expected to expand by 2.8%, with growth accelerating into 2004.

"The exciting news we found in doing this study is the tremendous growth opportunity in Asia today, which we expect to continue over the next decade. India and China, in particular, offer major business opportunities and an increase in revenue growth for construction companies," said Chris Holling, director of Global Insight's Business Economics and Custom Solutions Group. "By 2005, the United States and Western Europe will also be on the upswing, so the long-term forecast looks encouraging for the industry as a whole."

Inexpensive labor and manufacturing costs, coupled with plentiful land for building factories, plants, and the supporting infrastructure, are the drivers for China's current construction boom. In India, government infrastructure initiatives for building roads, railroads, bridges, and power lines are helping to create an expected growth rate of 10.6% over the next five years.

More information on the study is available on the company's Web site at *www.globalinsight.com/construction2003*.

Kinder Morgan Energy Partners and Praxair Enter into Long-Term Natural Gas Supply Agreement

Kinder Morgan Energy Partners, L.P., Houston, Tex., recently entered into a 15-year agreement to supply Praxair, Inc., with up to 90,000 MMBtu of natural gas per day through its intrastate pipeline system.

Under the agreement, Kinder Morgan will supply natural gas to Praxair's new hydrogen facilities in Texas City and Port Arthur, Tex. The new hydrogen facilities are scheduled to be in production in 2004.

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What Does It Mean to You?

Do you belong to AWS for career enhancement, for discounts on technical standards and other publications, for the subscription to the *Welding Journal,* or, perhaps, for the opportunity to network with your peers at Section meetings? What does membership in the American Welding Society mean to you?

As with most organizations, AWS member benefits can be collected into two categories. The first are the passive member benefits. Things like receiving the *Welding Journal* or getting a discount on a book are easily accomplished with little personal involvement. The other category requires active involvement in the organization. These benefits include meeting peers at AWS events, exchanging information at technical committee meetings, or working toward attaining one of the AWS certifications.

While I have enjoyed and gotten value from many of the long list of AWS benefits, I have determined the absolutely most beneficial category for me is active participation. Active participation returns value manyfold over the time and energy invested.

During my 30 plus years of membership, the most valuable benefit I have received is the enduring friendships I've made through my participation in AWS events. I could not have met the many men and women who comprise the backbone of not only AWS but also the welding industry without my active participation in the organization.

I have been fortunate to have been able to participate in my local Sections, various volunteer committees, and several District and National positions during my career. The one constant at all of those levels, the attribute I have appreciated most, is the quality and dedication of the people I have met.

Through my active participation, I have gained many friends (a word with a strong connotation to me) from the AWS volunteer and staff communities. Only by my participating has this been possible.

As a personal example of this membership benefit, I would like to share with you my activities of last weekend. Many years ago, 1985 to be exact, my wife Leslie and I met this wild and crazy guy living on a sailboat in San Francisco Bay. Little did we know, by our attending a social event at the AWS Show, we would meet and develop a long-term friendship with future AWS President John Bartley and his wife, Patty. Now retired and living in Texas, they dropped by our home on the way to a three-week camping trip. After catching up on recent events, more family than business or even AWS, and devouring fresh strawberries, boiled shrimp, and a few bottles of sparkling wine, we saw them off on their long journey. Long-term friendships come from active AWS participation.

I could continue with a list of people encountered and now considered friends, but with the limited editorial space, let me just encourage you to become a very active member. Our Society needs volunteers in many areas, and I am sure each of you can find your niche in the organization simply by offering your time and skills.

So, please, reap the full rewards of membership. Get active and collect the benefits. I did.

Lee G. Kvidahl
AWS Past President (1993–1994)
and Chair, Membership Committee

EWI to Lead Development of Internal Pipeline Repair Technology

The Edison Welding Institute (EWI) is leading a program to evaluate, develop, and validate internal repair methods for natural gas pipelines in order to permit the repair and continued operation of pipelines that otherwise might have to be retired from service. The program is through the U.S. Department of Energy's National Energy Technology Laboratory.

Standard methods call for excavation of the damaged area to permit access to the pipeline. Repairs are made by either cutting out the damaged section and adding a replacement, adding a full encirclement sleeve or clock spring, or welding directly onto the pipeline. These methods work well in situations where the pipe can be readily excavated, but are not applicable in situations such as river or estuary crossings, where pipelines run through swampland or similar terrain, subsea pipelines, or environmentally sensitive and heavily populated urban areas. In those cases, an alternative is to repair the pipeline from the inside.

A single "cut out and replace" pipeline repair can cost as much as $1 million depending on environmental and operating conditions, but new internal repair technology could reduce repair costs by as much as 50%.

EWI will perform a laboratory demonstration of internal pipeline repair and develop a functional specification for a combined prototype system to perform internal inspection and repair. The demonstration is expected to take place fall 2004.

The other members of the team are Pacific Gas & Electric Co., which will assist with technical work, and Pipeline Research Council International, Inc., which will cofund the project and provide additional industrial oversight.

Labor Department Awards Grant for Metalworking Apprenticeship Programs

The U.S. Department of Labor recently awarded a $1.9 million grant to the National Institute for Metalworking Skills (NIMS) to update existing metalworking apprenticeship programs. The new model will use industry proficiency standards NIMS has established to provide a consistent credentialing system for metalworking companies.

"This administration wants to help young people starting out, as well as displaced workers looking for new opportunities to get into good jobs with promising futures," said Secretary of Labor Elaine L. Chao. "Today's grant will help targeted workers to quickly develop the needed skills and competencies to move up the career ladder of their choice."

With the grant monies, NIMS will develop curriculum guides for four metalworking occupational areas: metal forming, machining, tool and die making, and machine building. Students enrolled in the program will receive national credentials that are consistent across the industry and can be used by metalworking companies in making recruitment, hiring, training, and promotional decisions. Under these competency-based programs, motivated workers will be able to move at a quicker pace.

The Precision Metalforming Association is a founding partner of NIMS. Other industry partners include the Association for Manufacturing Technology, the National Tooling and Machining Association, the American Machine Tool Distributors Association, the Tooling and Manufacturing Association, and the Precision Machine Products Association.

Northrop Grumman Receives Two Environmental Awards

Northrop Grumman Corp.'s Newport News sector recently received a Platinum and a Gold Pretreatment Excellence Award from the Hampton Roads (Va.) Sanitation District.

The Platinum Award signifies five consecutive years (1998–2002) of perfect compliance, and the Gold Award signifies a perfect compliance record for the year 2002. The company achieved perfect compliance by sampling and analyzing all industrial wastewater at the facility and meeting the discharge limits mandated by the sanitation district. It also met all the district's technical and administration requirements.

Industrial Gases Market to Reach $52 Billion by 2008

The current global market for industrial gases is estimated at $36 billion. According to *RC-237 World Industrial Gas Business*, a report from Business Communications Co., Inc., the market is expected to reach nearly $52 billion by 2008, climbing at an average annual growth rate of 7.5% through the forecast period.

The growth will be the result of the worldwide manufacturing sector using huge quantities of industrial gases for the production of environmentally cleaner products such as food and fuels and to upgrade increasing supplies of heavy crude oil. Applications for glass production, steel, and nonferrous and new materials processing also will help drive demand.

Metal manufacturing and fabrication will remain the largest volume market for industrial gases. Increasing gas demand in this market are expectations of favorable forecasts for crude and stainless steel. Gas demand will also expand as steel producers in developing countries strive to upgrade production technologies and improve efficiencies. By 2008, that market will reach $7.2 billion, growing an average 5.1% annually through the forecast period, according to the report.

The cost of the report is $3950. For additional information, contact Business Communications Co., Inc., 25 Van Zant St., Norwalk, CT 06855; telephone (203) 853-4266, ext. 309; e-mail *publisher@bccresearch.com*.

Lincoln Electric Unit to Supply Welding System for Russian Pipe Mill

Lincoln Electric Holdings, Inc., was recently awarded a $6 million contract to supply advanced automated welding equipment to the Chelyabinsk Tube Rolling Plant in Chelyabinsk, Russia. The company is one of Russia's largest pipe manufacturers.

Lincoln's wholly owned German subsidiary, Uhrhan & Schwill,

will provide overall project management. The system's components will be manufactured both in Europe and at the company's Cleveland, Ohio, operations.

Vessel Head Repairs Scheduled for Cook Unit 2 Refueling Outage

American Electric Power, Bridgman, Mich., recently repaired several minor defects on the Cook Nuclear Plant Unit 2 reactor vessel head. Repair of the five small, shallow indications did not affect the refueling outage duration.

The indications, originally identified during inspections in 2002, showed no signs of increasing; however, new industry rules dictate they be repaired before the unit was returned to service.

A full visual inspection is planned for the Unit 1 reactor head during a refueling outage in the fall. The company continues to evaluate reactor vessel head replacement for both units but has not reached a final decision.

Both Cook units were taken off-line on April 24 when a massive intrusion of fish temporarily disrupted cooling water flow to the plant. A fish deterrent system was installed in the Lake Michigan water intake system and Unit 1 returned to service at the end of May.

Two Iron- and Steel-Related Organizations Plan to Consolidate

The Iron & Steel Society (ISS) and the Association of Iron & Steel Engineers (AISE), both based in Pittsburgh, Pa., recently announced their intention to consolidate into a single, as-yet-unnamed entity. The two organizations plan to merge as of January 1, 2004. Both boards of directors have approved the consolidations; the matter goes out for a ballot to members of both organizations for final approval.

"This consolidation presents a great opportunity to add significant value for our members," said Ian Sadler, president of ISS. "With one combined organization focused on member needs, we will be able to meet those needs in a more comprehensive and cost-effective manner. The added value comes in taking the best from both organizations to deliver a more powerful set of services to a wider membership base. We have a very clear mandate from the members of both organizations. They want this to happen."

ISS dates back to 1871 and AISE to 1907. After the merger, the new entity will have more than 12,000 members and 45 technical committees.

Greer Steel Invests $2.5 Million in Michigan Facility

Greer Steel, a producer of cold-rolled strip steel, recently invested more than $2.5 million in new equipment for its Ferndale, Mich., service center.

Robert Ulbrich, the facility's general manager, outlined the improvements: "Our dual header slitter has been upgraded to include new payoff and takeup reels. We have also added a tension stand, a four-arm input stager, unloading turnstile, and completed the construction of a 35-ft looping pit. Our Bliss 2, high-temper mill is being upgraded to include a new sealed bearing pack, Vollmer gauger and printer, new payoff infeed, and drive motor. We have also added a new ten-ton-capacity, high-speed overhead crane, new coil upenders, and 6000 sq ft of new space to our facility."

The company's products include low-carbon strip, annealed spring steel, high-strength low-alloy strip, and oscillate-wound flat wire.

Design Consortium Presents Award to Lincoln Electric

Design Consortium recently recognized The Lincoln Electric Co., Cleveland, Ohio, for its advanced applications of the PVM℠ process.

The Product Value Matrix℠ is a proprietary process for understanding the value of products, services, and markets. Lincoln Electric adopted the process in 1997 and has used it to help define and specify products, services, and new business opportunities.

Industry Notes

■ GOWELD®, a battery-powered portable arc welding machine that features an onboard computer, recently won two international design awards. Broco, Inc., Rancho Cucamonga, Calif., manufactures the machine. GOWELD won in the industrial equipment category of the Chicago Athenaeum: Museum of Architecture and Design's GOOD DESIGN™ Awards for 2002. It also picked up Germany's Industrie Forum (iF) Design Award 2002. Founded in 1950, the GOOD DESIGN Awards recognize designers and manufacturers for advancing new and innovative product concepts and originality and for stretching the envelope beyond what is considered standard design. The iF award is an international design competition that recognizes products with exemplary design quality.

■ The Lincoln Electric Co. recently added more than 400 American Welding Society (AWS) Certificates of Conformance to its Web site at *www.lincolnelectric.com*. The Certificates of Conformance provide documentation that Lincoln has conducted and passed all the tests required by the applicable AWS Filler Metal Specification. These documents indicate the level of mechanical or chemical properties typical for the product tested, and are typically used for quality assurance reporting, specifying electrodes, and to provide engineering data.

■ Pratt & Whitney, East Hartford, Conn., recently received a $481 million supplement to its U.S. Air Force contract to produce F119-PW-100 engines for the F/A-22 Raptor fighter aircraft. The supplement represents the third production contract for F119 engines and covers 40 engines to be delivered in 2004, along with associated spares and support services to be delivered this year.

■ The Greenbrier Companies, Lake Oswego, Oreg., recently announced it received orders for 1500 railcars valued at $90 million during its second quarter ended February 28. The orders push the company's backlog to 5800 railcars valued at $330 million, up from 5700 cars valued at $310 million on November 30, 2002. The orders included 1300 riserless deck center partition cars, including 600 cars from Canadian Pacific Railway and 350 cars from Canadian National Railway.

■ ASTM International recently established a new Student Membership category for undergraduate and graduate-level students. The membership is free of charge to eligible students. Benefits include e-mail delivery of *Standardization News*, the organization's monthly magazine, and other publications; free admission to ASTM symposia; a reduced fee for the first year of membership after graduation; access to a new student member Web page; and exclusive eligibility to participate in the ASTM Student Paper Contest. For further information, contact Lisa Wellington at *student@astm.org*.

■ North American manufacturing companies ordered 3500 robots valued at $219.5 million, and another 132 robots valued at $11.4 million were ordered from North American robot suppliers by companies located outside North America during the first quarter of this year. This represents first quarter gains of 48% in robot units, the industry's best start since 1999, according to Robotic Industries Association, the industry's trade group.

■ Kobe Steel Ltd., Tokyo, and Infra, S.A. de C.V., a unit of Mexico's Infra Group, are collaborating to expand the marketing of Kobelco products in Central and South America. The Infra Group is one of Mexico's leading welding equipment manufacturers. As part of the agreement, Kobelco Welding of America, Inc., Kobe's U.S. subsidiary, will provide Infra customers with product support and technical services and Infra will sell Kobe's flux cored welding wire. Kobe will also assist in increasing the quality of Infra's solid welding wire.

■ The Lincoln Electric Co., Cleveland, Ohio, recently signed a partnership agreement with Genesis Systems Group, Davenport, Iowa, to represent the company's Platformation brand of products. The Platformation line includes Genesis's array of robotic positioners and platforms. These will be incorporated into arc welding robotic cells to complement Lincoln Electric power sources and FANUC robotic arms.

Do You Have Some News to Tell Us?

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

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

Items can also be sent via FAX to (305) 443-7404 or by e-mail to *mjohnsen@aws.org*.

NEW SEMINAR DAYS AND TIMES

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.

SEMINAR AND EXAM SCHEDULE FOR SEPTEMBER 2003 THROUGH NOVEMBER 2003

SEPTEMBER 2003	SEMINAR DATES	EXAM DATES
Anchorage, AK	9/7-12	9/13/2003
New Orleans, LA	9/7-12	9/13/2003
Minneapolis, MN	9/14-19	9/20/2003
San Diego, CA	9/14-19	9/20/2003
Dallas, TX	9/21-26	9/27/2003
Detroit, MI	9/21-26	9/27/2003
Milwaukee, WI	9/28-10/3	10/4/2003

OCTOBER 2003	SEMINAR DATES	EXAM DATES
Denver, CO	10/5-10	10/11/2003
Phoenix, AZ	10/12-17	10/18/2003
Pittsburgh, PA	10/19-24	10/25/2003
Tulsa, OK	10/19-24	10/25/2003
Chicago, IL	10/26-31	11/1/2003
Atlanta, GA	10/26-31	11/1/2003

NOVEMBER 2003	SEMINAR DATES	EXAM DATES
Long Beach, CA	11/2-7	11/8/2003
Beaumont, TX	11/2-7	11/8/2003
Portland, OR	11/9-14	11/15/2003
Louisville, KY	11/9-14	11/15/2003
Rapid City, SD	11/16-21	11/22/2003
San Juan, PR	11/16-21	11/22/2003
Columbus, OH	11/17-22 at NBPVI	11/22/2003
Miami, FL	11/30-12/5	12/6/2003

Seminar and Exam Schedule

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

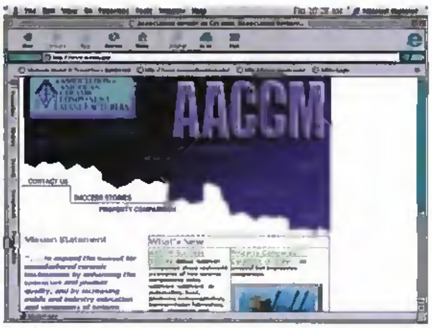
To register or for more information on an exam prep course, call (800) 443-9353. ext. 229; to request an application for CWI exam qualification, call ext 273.

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 for additional dates.

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

Web Site Details Ceramic Component Design



Association of American Ceramic Component Manufacturers (AACCM). The mission of this Westerville, Ohio, based organization is "to expand the market for manufactured ceramic components by enhancing the process and product quality, and by increasing public and industry education and awareness of ceramic applications." To help fulfill that mission, AACCM recently updated its Web site to offer more information regarding material design challenges and solutions for a variety of industries. The site now includes "success stories" from seven of its member companies that address specific design challenges and their solution through the proper choice of ceramic material, component design, and fabrication technique.

The site includes a list of members. Hyperlinks bring visitors who click on a company's name to its Web site; clicking on the e-mail address allows visitors to send the company a message or requests can be sent to all the members by clicking on the "e-mail all members" button at the bottom of the page. The "Member Capabilities" section provides information in two tables about each AACCM member's manufacturing capabilities, as well as applications and industries served. The "Industry Matrix" shows the industries and applications the companies serve. The "Capabilities Matrix" shows the ceramic materials, forming methods, and machining/finishing services available from each member. The site also includes membership information, a "Why Ceramics" section that addresses some of the properties, benefits, and uses of ceramic materials, and a "Property Comparison" that compares the properties of steel to those of seven different ceramic materials.

www.aaccm.org

A Resource for Saw Blade Users

The M. K. Morse Co. The Canton, Ohio, based company, which is celebrating its fortieth anniversary this year, manufactures industrial band saw blades and a wide range of hand and power tool accessories including metal-cutting circular saw blades, hole saws, reciprocating saw blades, jigsaw blades, portable band saw blades, and hacksaw blades. It also produces a line of abrasives and mounted points. The company's Web site offers

detailed information on all of these products. Technical information is included for all the product lines. These include explanations of how saw blades work, a blade selection chart, sheet metal gauge thickness and Schedule 40 and 80 pipe wall thickness charts, problem solving information, and troubleshooting info to help you prevent problems.

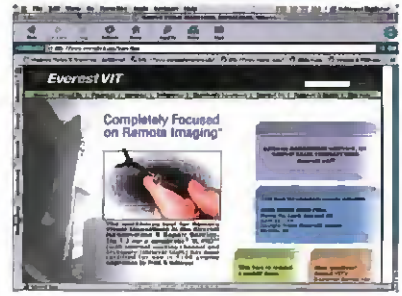
Plenty of details about the company, including a history of the firm, location of manufacturing plants, and information about product guarantees, are also available. While the site promises a virtual tour of the company's manufacturing plant, that area was still under construction when the *Welding Journal* visited it.

www.mkmorse.com

Site Highlights Remote Visual Inspection Equipment

Everest VIT, Inc. Video borescopes, rigid borescopes, fiberscopes, robotic crawlers, pan-tilt-zoom cameras, light sources, and other remote visual inspection products are featured in the company's Web site. The "Industries" section details how these products are used in the manufacturing, aviation, power, and natural gas industries, among others, and includes sample application shots from those industries taken with the company's products.

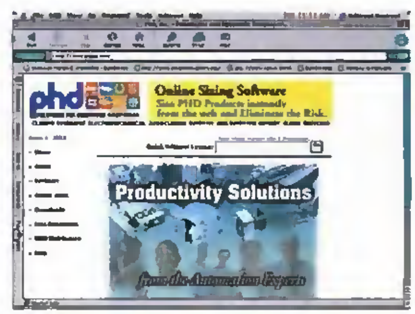
Visitors can also learn the company's



history, find out about career opportunities, obtain answers to frequently asked questions (which pop up in more than one section of the site), look up the company's locations and distributors anywhere in the world, and request a product demonstration.

www.everestvit.com

Clamping Products Featured



PHD, Inc. The company, based in Ft. Wayne, Ind., has named its Web site the "Instant Clamp Expert™." Clamping solutions for welding environments are among the products featured.

Using the site, visitors can view complete clamp animations, working principles, and competitive comparisons; access clamp catalogs; configure accurate part numbers using graphic prompts; request CAD models; obtain pricing; and place orders online. Offerings in the "Free Resources" section include the Designer's Resource® CD-ROM, a collection of tools to aid engineers and designers in selecting the proper products for their applications; product catalogs; newsletters; product videos; and application examples in Macromedia® Flash and video.

The "On-Line Tools" and "Downloads" sections offer the company's CAD Configurator software, unit conversion software, online product sizing, and screen savers, among other offerings.

www.phdinc.com

American Welding Society

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. Cable
Chairman, Counselor Selection Committee

(please type or print in black ink)

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. ____________

SUBMISSION DEADLINE FEBRUARY 1, 2004

American Welding Society

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, VICA, 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 partici pation of its employees in industry activities such as AWS, IIW, WRC, VICA, 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 he 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

Reader Reacts to NASCAR Article

The following letter was sent by a reader who takes issue with Jerry Uttrachi's article on welding for NASCAR that appeared in the April 2003 issue of the Welding Journal. *Uttrachi's response follows.*

Dear Editor:

As a thirty-year member of the American Welding Society, I would like to thank you for the referenced article ("NASCAR Race Team Demands Quality Welds") in the American Welder section of the *Journal*. Being the more hands-on type of welding engineer (LeTourneau College, BSWE '74) that I am, I have enjoyed these types of articles more often. I usually glean some tidbit of information that is more directly applicable to my current position than the research supplements.

While many of the points brought out in this article are valid and informative, I feel care must be taken when painting with such a broad brush. For instance, I happen to have worked as a welding engineer at a well-known East Coast shipyard in the first days of my career, and my last perusal of MIL-STD-278 said that the gas metal arc welding (GMAW) process was not permitted in the short circuit arc mode, an exception that seems slightly overlooked by Mr. Uttrachi when he states: "The GMAW process is used extensively in industry to make very high-quality, critical welds in items such as submarine hulls."

We have to remember to whom we are writing when making such blanket statements. First of all, the majority of guys who build race cars are not going to read the *Journal* or a *Welding Handbook*. Second, I have maintained for years that sanctioning bodies should require more testing of the people who fabricate these vehicles to assure quality weld deposits. It is too easy to create incomplete fusion with the typical GMAW short circuit arc power supply that most shops have (i.e., a bottom-end body shop-type machine that can only handle 0.023-in.-, perhaps 0.035-in.-diameter wire max) as the operator progresses around a small-diameter (less than 2-in.) tube at odd angles, and sometimes with shallow angles of intersection, with quite a few stops and starts. You would not believe some of the techniques I have seen utilized with this process in the field. Mr. Uttrachi does state in his summary, "resulting welds should be checked and verified to be sure they meet the requirements." Again, my point is I don't believe NASCAR has any requirements, and certainly not for any of the fabricators, whether they are on a team or working for one of the many chassis manufacturers who provide bare frames to customers. We, the so-called experts, need to be telling these people they must do testing before the driver straps in — not after the fact as they, the sanctioning body, try to determine the cause of a failure after a major accident. It is neglect on the part of everyone involved to expect anyone who claims to be a fabricator to pick up a torch and "have at it" in a life-and-death situation such as this. We have lost too many drivers in crashes over the years to allow this to continue.

I also read with interest the sidebar article discussing the welding of 4130 chrome moly. There certainly seems to be a lot of difference of opinion about the proper technique for welding this material. For the past six years, I have been working for a major well-respected chassis manufacturer in Indianapolis where we have put our product to the test at the Indy 500, the 24 Hours of Daytona, and LeMans, as well as the pounding punishment of the 12 Hours of Sebring, to name a few. In addition, we have modified a few Winston Cup-type cars to improve their handling characteristics. All of our suspension components are 4130, ranging in thickness from 0.035 to 0.5 in. All threaded bushing inserts are machined from solid 4130. We do not use any preheat and utilize the GTAW process exclusively with ER80S-D2 filler metal. Components that need to remain in fixturing to maintain dimensional stability are "stress relieved" with an oxyfuel torch at 950°F, checked by a temperature-indicating crayon. Components of a more highly stressed nature that require machining after welding are vacuum stress-relieved at 1100°F by a local vendor. Most components are Magnafluxed® for any possibility of cracking. Most welding of 4130 is accomplished with the aid of a pulsed-type current either with the remote foot control or power supply timers. It is significant to note that the Hobart Brothers Company determined this type of technique can produce welds higher in strength than welds made with straight nonpulsed current.

I believe the National Hot Rod Association has more stringent specific requirements for the fabrication of frames made of 4130 tubing.

Additionally, shop practice can tend to be a bit abusive with this material, including autogenous welds, and placement of weld beads without regard to interpass temperature control. The AWS-recommended practice for this material does not cover thickness less than ¾ in., therefore I would solicit further research in this area, particularly in regard to the amount of preheat required.

It may sound like I am talking out of both sides of my mouth when I tell you my employer does not require any testing of our personnel to determine operator ability or qualification. We usually do a cursory test when a person interviews or tries out for the position as fabricator, but, on the other hand, we are utilizing the GTAW process and it is more difficult to have incomplete fusion with this process.

I trust that you and Mr. Uttrachi, as well as anyone else who may read these comments, will take them as constructive, and if I can provide any further feedback, please do not hesitate to contact me at your earliest convenience. Keep up the good work.

Keith Wyckoff
Indianapolis, Ind.

Dear Mr. Wyckoff:

You raise some interesting points. You are obviously well versed with not only the material but also race car preparation practice. I agree it's difficult when you make generalities, which one must for a short article, but I believe the recommendations made by Bob Bitzky and myself are conservative. I'll provide the reasons:

First, the use of short circuit vs. pulse GMAW was discussed with Bob Bitzky in a "bench welding" session after the training. Bob is an expert in pulsed GMAW, having worked in the Airco R&D laboratory when the process was developed. Bob is also an excellent welder. He felt pulsed GMAW would not be as good a choice as short circuit GMAW for this application for operator weld control reasons. The material thicknesses and joint positions involved make short circuit GMAW ideal for the intersecting tube joints. You'll note he did mention keeping the arc at the leading edge of the weld pool, employing short tip-to-work distances, and the need to be a "skilled welder." It's hard to overemphasize the need to be a "skilled welder." The Navy does specify the use of pulse GMAW on heavy sections when welding out of position; however, for the thicknesses and joints involved in this application, short circuit GMAW is the proper choice.

Second, welding 4130. Your work on welding 4130 for race cars certainly is impressive, and it appears you are taking all the precautions. The use of ER80S-D2 filler material was mentioned in the article. The way you are applying it sounds fine. You mention that some welders are making autogenous GTA welds in 4130, which should not be done. The resulting high car-

bon deposit is very crack sensitive. In fact, the amount of filler material added to the joint is also an important factor, especially when using ER80S-D2 filler material. When GTA welding, sufficient filler material must be added to dilate the high carbon going into the weld deposit from the base material. The use of ER70S-2 is also being widely recommended. I believe this is a more conservative approach for the general race car fabricator. As mentioned in the article, when needed to offset the undermatch in weld strength, a slightly larger fillet weld or the use of gussets can be employed. It is of interest to note that NASCAR requires the use of gussets on intersecting tube joints, even on carbon steel materials. See the following Internet sites, from a consultant to the race car welding field and the Art Morrison dragster frame company, who recommend and use this class welding material on their NHRA approved frames:

http://www.archive.metalformingmagazine.com/2001/01/Lincoln.pdf

http://www.artmorrison.com/F_DragsterChassis.htm

I appreciated your comments, input, and experience. As mentioned above, there are a number of reasons a skilled welder needs to be employed to make these critical welds.

Jerry Uttrachi
Florence, S.C.

BY DAMIAN J. KOTECKI

Q: We have qualified welding procedures for 409 stainless steel without difficulty. Now, in an attempt to make the same exhaust system parts with higher corrosion resistance, we have tried to qualify welding procedures for 430 stainless. We couldn't locate a source of ER430 wire, so we tried ER308LSi. Using the 409, welded with 409 filler metal, we could pass a transverse face bend test and a transverse root bend test. But the 430 samples break beside the weld. I don't think this can be due to using ER308LSi filler metal. I thought 430 stainless is a ferritic stainless, just like 409, and is not supposed to be hardenable, but these samples all seem hard beside the weld. Does the use of nonmatching filler metal have anything to do with this? What is the problem here?

A: To begin, I agree with you that using ER308LSi is not the cause of your problem. Type 430 stainless steel is commonly described as a ferritic stainless steel, but that is a bit of an oversimplification. We can think of ferritic stainless steels as having been developed in three generations. Working backward, the most modern ferritic stainless steels, like 444, were developed after steelmakers became efficient at decarburizing iron-chromium melts so they contain 0.025% C or less. These third-generation ferritic stainless steels are ferritic at all temperatures, so they are completely

Table 1 — Representatives of Three Generations of Nominally Ferritic Stainless Steels

Generation	UNS No.	Type	%C	%Mn	%P	%S	%Si	%Cr	%Ni	%Mo	Other %
1	S43000	430	0.12. max.	1.00 max.	0.040 max.	0.030 max.	1.00 max.	16.0 to 18.0	0.75 max.	–	–
2	S40900	409	0.030 max.	1.00 max.	0.040 max.	0.020 max.	1.00 max.	10.5 to 11.7	0.50 max.	–	N 0.030 max.[a]
3	S44400	444	0.025 max.	1.00 max.	0.040 max.	0.030 max.	1.00 max.	17.5 to 19.5	1.00 max.	1.75 to 2.50	N 0.035 max.[b]

(a) There are three subdivisions of 409 with slightly different requirements. UNS S40910 contains Ti = 6x(C+N) min., 0.50% max.; Nb = 0.17% max. UNS S40920 contains Ti = 8x(C+N) min., 0.15 to 0.50%; Nb = 0.10% max. UNS S40930 contains (Ti + Nb) = [0.08% + 8x(C+N) min., 0.75% max.; Ti = 0.05% min.]. All are included under the UNS S40900 umbrella.

(b) (Ti+Nb) = [0.20% + 4x(C+N)] min., 0.80% max.

Table 2 — Type 439 Ferritic Stainless Steel

Generation	UNS No.	Type	%C	%Mn	%P	%S	%Si	%Cr	%Ni	%Mo	Other %
2	S43035	439	0.030 max.	1.00 max.	0.040 max.	0.030 max.	1.00 max.	17.0 to 19.0	0.50 max.	–	N 0.030 max.[c]

(c) (Ti+Nb) = [0.20% + 4x(C+N)] min., 1.10% max.; Al = 0.15% max.

nonhardenable (excluding long time aging to precipitate intermetallic compounds). The predecessor to these very low carbon ferritic stainless steels is the second generation, those stainless steels with a little more carbon but with alloy elements (Ti, Al, Nb) added to tie up the carbon at high temperatures and/or promote ferrite. Your Type 409 is an example of this second generation of ferritic stainless steels. Through the 1997 version of ASTM A240, 409 was permitted to contain up to 0.08% C, which sometimes allowed traces of austenite to form under certain circumstances. The 1998 version of ASTM A240 reduced the allowable carbon in 409 to 0.030%, which largely eliminated traces of austenite at high temperatures. The still older first generation of ferritic stainless steels includes those with appreciable carbon but no extra alloy elements to tie up the carbon or promote ferrite. This first generation of ferritic stainless steels includes your Type 430 (up to 0.12% C). As originally developed, they tended to contain considerable free carbon, and they still largely do today. Table 1 lists compositions of these three ferritic stainless steels, as given in ASTM A240, 2003 version.

In the annealed condition, as Type 430 would normally be supplied, with a normal carbon content of about 0.07%, the microstructure consists of scattered chromium carbides in a matrix of ferrite. ASTM A240 requires it to be soft (89 Rockwell B hardness maximum) and ductile (20% or 22% elongation in 2 in., minimum, depending upon thickness). However, any subsequent exposure to temperatures above about 1650°F (900°C), as occurs in the heat-affected zone of a weld, will cause at least part of these carbides to dissolve and austenite to form in place of the carbides and in place of some of the ferrite. This austenite will be high in carbon. On cooling after welding, this austenite will mainly transform to martensite, with quite detrimental effects on the cross-weld ductility. This, I expect, is the root cause of your problem.

This austenite formation should not be viewed as all bad. The austenite effectively prevents grain growth of the ferrite, a problem that plagues the third generation of ferritic stainless steels. While the third generation of ferritic stainless steels has outstanding corrosion resistance, the loss of ductility and, especially, of toughness in the heat-affected zone (HAZ) is a major limitation to their more widespread application.

There are two ways your problem can be solved. One way would be to perform a postweld heat treatment to return the HAZ to its annealed condition. This can be accomplished at about 1450°F (790°C), in as little as 5 min at temperature, followed by air cooling. At this temperature, the scattered chromium carbides precipitate again, and the martensite, with carbon removed, becomes ferrite.

If postweld heat treatment is not acceptable, and you cannot live with the reduced cross-weld ductility, then I think you have to change base metals. You indicated that you wanted an improvement in corrosion resistance over that of 409, which steered you to the 17% Cr of 430. I suggest you consider switching to Type 439 stainless steel. This is a low carbon, 18% Cr ferritic stainless steel stabilized with titanium, much as your 409 is stabilized — Table 2. You can continue using ER308LSi filler metal, or you can obtain tubular metal-cored welding wires that match the composition of the 439 stainless. Type 439 has a proven track record in automotive exhaust system components, so there should be no concern about making this change. ◆

DAMIAN J. KOTECKI is Technical Director for Stainless and High-Alloy Product Development for The Lincoln Electric Co., Cleveland, Ohio. He is a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals; AWS D1 Structural Welding Committee, Subcommittee on Stainless Steel Welding; and a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel Base Alloys. Questions may be sent to Mr. Kotecki c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126 or via e-mail at Damian_Kotecki@lincolnelectric.com.

Simulation Software for Robot Programming Developed

WeldPRO is a simulation tool for robotic arc welding and cutting processes. The technology simplifies 3-D programming of work cell functioos by importing CAD models of tooling and workpieces.

FANUC Robotics 100
3900 W. Hamlin Rd., Rochester Hills, MI 48309

Laser Beam Cutting System Introduced

The Mark II HS 4000-W CO_2 laser beam cutting system automatically adjusts to sheet metal thicknesses from very thin to 0.75-in. plate and also processes preformed sheet metal and pipe.

Mazak Nissho Iwai 101
140 E. State Pkwy., Schaumburg, IL 60173

Replacement Plasma Torch Fits Most Systems

The SL100™ 1Torch™ RPT plasma torch fits most plasma cutting systems and a variety of start systems. Tip tuning eliminates the need for a gas distributor or swirl ring.

Thermal Dynamics Corporation 102
16052 Swingley Ridge Rd., Ste. 300
St. Louis, MO 63017

Digital Inverter Power Sources Include Network Features

The Power Wave® 455M robotic power sources feature capabilities for high-speed waveform control for a variety of welding processes and materials. Networking capabilities allow the power sources to communicate with other industrial machines to create an integrated welding cell.

The Lincoln Electric Company 103
22801 St. Clair Ave., Cleveland, OH 44117

Portable Fume Collector Uses 3 Filter Stages

The self-contained Zephyr II® fume and dust collector uses three independ-

ent stages of filtration to remove welding and soldering fumes, grinding dust, and other airborne particles. The unit has a capacity of 700 ft^3/min.

Farr Air Pollution Control 104
3505 S. Airport Rd., Jonesboro, AR 72401

Automatic System Fills Natural Gas Cylinders

The Refueler 180 allows users to fill their own cylinders with 275 lb/in^2 natural

gas. The unit fills four 520-ft^3 cylinders in about three hours, then automatically shuts itself off.

G-TEC Natural Gas Systems 105
401 William L. Gaiter Pkwy., Ste. 4, Buffalo, NY 14215

Kevlar Gloves and Sleeves Protect against Jagged Edges and Sparks

ArmorKnit™ gloves and sleeves are fabricated of DuPont Kevlar® Armor and standard Kevlar to offer enhanced protection without bulk. Gloves are available in

sizes 7 to 10 and with PVC dots in sizes 7 and 9. Plated blouse sleeves are available in 12- and 18-in. lengths.

Ansell Occupational Healthcare 106
P.O. Box 6000, Coshocton, OH 43812

Crimped Wire Wheels Offer Brushing Performance

The company's large diameter crimped

wire wheels have a high fill density for light- to medium-duty cleaning, surface preparation, rust removal, and finishing.

Anderson Products 107
1040 Southbridge St., Worcester, MA 01610

Small Motorized Positioner Has 300-lb Capacity

The Mini Pro table top welding positioner features motorized variable speed rotation with a forward/reverse switch and

dynamic braking. Its tilt range is from 0 to 90 deg with pinned 15-deg increments.

Pandjiris 108
5151 Northrup Ave., St. Louis, MO 63110

System Tests Hardness on Rockwell Scales

The LCR-500 self-compensating load cell hardness testing system features automatic display of all Rockwell scales (reg-

ular and superficial). Test parameters can be configured to duplicate or modify NIST test cycle times.

LECO Corporation 109
3000 Lakeview Ave., St. Joseph, MI 49085

Overhead Robot Configuration Saves Floor Space

MotoSweep beam-mounted robot so-

lutions feature movable or fixed servo gallows that can provide repeatable or manual movement of a robot to service multiple workstations from overhead. An XRC 2001 controller operates the robot in six axes, plus the movable beam as a seventh axis. For example, the system can be deployed with existing layouts to transfer parts to a series of workstations.

Motoman Inc. 110
805 Liberty Lane, West Carrollton, OH 45449

Saw with Track Cuts up to 60-in. Pipe Square

The APS-438 air powered saw is available with a WrapTrack® band track assembly that clamps around a pipe circumference to assure a square cut. The track is available in 28 sizes for pipe from 6-in. to

60-in. in diameter. The 3-horsepower saw can cut pipe wall thicknesses up to 4⅜ in.

ESCO Tool 111
P.O. Box 530, Medfield, MA 02052

Process Replaces Submerged Arc Welding

The company's surfacing process can provide full chemistry with a single 6-mm

layer of ThermaSlag wire, replacing the need for submerged arc welding and over-alloyed wire.

Stoody Company 112
16052 Swingley Ridge Rd., Ste. 300
St. Louis, MO 63017

Respirator Masks Provide a Comfortable Fit

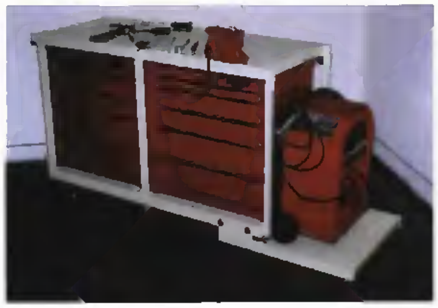
The X-plore series of masks and filter respirators features lightweight materials and a design for a comfortable face seal. The products are available in three sizes

and in three configurations: two half-mask respirators and one full-mask respirator. Cartridges and filters feature a two-point bayonet connector.

Draeger Safety, Inc. 113
101 Technology Dr., Pittsburgh, PA 15275

Rolling Workbenches Provide Mobile Repair Platforms

RollaBenches incorporate tool storage and a 27-in x 54-in. steel tabletop work space for maintenance projects. Wheeled



models are available in a wide range of configurations

Torqer, Inc. 114
1145 Galewood Ave., Cleveland, OH 44110

An Important Event on Its Way?

Send information on upcoming events to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. Items can also be sent via FAX to (305) 443-7404 or by e-mail to *campbell@aws.org*.

PIPE ALIGNING AND REFORMING CLAMPS EXPLAINED

The pipe clamping systems available today are safe, accurate, and designed for just about every application

Chain clamp is used to align and hold in position 48-in. pipe for welding.

Thousands of dollars in labor are lost annually by companies continuing to use old-fashioned methods to align pipes and fittings, such as weld-on lugs, hydraulic bottle jacks, or ratchet cable pullers, to critically align pipe ends. Companies today cannot afford the loss in productivity or to have their product rejected if it fails to meet alignment criteria.

Personnel are sometimes asked to hold a heavy pipe or fitting in place while the welder tack welds the pipe to the fitting. This process presents a risk of back injury to the person holding the pipe or fitting. Also, the valve or fitting is sometimes incorrectly aligned and the tack welds must be removed and rewelded.

The welding distributor must have sources for companies to purchase the proper

Story based on information provided by Mathey Dearman (www.mathey.com), Tulsa, Okla.

clamping equipment to align pipes and fittings faster without sacrificing the safety of the welder.

Clamps to Fit the Application

Five different types of alignment clamps are on the market to cover every aspect of pipe and fitting alignment and reforming needs of companies. Whether the workplace is a small tube or large vessel, a clamp is available to fit the customer's requirements. Clamps are available to internally or externally align pipe or shell diameters from ⅜ in. to 20 ft (9.5 mm to 6 m). Clamps are available to reform pipes or tubes with a wall thickness up to Schedule 80 with an out-of-round condition up to 2 in.

Clamping systems are available for all the purposes listed below.

1) To align and reform the mating side of the weld joint.

2) To align and reform both sides of the weld joint.

3) To align and reform pipes, tubes, elbows, tees, flanges, and other fittings.

4) For rounding pipes.

5) To hold tubes in position for orbital welding.

6) Pneumatic or hydraulic internal alignment clamps to align the interior of pipe or fittings.

7) For full-circle welding of the pipe without removal of the clamp.

8) To hold pipe ends against a consumable welding insert.

9) To hold pipes in place on jack stands.

10) For carbon steel, stainless steel, and other specialty alloys.

Types of Clamping Systems Available

Chain-type clamps align and reform pipe diameters as small as 1 in. (25 mm) and as large as 20 ft (6 m). Chain clamps allow pipe, elbow, tee, flange, and other fittings to be held safely and securely in place during the alignment and welding process. Each style of chain clamp is designed to reform multiple pipe sizes. Most manufacturers of this style clamp have enough clearance under the jackbar to permit the use of a gas metal arc welding gun or gas tungsten arc welding torch. The inside or outside of the pipe can be aligned with these clamps. Accessories such as level and support devices assist the welder in holding and accurately positioning pipe or fittings for welding. Other accessories such as spacing screws will allow the operator to accurately adjust the weld root opening without risk of injury.

Cage clamps are available for pipe sizes 2 to 60 in. (51 to 1524 mm). These cable or rigid frame clamps are designed for rapidly aligning the outside diameter and come in two basic styles. The "tack type" cage clamp is used to align pipes for tack welding. The "no-tack" type allows the joint to be completely welded without removal of the clamp. These clamps are designed to align only one pipe size per clamp. The clamps are available in hand lever, ratchet, and hydraulic models.

Full-circle steel-type clamps are available for pipe sizes 6 to 72 in. (152 to 1829 mm) and have multiple contact points to handle aligning, reforming, or rounding applications. These clamps are designed to put pressure on the high point of the pipe or shell and bring them into alignment. The welder is able to do a 100% weld and grind without removal of this type of clamp.

Frame-type clamping devices that make three-point contact with the pipe are available for pipe sizes 1 to 14.5 in. (25 to 368 mm). These clamps adjust from one pipe size to another by means of a T-handle located at the top of the clamp. A range of three or four pipe sizes can be covered with one clamp. The clamps can be used to align the inside or outside of carbon steel or stainless steel pipes. These clamps are used for aligning the pipes and not for reforming the pipe wall.

Some small precision clamps, with a pipe range from ⅜ to 12 in. (9.5 to 305 mm), have jaws that work independently of each other. They align and securely hold two sections of small diameter steel or stainless steel pipe or tubing for autogenous welding. The radial clearance and distance between the jaws is such that most orbital welding heads will fit between them. Pipes or tubes align with the clamps. The clamps are available in both carbon steel and stainless steel to complete welds on small diameter steel and stainless steel pipes and tubes.

Internal hydraulic and pneumatic alignment clamps are used mainly for pipeline applications and are available for pipe sizes 6 to 60 in. (152 to 1524 mm). These clamps cover a range of one to six pipe sizes, depending upon the make and model. These clamps allow a full circle to be completed without obstruction. An automated welding system used in conjunction with the clamp increases productivity, lowers weld rejects, and reduces operator fatigue.

When proper clamping devices are employed, the operator is able to safely and precisely align and reform the pipe or fittings.

Safety Considerations

Pipe clamping devices help speed the aligning process, lowering operator fatigue. These clamping devices eliminate hydraulic jacks, come-a-longs, and weld-on lugs, which can be an extreme safety hazard to all personnel involved in the aligning and reforming process. When proper clamping devices are employed, the operator is able to safely and precisely align and reform the pipe or fittings. Needless cutting and regrinding are not required because the two pipes or fittings are mated correctly the first time.

Prior to operating the equipment, it should be checked for proper operation and any required maintenance. If an air, hydraulic, or electrical power source powers the tool, it should be disconnected from the equipment prior to inspection or maintenance. The tool should never be used if it is not in proper working order.

The maintenance area should be kept as clean as possible to prevent foreign debris, such as sand, grinding dust, or metal shavings, from being introduced into the final assembly as subcomponents are installed. High-temperature grease, such as gun grease, that is not water-soluble should always used to lubricate the compenents of the tool. Lithium grease is not recommended.

Clamps used to align and/or reform pipes and fittings are some of the most misunderstood and misused pieces of equipment. Due to the weights and tensile strengths of pipes, it is extremely important that operators receive adequate training on the reforming and aligning of pipes to fittings, valves, and flanges. Personnel who use makeshift devices or the incorrect clamp for an application cause many accidents.

Know Your Needs

The following points should be considered when selecting a clamp:

- Diameter of the pipe
- Pipe wall thickness
- Tensile strength
- Type of material
- Need for alignment and reforming
- Operator fatigue.

The customer service departments of clamping device manufacturers are always available to assist the welding distributor in selecting the right clamp to fit the customer's application. ◆

Trackless Welding of Large Steel Structures

A method is proposed for one-sided arc welding without a track or beveling

By S. B. Zhang, D. Sun, and P. Xu

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By utilizing large, expensive equipment with a track and undertaking multipass welding and beveling of steel plate, conventional arc welding processes for large steel structures suffer from low productivity and high costs (Refs. 1–4). On smaller structures, the normal practice is to make welds in butt joints from both sides of the plate to achieve complete joint penetration. In large steel structures, however, the ideal approach is to complete welds in butt joints from one side since it is difficult, for example, to turn a ship over for welding the second side. This has led to the development of complete joint penetration welding from one side.

It is widely known that complete joint penetration welding from one side can typically be achieved in two ways. First, methods have been proposed to sense joint penetration, with infrared sensing, ultrasound, or pool oscillation for the gas tungsten arc welding process (Refs. 5–8), or by measuring the keyhole to control weld penetration for the plasma arc welding process (Refs. 9, 10). However, sense and control of weld penetration

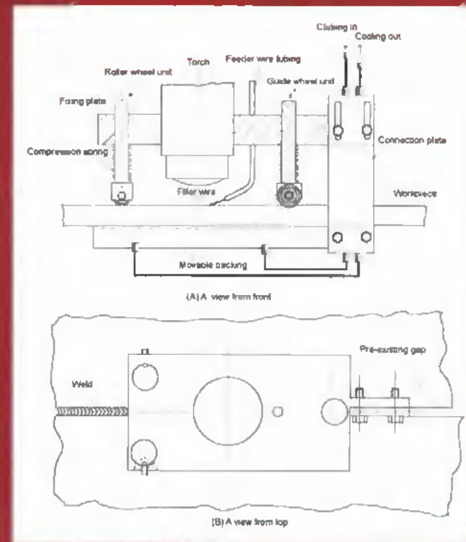

Fig. 1 — TMFP welding apparatus.

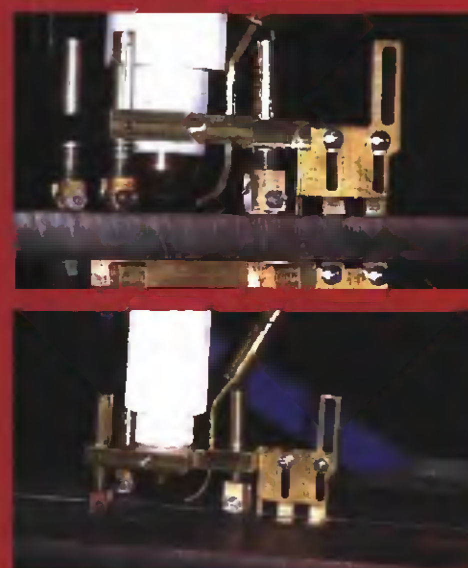

Fig. 2 — Photographs of the TMFP welding apparatus: A — view from bottom; B — view from top.

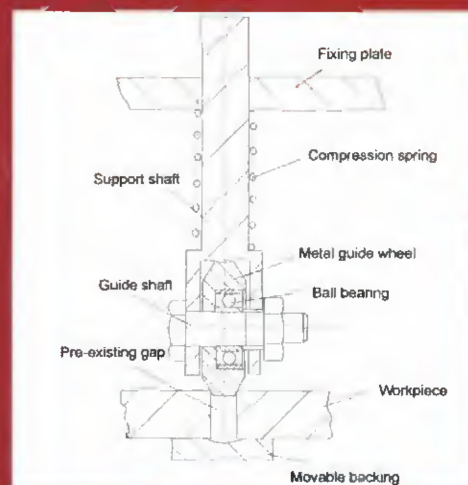

Fig. 3 — A guide wheel unit.

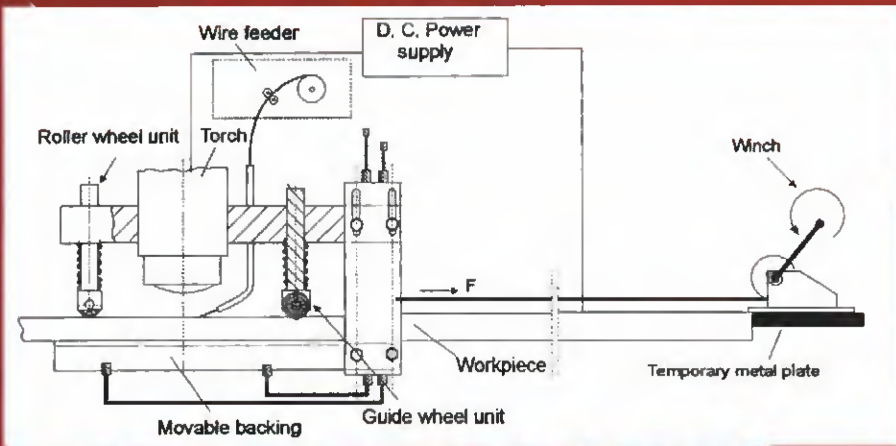

Fig. 4 — TMFP flux cored wire plasma arc welding with a winch driver.

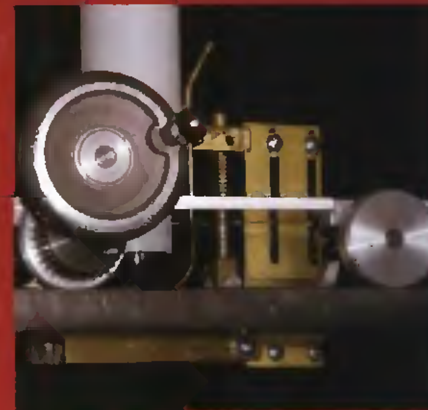

Fig. 5 — A photograph of the TMFP mechanized carriage.

Table 1 — Welding Parameters

Material: HSLA-DH-36
Thickness: ⅜ in.

Test No.	1	2
Position	Flat	Flat
Joint Preparation	Square Butt	Square Butt
Preexisting Root Opening	4.5 mm (0.18 in.)	3 mm (0.12 in.)
Wire Feed Speed	254 cm/min (100 in./min)	254 cm/min (100 in./min)
Wire Size	0.9 mm (0.035 in.)	0.9 mm (0.035 in.)
Current	300 A	340 A
Travel Speed	20 cm/min (7.8 in./min)	24 cm/min (9.4 in./min)
Shielding Gas	18.4 L/min (40 ft³/h)	18.4 L/min (40 ft³/h)
Plasma Gas	2.3 L/min (5 ft³/h)	2.3 L/min (5 ft³/h)
Orifice	3.8 mm (0.15 in.)	3.8 mm (0.15 in.)

depend significantly on welding conditions. When a joint opening is not constant throughout an entire weld interface, sense and control of weld penetration will be very difficult for an automated arc welding process.

The second approach is to use a weld backing, made from copper or ceramic, with a length equal to the length of the weld interface and a configuration fit to the shape of the interface, which is held against the underside of the weld zone where a groove is formed. The cost of the material, processing, and application for these conventional weld backings increases with the length of the weld interface. In addition, the installation and removal of such backings in many applications are difficult. In fact, either one-sided or two-sided welding of a complete joint penetration weld of a butt joint using conventional arc welding processes requires a multipass weld. Conventional arc welding equipment normally employs a track for making a long weld, so joint tracking plays a critical role in many automatic welding processes (Ref. 12). The expense and complexity of conventional arc welding processes have forced engineers to explore new technologies in welding large steel structures (Refs. 2, 13).

The proposed project was to develop an innovation, "Trackless Movement and Full Penetration" (TMFP) arc welding, in which complete joint penetration and joint tracking are integrated. The basic TMFP prototype was designed according to the requirements of arc welding production. Based on this apparatus, the flux cored wire plasma arc welding process was studied and developed for high-strength steel (DH-36). The preliminary experimental results verified that the proposed TMFP apparatus and process were able to perform trackless movement and complete joint penetration welding. This technology can be used to perform one-sided, one-pass welding, substantially simplifying the automated arc welding system, for fabricating butt joints of thick metal plates of large structures.

The TMFP Apparatus

The prototype apparatus was designed for a butt joint based on a preexisting root opening (3–5 mm) in a weld interface. Figure 1 illustrates the TMFP apparatus. The prototype is shown in Fig. 2. In the apparatus, the movable weld backing is held against the underside of the weld to support liquid metal and to control the backside bead. The movable weld backing and a fixing plate of the weld head are arranged underside and front side of the weld interface, respectively, using a connecting member through the preexisting root opening of the interface. Thus, the weld backing moves synchronously with the weld head along the entire weld interface to continuously perform complete joint penetration welding. Three compression springs are installed in one guided wheel unit and two roller units to hold the movable backing against the underside of the workpiece in flat position welding. The movable backing is water cooled and made of copper. CO_2 is used as a back purge gas to protect the backside weld region from atmospheric contamination (by oxygen and nitrogen) for the welding of alloy steel materials.

In order to perform trackless movement, the preexisting root opening acts as a "guide slot," in which a guide wheel unit can track the joint — Fig. 3. In practical application, the guide wheel unit is placed ahead of the weld head, and a metal guide wheel with inclined planes makes contact within the root opening to guide the apparatus along the weld interface, automatically providing joint tracking without an external track or joint tracking device. As shown in Fig. 4, an electric or manual winch can be placed at the end of the plates to be welded, to drag the welding apparatus by a chain along the weld interface, irrespective of the length, configuration, or other factors of the butt joint. This system is not limited by an external track, and provides an accurate, reliable, and flexible joint tracking technique for the arc welding of long butt joints.

Another design model, shown in Fig. 5, has a trackless mechanized carriage for the movable backing. A servomotor or a handle can be used to drive a gear mechanism

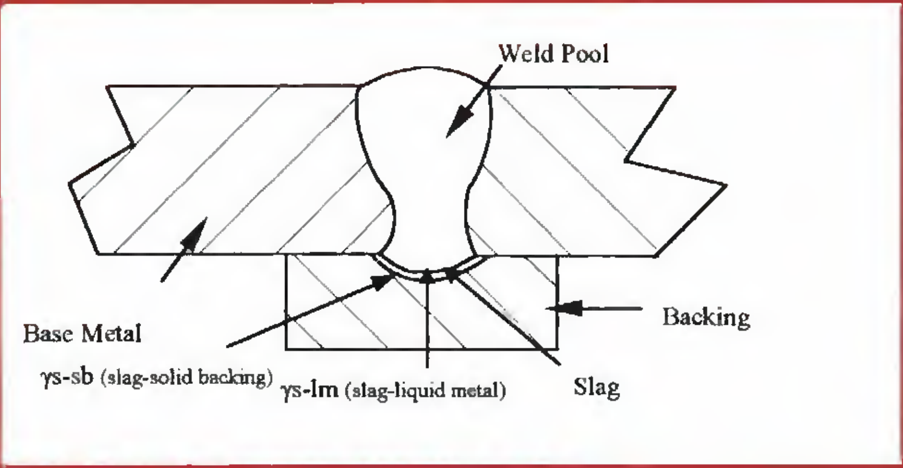

Fig. 6 — The working model of slag in TMFP arc welding.

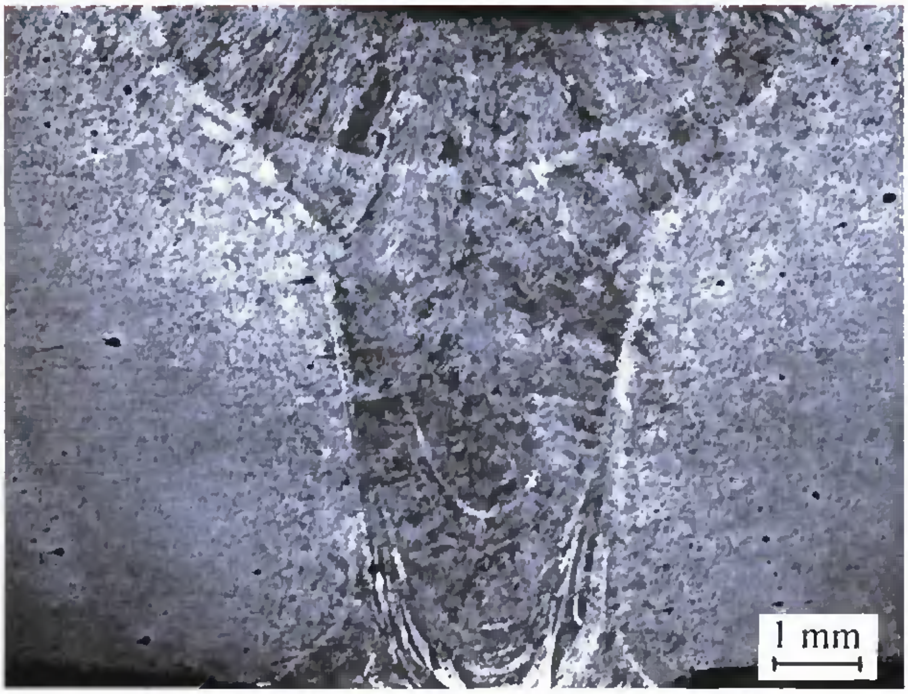

Fig. 7 — Cross section micrograph of a weld in a butt joint using TMFP flux cored wire plasma arc welding, 3-mm (0.12-in.) preexisting joint opening.

to move the carriage with the backing and weld head along the weld interface.

TMFP Plasma Arc Welding Process

The TMFP technology can utilize a plasma arc to melt the weld joint zone and weld metal to fill the preexisting root opening and form the weld reinforcement using a movable backing. A plasma arc is preferred over a non-constricted arc because of its higher concentrated heat and higher temperature (Ref. 14). Thus, a plasma arc can deeply penetrate metal materials and weld thick plates in some applications.

In addition, with the plasma arc process, flux cored wire can be added to the leading edge of the weld pool using a mechanized wire feeder. Based on its physical and chemical characteristics, flux cored wire can provide the following effects as a filler metal:

■ A layer of liquid slag between the moveable backing and the liquid metal of the backside weld pool will act as a lubricant to increase the sliding ability of the movable backing. A working model of the liquid slag film in this process (Fig. 6) shows the effects of the film in contact with the liquid metal and the solid backing. The interfacial surface tensions of the slag-liquid metal and the slag-solid backing can be altered by changing or adjusting the components in the flux cored wire (Ref. 15) so that the liquid slag of the flux cored wire can act as a lubricant in this process.

■ The layer of liquid slag acts as a very efficient heat insulator and thus reduces the rapid dissipation of the heat of the arc (Ref. 15) to protect the backing from the high temperature of the plasma arc.

■ The liquid slag film can provide a layer of shielding from atmospheric contamination (oxygen and nitrogen) for the weld pool.

■ The layer can substantially improve the composition and microstructure of the weld and mechanical properties of the weld joint due to an increase of alloy element transfer efficiency and deoxidation.

Therefore, the process of flux cored plasma arc welding is proposed for complete joint penetration welds in large steel structures in a single pass, without the preparation of bevels.

Preliminary trials of TMFP welds in square butt joints with a preexisting root opening, with flux cored wire (E71T-1) as a filler material, were conducted on ⅜-in.-thick plates of high-strength low-alloy steel (HSLA-DH-36). The dimensions of the specimens were 304 × 76 × 9.5 mm (12 × 3 × ⅜ in.). The welding parameters and conditions are shown in Table 1. Figure 7 shows the cross section micrograph of a butt joint using the trial process.

The preliminary results showed that the apparatus implemented trackless movement and complete joint penetration of HSLA materials. They also proved that flux cored plasma arc welding was able to make a crack-free and porosity-free weld, as shown in Fig. 7. Compared with conventional arc welding methods, such as submerged arc welding (SAW), the process significantly increases weld penetration under low heat input to the weldment. The maximum allowable heat input for welding HSLA steel materials is limited to less than 60,000 J/in. (Refs. 2, 14). Due to the inherent nature of one-sided SAW, heat input limitations of HSLA steels are often exceeded (Refs. 2, 14). These experiments demonstated that this process can perform complete joint penetration welding of a ⅜-in.-thickness butt joint from one side with

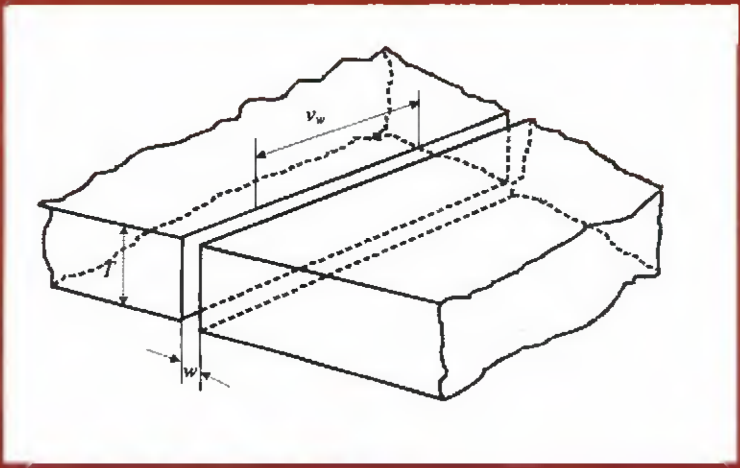

Fig. 8 — A drawing of a butt joint.

heat input of less that 50,000 J/in., compared to 78,000 J/in. for SAW (Ref. 16).

In addition, reinforcement of the underside of the weld was obtained using the removable backing, as seen in Fig. 7. In order to obtain reinforcement of both sides of the weld, a minimum weld metal deposition rate will depend on the thickness of the metal plates to be welded and the preexisting root opening, as shown in Fig. 8. The minimum weld metal deposition rate R_{min} (in kg/h) can be calculated from the following expression:

$$R_{min} = T \times W \times v_w \times g \times 1000$$

where T is the thickness (m) of the base metal plates to be welded, W is the pre-existing root opening (m), v_w is the welding speed (m/h), and g is the specific gravity of steel (7.8 tons/m³). In practical applications, the weld metal deposition rate should be higher than R_{min} to fully fill the root opening to make reinforcements to both sides of the weld. Hence, for a complete joint penetration single-pass weld with reinforcements in both sides, the welding parameters, such as plasma arc current, wire feed speed, travel speed, and filler metal diameter need to be calculated prior to welding. The preliminary experimental results demonstrated that one of the advantages of the process is that the weld metal deposition rate can be adjusted for welding parameters and root opening so that both-side reinforcements can be controlled. Another advantage is high alloy transfer efficiency from the flux cored wire to control the composition of the deposited metal.

Commercial Potential and Future Work

Compared with conventional arc welding processes for welding large steel structures, the new TMFP flux cored plasma arc welding process will bring the following advantages:

- Complete joint penetration welding of butt joints with consistent quality.
- Implementation of automatic joint tracking for long welds without the limitations of a track.
- Significant simplification of automatic arc welding equipment with a corresponding reduction in production costs.

This process has great commercial potential in the heavy steel fabrication industries such as shipbuilding and manufacturing of high-pressure vessels, pipe, and heavy cranes.

Continuing developmental research is being performed to improve the successful application of the TMFP arc welding processes. Extensive investigation of TMFP arc welding technology is ongoing to develop other arc welding processes.

The submerged arc welding process has found the widest application in heavy weldments because of its high welding current and high deposition rate. In the submerged arc welding process, the flux, which is delivered to the area just ahead of the welding electrode, may be melted under the arc and create a layer of liquid slag between the movable backing and backside weld pool. Therefore, submerged arc welding, along with flux cored self-shielding or shielding gas arc welding processes, based on the TMFP arc welding mechanized apparatus will be studied for complete joint penetration welding of large steel structures. ◆

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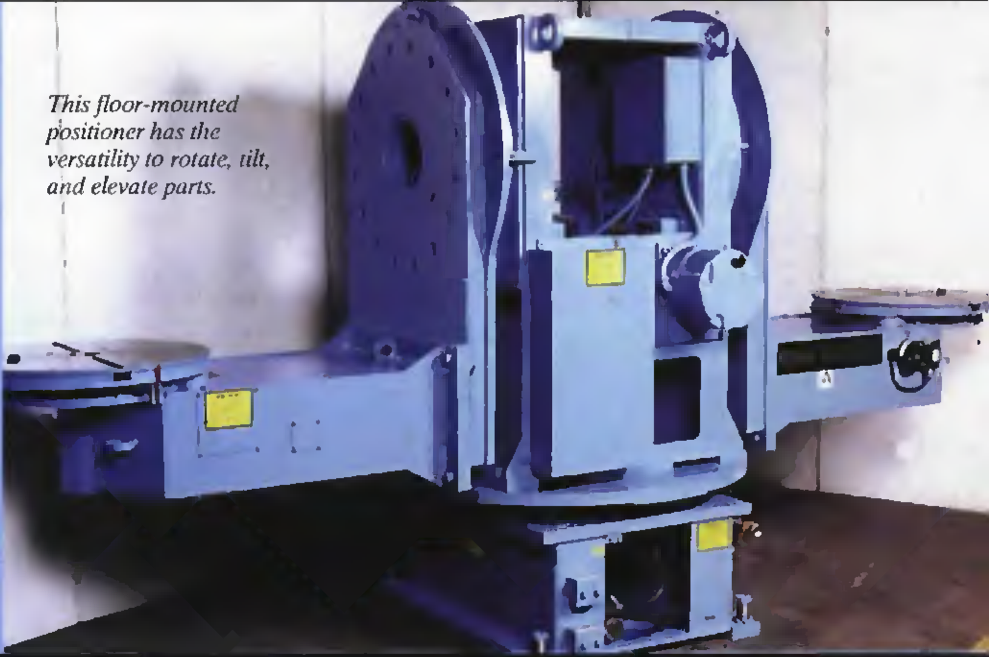
There is a positioner for just about every fabricating and material handling job, but before selecting one that's right for you, know the basics



This floor-mounted positioner has the versatility to rotate, tilt, and elevate parts.

BY DONALD R. BURGART

Fundamentals for Choosing a Positioner

A positioner is a machine that will support and maneuver a part and place that part into the best working position.

The basic positioner was developed to allow a part to be fixtured onto a table, then tilted and rotated, allowing that part to be moved for flat position welding, which is cheaper and safer than welding out of position. By moving the part, the operator is situated in the best working position, thus reducing fatigue and poor quality welding. Welding in a flat position can also increase production.

Today, there are many types of positioners, each one designed to assist in a material-handling role.

Positioners range from a simple "lazy Susan" type turntable to several-axis units for robotic applications. Positioners are designed to handle loads up to several hundred thousand pounds. To select the correct positioner, you need to know what you will be doing with the positioner, what

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is the maximum load of your work part, where is the center of gravity of your part, and what is the maximum dimensional size of the part.

The Selection

Turntable

A turatable is a single-axis unit with its table fixed in the horizontal position. The table will support a workpiece and allow the part to rotate clockwise or counter-clockwise either manually or by power. A turntable allows the operator to stay in one spot during operations such as flame cutting, assembling, inspection, or welding. Capacity range is unlimited for a turntable.

For sizing a turntable, first consideration is maximum weight of the part and then the center of gravity of that part. All turntables are sized with a weight and a certain distance the center of gravity can be from the rotation axis. Besides weight consideration, table size and table height must also be discussed.

On large loads or at high speeds, inertia is also taken into consideration while sizing. Acceleration and deceleration times can be adjusted for inertia problems.

Headstock and Tailstock

Headstock and tailstock units are also single-axis units with the table in the vertical position. The headstock is a powered unit that will rotate about the table centerline. The tailstock is usually identical to the headstock except there are no provisions for power. The table is freewheeling. The headstock and tailstock are usually used together for supporting and rotating long weldments. Typical applications would be trailers, truck beds, trusses, railcars, and elliptical vessels.

A headstock can also be used alone for applications where you need to have access to the end and sides of the workpiece.

For sizing a headstock and tailstock, begin with the maximum weight and center of gravity of the part from both the face of the table (overhung load) and (eccentric load) the centerline of the rotation axis. If the headstock is used alone, the overhung load, or the distance off the face of the table, must have its center of gravity within the rating of the unit. This dimension is a fixed distance based on load rating specified by the equipment manufacturer. When used together as a set, the overhung load does not matter because the load is being supported by both units. The location of the load in relationship to the centerline of the rotation axis (eccentric load) must also be held within the center of gravity rating of the machine.

With the headstock and tailstock, the rotation axis height must also be considered when specifying a machine. The center height must be enough so the workpiece can rotate without hitting the floor. To compensate for this problem, most headstocks and tailstocks can be provided with either adjustable bases, sub-bases, or powered elevation to raise the center line while rotating. The power elevation feature also allows one to lower the work part back to the floor after rotation to allow better access for the welders or for assembly.

Often a set of head and tailstocks is used for parts that vary in length. When this application occurs, the headstock is usually bolted to the floor, and the tailstock is mounted on some type of track-guided carriage. Carriages can be provided with either power motion or manual control.

Positioner

The most common type of positioner is the tilt and turn. This positioner is normally a two-axis machine that allows a workpiece to be loaded onto the table like a turntable and then tilted to a headstock position or greater.

A positioner can be configured with many different features and options. The most common is the floor-mounted model with 135-deg tilt and 360-deg continuous rotation. A standard 135-deg floor-mounted positioner will usually rotate, tilt, and elevate. The rotate-and-tilt functions are normally powered, while the elevation is a set-up procedure. These models are usually rated with a weight capacity of 1000 lb or more. The floor model 135-deg unit has a tilt axis that will go from a flat position and then tilt forward 135 deg until the table is facing 45 deg from the floor.

As with the turntable and head and tailstocks, when sizing a positioner, the first consideration is weight, then it is eccentric loading with an overhung load of the center of gravity.

As an example, a 2500-lb positioner would have a maximum load capacity of 2500 lb with the load being off center by the rated eccentric dimension. The load's center of gravity off the face of the table must also be within the overhung load rating. Consideration must also be taken to make sure the tilted part has swing clearance when rotated to prevent rotating or tilting the part into the floor.

What's Available

Positioners are available in a wide array of sizes, ranging from a 100-lb bench positioner to the 1,000,000-lb positioner.

Positioners are available in several configurations, beginning with the small bench model with a typical weight capacity of less than 500 lb. Most units are provided with powered rotation but the tilt is provided with pins or a hand crank.

On the floor-mounted units, the rotation and tilt axes are powered. The elevation can be fixed at one height, adjustable by pinning in place or with powered elevation. On larger machines with the height of the table fixed, the unit can be provided as a 45/90 unit. This allows the table to tilt from a flat position 45 deg backwards and 90 deg forward.

There are several other types of positioners and positioning equipment. Universal balance positioners, specialty positioners, drop center positioners, skyhooks or two-axis positioners, and combination positioners are some of the different types. There are also specially designed positioners to work with robots that provide a high degree of accuracy and repeatability.

Positioners today are not used just for moving a piece of steel around. Today's positioners work in all fields of material handling.

Positioners are available in a wide array of sizes, ranging from a 100-lb bench positioner to the 1,000,000-lb positioner.

Selecting for the Application

All positioners will require the same basic information to size the correct one for your application. Below are some questions you should ask yourself to help get the right positioner for the job.

- What are you doing with the unit?
- Do you need a turntable, headstock and tailstock, or positioner?
- What is the maximum weight of the part?
- Where is the center of gravity of that part (both overhung and eccentric loading)?
- What is the maximum physical size of the part (swing radius)?

With this information, you will be able to look at a positioner sizing chart and determine what positioner will be required for your job. ◆

DESIGNING POSITIONERS FOR ROBOTICS

Understanding a few principles of positioner design will help your robot and positioner become an integrated whole

BY ZANE MICHAEL AND GEORGE SUTTON

ZANE MICHAEL is Director, Standard Engineering and Development, and GEORGE SUTTON is Associate Chief Engineer, Motoman Inc., West Carrollton, Ohio.

Part positioners for robotic welding have many things in common with traditional welding (manual or hard automation) positioners. Both must be able to support the tooling fixture and parts (load) for welding, and provide a suitable current return path to the welding power supply. They might also need to manipulate or turn the load to provide optimum welding orientation. Additional positioner features required for robotic welding applications might include operator safety

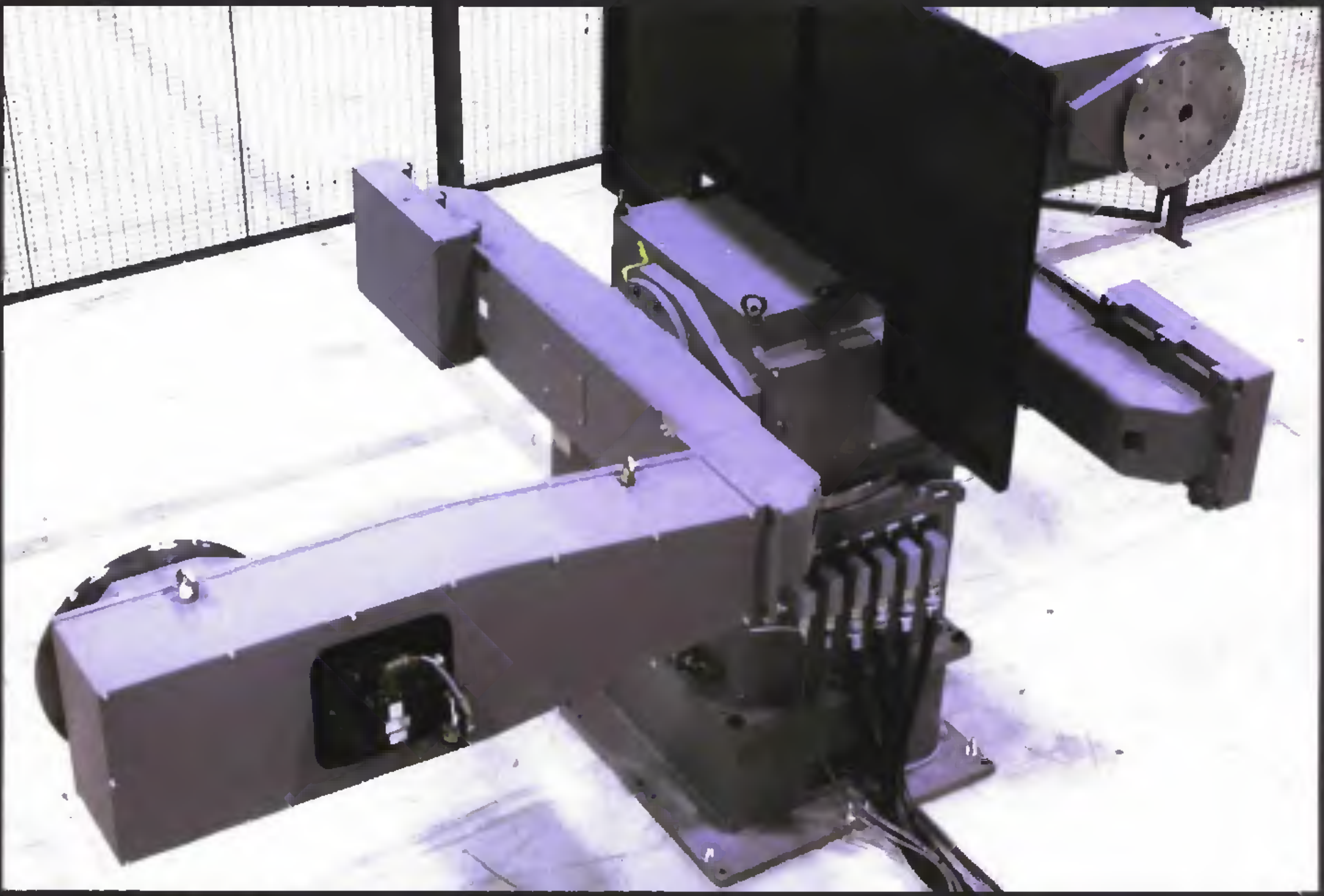

Fig. 1 — Example of a multiaxis positioner used with robots.

interlocks, equipment safety interlocks, and coordinated motion with the robotic manipulator. If multiple welding power supplies are used, separate current paths for each power supply are recommended.

Choose from Many

The spectrum of robotic welding positioners runs the gamut from the simple flat table to very complex multiaxis, servo-driven devices. The servo-driven head- and tailstock system might be the most common, versatile robotic welding positioner in use today. The application challenges of properly supporting and manipulating the load, providing suitable safety interlocks and weld ground return paths with this system, are representative of most robotic positioners.

Types of Positioners

Simple positioners include stationary tables, manual indexing tables, and pneumatic- or motor-driven indexing tables. Single-axis servo positioners include the servo-driven rotary table, cantilever-type headstock, and the headstock/tailstock (HS/TS) configurations. Multiaxis servo positioners come in a wide variety of configurations, including the popular ferris-wheel type headstock/tailstock, the tilt and rotate (skyhook), and table/headstock combinations. Also in this category are custom positioners with as many axes as required by the application — Fig. 1

Process Requirements for Robotic Welding Positioners

Robotic welding power sources are sophisticated pieces of equipment that require suitable weld ground circuits to ensure proper feedback and optimal performance. Noise and interference on the feedback circuits can cause poor quality or inconsistent welds in addition to other process problems.

Single welding gun systems must provide a well-defined, low-resistance return current path. Some manufacturers return weld current through preloaded bearings. However, dedicated contact brushes with prescribed current paths are the preferred method.

Multigun systems also must provide a low-resistance weld current return path. However, it is recommended that the individual welding gun circuits avoid shared current paths. This can cause cross talk between the power source feedback systems, resulting in poor weld control and inconsistent quality. Therefore, each weld system should have its own independent weld ground system — Fig. 2.

Production tooling might require electrical I/O control signals, pneumatics, cooling water, and other peripherals. When reciprocating motion is required, managing the interconnecting cables and/or hoses gets more challenging. Cables and hoses can tolerate a limited amount of reciprocating motion if they are properly managed, protected, and terminated. Common ways to manage reciprocating motion include using a through-hole on the rotational axis; energy chains (flexible cable trays); slip rings (rotary connectors); or overhead suspension. Slip rings are required for continuous motion applications.

A high-quality robotic positioner should have features that allow it to repeatably identify the "zero" or "home" position. This will help minimize robot program touch-ups after collisions or re-

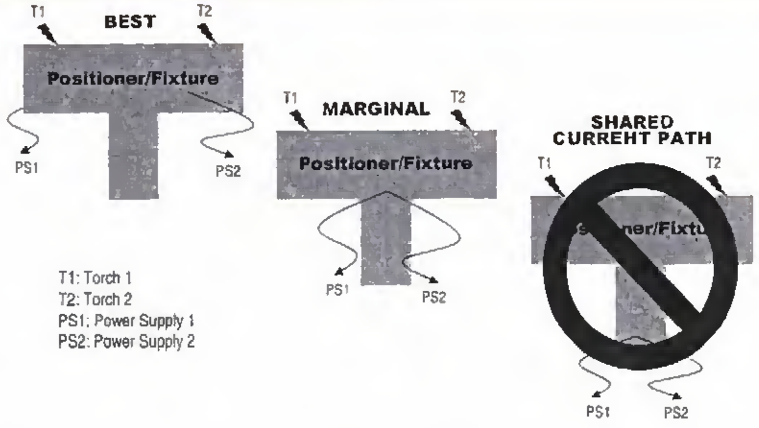

Fig. 2 — Schematic showing the progression from good to bad for current path systems.

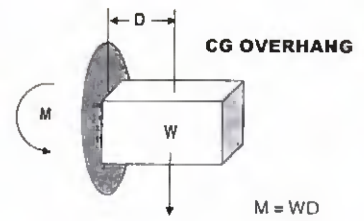

Fig. 3 — Method for determining bearing capacity of headstock.

pairs. The homing feature should be easy to use and repeatable. It can be accomplished by using a metal or plastic pin, gauge, alignment tab, or other physical feature.

Safety Requirements — Operator and Equipment Protection

The ANSI/RIA R15/06-1999 safety standard applies to robotic workcells and contains specific safety guidelines that must be followed to protect the operator and the robot. The equipment also must meet all applicable local, state, and federal codes. Safety-related features of the positioner must integrate with the cell controller architecture and should include dual-channel compatible switches or sensors, and emergency stopping (E-stop) capability.

The E-stop time and distance traveled is a performance characteristic of the positioner. This should be tested under prescribed load and speed conditions. The documented results can be used to design the operator safety plan for the production cell.

Part Support and Manipulation

Robotic welding positioners generally are rated by their capacity to support and manipulate the load, which includes both the weld tooling and the part. For table-type positioners, this represents the thrust capacity of the table bearing system. For headstock, HS/TS, and other multiaxis positioners, this represents the moment and radial capacity of the drive and free-end bearing systems. Single- or multiaxis positioners all must have the ability to manipulate the load in a smooth and controlled fashion. Excess vibration or settling time at the end of motion might adversely affect cycle time and overall weld quality.

Headstock and headstock/tailstock positioners are commonly used in robotic cells due to their versatility and simplicity. When used in tandem, the operator can load one positioner while the robot is welding on the other one, thus improving throughput. A detailed study of this configuration provides insight into evaluation of the other positioner types.

Calculating Load Capacity

The stand-alone headstock must support the load in a cantilevered fashion. This creates high moment loads on the bearing system, which, in turn, defines the load capacity of the headstock. The moment load (M) equals the load (W) multiplied by the distance (D) from the bearing center and should not exceed the limits set by the bearing manufacturer — Fig. 3. Many positioner manufacturers rate their headstocks at 50% of this bearing capacity value, providing a safety margin for overload conditions.

The capacity of the headstock can be significantly increased with the addition of a tailstock (free-bearing support) because the load is no longer cantilevered. Traditionally, the tooling has been rigidly mounted between the headstock and tailstock bearing systems. This capacity can be modeled and the bearing loads (moments) can be calculated using fixed-beam theory. The bearing moments are a function of the load distribution on the beam and the distance between the support bearings. This limits the allowable span between the head and tailstocks. Additional disadvantages of this rigid tool mounting approach include the need for precise alignment between the headstock and tailstock (including precision machine bases) and precision tooling. These combine to increase cost and limit the bearing capacity of the positioner system.

An alternative to rigid tool mounting is a simply supported, or flexible, tool mounting system. The primary advantages of this approach include more controlled and predictable moment loads on the support bearings with no limitation on the span between the head and tailstocks. Additional advantages include less stringent alignment and tooling precision requirements — Fig. 4.

The challenge of this approach is to allow the beam to flex while still controlling the rotational motion. Generally this has been achieved with custom designs that might include "dog and pins," clevis pins, or other types of flexible rotational limiting devices. However, at least one robot manufacturer[1] now provides a cost-effective standard design that meets the challenges of simply supported beam motion. This system allows up to two degrees of total misalignment and eliminates the need for precise alignment, costly machined bases, and high-precision tooling.

Manipulating the Load

The headstock output torque is required to manipulate and hold the load in orientations required by the welding application. The available headstock output torque (T_r) can be calculated by multiplying the motor torque (T_m) by the total gear reduction ratio (R) — Fig. 5.

Most positioner manufacturers rate their headstocks by holding torque, or the torque required to hold the load (W) in a horizontal orientation, at a prescribed distance (r) from the turning axis. However, no standard rating system exists, so when evaluating different positioners, it is very important to understand how the positioner is rated to ensure it is capable of moving and controlling the intended load.

1. *Motoman Inc.*

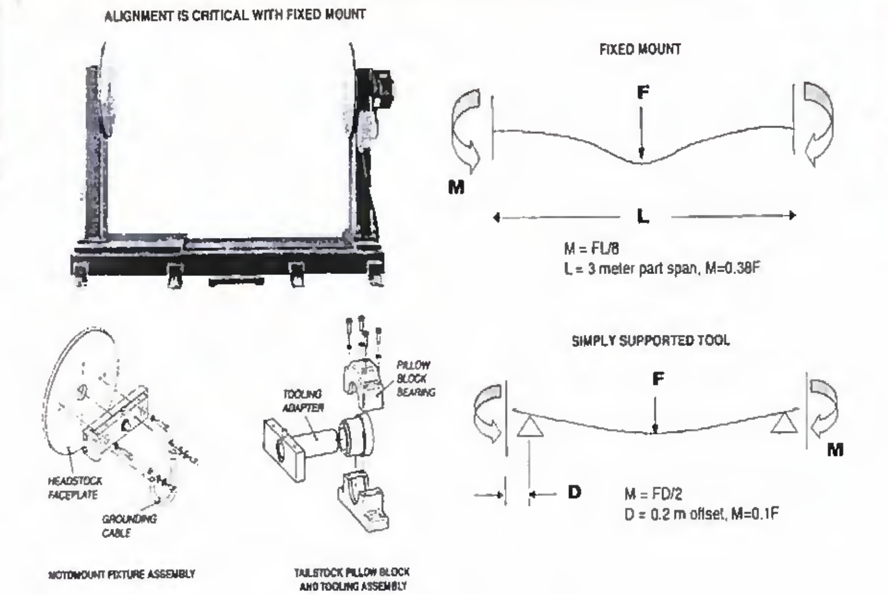

Fig. 4 — Load-bearing capacity of a stand-alone headstock can be increased with a headstock/tailstock setup.

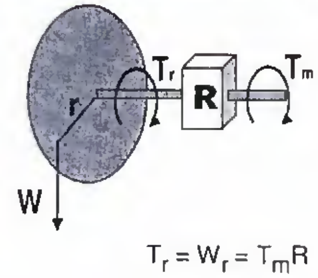

Fig. 5 — Method to calculate headstock output torque.

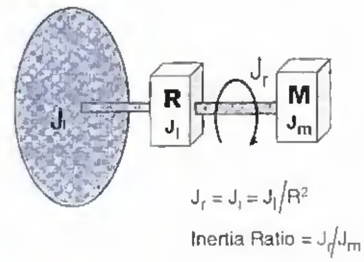

Fig. 6 — Calculation for determining total inertia.

As an example, one manufacturer might rate its 450-kg headstock at 150-mm turning radius and require 50% rated motor torque under those conditions. Another manufacturer might call the same motor-reducer combination a 500-kg headstock rated at 216-mm turning radius and require 80% rated motor torque. While the headstocks might appear to have different ratings, they would be expected to have identical performance characteristics.

The motor-reducer torque is also required to accelerate and decelerate the application load about the rotational axis. This torque is equal to the rotation mass moment of inertia (inertia, J) of the load multiplied by the angular acceleration and should not exceed the peak torque rating of the headstock.

Inertia is a property of the load and describes the distribution of mass about the rotational axis. While crude estimates for the inertia can be calculated based upon the load material and geometry, today's 3-D modeling packages used to design tooling can provide very accurate estimates and should be used whenever possible.

The total inertia is also a significant factor in the control stability of the servo-driven headstock. This is generally evaluated as the ratio of the reflected inertia (J_r) divided by the motor inertia (J_m). The reflected inertia is the sum of the reducer inertia (J_i) and the load inertia (J_l) divided by ratio squared, $J_r = J_i + J_l/R^2$ — Fig. 6. Most headstocks have a maximum recommended reflected ratio (J_r/J_m) of 5 to 10, depending upon the total mechanical stiffness of the headstock drive system. Applications with reflected ratios approaching or exceeding the recommended limit may demonstrate poor control stability, undesirable vibrations, or motor overheating.

The root mean square (RMS) duty cycle torque is an average of the total torque requirements (holding and motion) for a given application duty cycle. This value should be calculated and compared with the performance specifications of the proposed headstock. Root mean square torque requirements exceeding the headstock ratings may cause servomotor overheating and reduced headstock life. High RMS values due to excessive load imbalance can sometimes be corrected with the addition of counterbalances, provided this does not result in excessive load inertia.

Summary

Robotic welding positioners come in many styles as required by different welding applications. Properly designed and implemented positioners have a number of common characteristics. They must be able to support and present the part in an orientation for optimal welding. They must support all required tooling and process control functions including I/O and weld current isolation. Finally, the positioner must have features and capabilities that can be used in the robotic cell control and safety architecture. The user who considers these items when designing a system for a specific welding application will be well on the way to a successful project implementation. ◆

Special Report:

THE 2003 AWS WELDING SHOW

The AWS Show celebrated fifty years of service to industry by showcasing the latest welding technology

BY ANDREW CULLISON AND MARY RUTH JOHNSEN

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The crowd awaited the symbolic ribbon cutting that officially opened the 2003 AWS Welding Show.

The Annual Business Meeting of the American Welding Society opened with a moving rendition of "*The Star Spangled Banner*" by Ethel Levert, sister of outgoing President Ernest Levert. The gathering was officially welcomed to Detroit by Kenneth Hollawell, a representative from the mayor's office.

In his address to the attendees as president-elect, Tom Mustaleski emphasized the strength of the Society comes from the dedication of its volunteers. "Since its founding, volunteers have been at the center of the Society," he said, "working for the cause and not the pay. We are blessed with outstanding people who have given freely of their time and expertise."

That wealth of knowledge and spirit of sharing among volunteers can be the justification to employers for participation in the AWS. Mustaleski told of a time when his employer asked why his continuation in AWS should be supported. He related a story about a weld cracking problem he was asked to solve. It was a problem he was unfamiliar with but from his AWS committee participation he knew people who had expertise with this particular cracking. Through a series of contacts, he was able to find a solution to the problem almost immediately. Without exposure to those experts, he would have spent extensive time solving the problem at the expense of the employer.

During his presidency, Mustaleski has made the commitment to attract new volunteers and retain those already serving. He will do this by improving time management of volunteers and putting in place support programs for them. He proposed to initiate programs that improve communication among Sections, Districts, and Committees and to enhance recognition of those who give their time and energy. He also wants to improve ways that help local volunteers attract new members.

In closing, he challenged us all to get involved. "The greatest benefit any of us receive from the American Welding Society is the opportunity to know and learn from each other," he said. "It can't happen if you don't get involved."

Fig. 1 — President Ernest Levert (right) presents a plaque of recognition to Dr. Akira Matsunawa honoring him for the Adams Lecture.

Comfort A. Adams Lecture

Dr. Akira Matsunawa (Fig. 1), professor emeritus, Osaka University, Japan, presented the Comfort A. Adams Lecture on "The Physics of Laser Welding." Matsunawa began his presentation by noting his selection as the Adams speaker had a special meaning to him. He told how, after reading the Adams Lecture in the 1959 *Welding Journal*, a presentation by C. E. Jackson of Ohio State University, titled "The Science of Arc Welding," he was inspired to enter the study of welding phenomena. Since then, he has dedicated his life to that study.

He feels the laser is a twentieth century invention destined to affect the world on the same magnitude as the invention of the semiconductor. The laser is an artificial light that does not appear in nature, and it has the highest power density of any invention. Yet, he noted, there are still many misconceptions about the laser, primarily because it is a sum of many complex phenomena occurring simultaneously. The primary misconceptions center around the beam-plasma interactions and keyhole behavior. One misconception is the incident beam is blocked and reflected by a high-pressure, high-temperature plasma oscillation. There is now a new concept that states the incident beam can penetrate the plasma. The two kinds of plasma, metallic and shielding gas, must be controlled to enhance melting.

Observation of keyhole formation and pool dynamics by X-ray showed the keyhole fluctuating under constant power and bubbles ejected from its bottom became porosity. It was found turbulence from keyhole formation entrapped helium from the shielding gas in the molten pool. Tests using a modulated pulsed laser reduced porosity formation.

In his final statements, Matsunawa emphasized much study is still needed to fully understand the full potential of the laser. "Our present understanding of the laser welding phenomena is only half of what we should expect," he noted.

Plummer Lecture

In keeping with the Show's location in the heart of the U.S. auto industry, the topic of this year's Plummer Memorial Education Lecture was "Automotive Training." Glen Knight, administrator, Welding Training, DaimlerChrysler, presented an overview of how the auto industry trains its workers as illustrated through DaimlerChrysler's program. His group, which is located on the 60-acre campus of the DaimlerChrysler Tech Center, provides training for more than 70,000 workers at 34 manufacturing locations. It is also involved with the United Auto Workers/DaimlerChrysler Technical Training Center, a new joint venture with the union that operates much like a junior college.

The company's Advanced Technical Training Department has provided in-plant training of workers for 30 years. One of its primary functions is to support new vehicle launches by training the workers who will build those products. "The [department's] staff bridges the gap between what the engineers want and what the workers need to know," Knight said. "Many of the courses offered are custom-made for a specific application."

The department offers hundreds of courses. For example, there are 13 classes on robots and programmable controllers, 52 on manufacturing systems, 125 product-related courses, 26 resistance welding and 21 arc welding courses, as well as classes on laser welding, ultrasonic inspection, destructive testing, and other topics. The classes consist of approximately 20% classroom work and 80% hands-on.

Product Highlights

A total of 396 exhibiting companies brought their best and brightest products to the Show. It was a tantalizing enticement for those searching for better and more efficient ways to cut and weld. Unfortunately, it was impossible for the *Welding Journal* editors to sample each and every one of them, but below are a few products that drew our attention.

PerformArc 122S. During the AWS Welding Show, Panasonic Factory Automation showcased the high weld speed it has been able to achieve for aluminum GMAW with its PerformArc 122S robotic arc welding system. The company reports achieving 5 m/min (~200 in./min) in 2-mm-thick lap joints and 3 m/min for fillet welds. Demonstrations at the Welding Show were set at 160 in./min. The company credits this accomplishment in large part to integrated digital communications between the robot, welding power source, and servo-driven wire feeder. Panasonic builds each component of the welding cell, which comes fully assembled and can be put into place with a forklift. The robotic cell features an Underwriters Laboratories-approved six-axis arc welding robot; fully integrated controller; 350-A inverter power supply; servo-controlled, high-speed turntable with two headstock/tailstock positioners; integrated operator control station, and safety enclosure. Cost of the unit is approximately $100,000. *Panasonic Factory Automation Co., Elgin, Ill., (888) 726-9353, www.panasonicfa.com.*

MG3 series. Unitek Miyachi offered its MG3 series of compact, color, digital weld monitors (Fig. 2), which are designed to measure and monitor current, voltage, and displacement during the resistance welding process. The full-color screen can be set up in four quadrants, which permits simultaneous display of numerical and/or waveform information for current and voltage from two welding machines. It also includes a zoom function that can expand any quadrant and fill the entire screen with one parameter, if desired. The series includes three models. The basic model provides two channels of current and voltage. The next model includes an additional channel of displacement monitoring, and the third model features two channels of current and voltage and two channels of displacement monitoring. Depending on the model chosen and the sensors required, the monitors

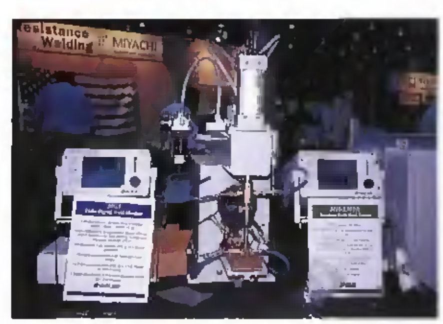

Fig. 2 — This series of compact, color, digital weld monitors can be used to help set up the welding machine and weld process, troubleshoot problems, and validate the welding process.

list between $8000 and $11,000. The units feature built-in statistical process control capabilities, including histograms and run charts. *Unitek Miyachi, Monrovia, Calif., (626) 303-5676, www.unitekmiyachi.com.*

Pipe Dissector. Matt Kniep, the pipefitter/welder who created this tool, said he invented the Pipe Dissector (Fig. 3) out of necessity because he needed a better method for laying out pipe. He and the other welders at the fab shop he runs use the stainless steel tool daily. With the tool, end marks can be made with four quick motions instead of eight hammer strikes. The user then hooks the tool on the end of the pipe to ensure parallel layout lines from the end marks. It can be used to quickly and accurately find the center on both contoured and flat surfaces and, with the use of two hole pins, can be used to dial in the flange fit. It features a built-in level and magnets on one edge for hands-free use. *Starr Products, Inc., Bellingham, Wash., (888) 378-2777, www.starrproducts.com.*

Fig. 3 — The Pipe Dissector tool helps welders make pipe layout marks quickly and accurately.

Manual Trepanning Head (MTH). Laser Mechanisms' manual trepanning head (Fig. 4) is designed for applications requiring either welding or cutting of ring-shaped patterns. Use of this accessory, essentially an orbital weld head for lasers, means only a small amount of mass must be moved to achieve circular welding or cutting because the head moves rather than the workpiece. While the MTH was primarily designed for applications requiring infrequent diameter changes, the circle diameter can be changed with simple tools. The diameter range is from 0.04 to 2.5 in. The two-mirror laser accessory can be fitted with a gas jet manifold and focusing lens for laser beam cutting. The MTH can be fitted with a parabolic head for high-power laser welding applications. The head, which can be used with either CO_2 or Nd:YAG lasers, costs approximately $15,000 to $20,000. *Laser Mechanisms, Inc., Farmington Hills, Mich., (248) 474-9480, www.lasermech.com.*

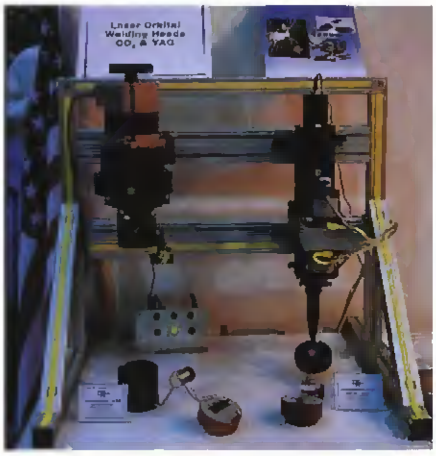

Fig. 4 — Laser Mechanisms' manual trepanning head delivers the laser beam in a circular pattern, making it useful for ring-shaped welding or cutting applications.

NorZon Plus™. This latest edition of a long line of NorZon products was designed to generate a fast cut rate as well as long life. These depressed-center abrasive wheels combine NorZon® zirconia oxide with Norton SG® ceramic alumina seeded-gel abrasives and a premium bond. According to the company, this produces a wheel that removes metal faster, lasts longer, and generates a better finish. The wheels are available in 4½- through 9-in. diameters and ¼-in. thickness with either ⅞-in. or ⅝–11 centers. *Norton Co., Saint-Gobain Abrasives, Inc., Worcester, Mass., (800) 446-1119, www.nortonabrasives.com.*

Tubemaster 514. When Magnatech was developing the Tubemaster Model 514 (Fig. 5), the company's goal was to cut the price from that of its previous system by 50%, reduce the size, and to offer more features in terms of software and capabilities. The size of this new programmable power source for orbital weld heads has been reduced to 19 in. long x 11 in. wide x 12.75 in. high and it weighs 54 lb. The suggested retail price of the power source alone is $9,995; with a water cooler and orbital weld head, the price is $20,000. The system was designed to work with most welding heads for both autogenous welds and welds made with a welding wire. Programming can be accomplished by manual entry or by using the Autoprogramming feature, which automatically generates weld procedures. The unit can store 100 weld programs internally, with up to 100 levels per program. Other features include 200-A output; programmable override limits to provide supervisory control; weld parameter monitoring; and out-of-limits reporting. *Magnatech Limited Partnership, East Granby, Conn., (860) 653-2573, www.magnatech-lp.com.*

Fig. 5 — The Tubemaster Model 514 programmable power source was designed to work with most types of orbital weld heads for both autogenous welds and those requiring filler metal.

PRO-WAVE® 185TSW. This machine is the cornerstone of Thermal Arc's new line of portable shielded metal arc, gas tungsten arc, gas metal arc, and multiprocess inverter arc welding power supplies geared for construction and maintenance jobs. The PRO-WAVE 185TSW (Fig. 6) weighs 41.8 lb. It generates a square-wave AC/DC output with a range from 5 to 185 A. It can handle most GTAW jobs, and precise wave shaping allows the welder to control cleaning, penetration, and heat input for aluminum applications. Standard features include up-slope/downslope control and pulse, variable frequency, wave balance control, and lift or high-frequency assisted starting. It also features the company's new voltage regulation device, which reduces the open circuit voltage when the power supply is not in use to help eliminate the chance of accidental electric shock. The welding machine comes with a GTAW torch, ground clamp, flowmeter, and foot pedal. The list price is $2100. *Thermal Arc, Inc., a Thermadyne company, St. Louis, Mo., (636) 728-3000, www.thermalarc.com.*

Fig. 6 — The Pro-WAVE 185TSW is a multiprocess portable power source geared for construction and maintenance jobs.

SuitCase™ 8RC/12RC. Welders do not need to return to the power source to adjust voltage levels on these suitcase-style wire feeders — Fig. 7. They feature remote voltage control for gas metal arc, pulsed gas metal arc, and flux cored arc welding. This feature and their small size work well for sites where maneuverability is a problem. The 8RC takes an 8-in. spool of wire and weighs 22 lb; Model 12RC uses a 12-in. spool and weighs 25.5 lb. The feeders feature an injection-molded, crush-proof, flame-retardant case that protects internal components from dirt, moisture, and contaminants. Large-sized components allow adjustment of wire tension and handling of other parts without the need for welders to remove their gloves. A thermostat inside each feeder monitors operating temperature and shuts the unit down to avoid damage if too high a temperature is reached. Two drive rolls rather than a drive roll plus an idler roll ensure smooth wire feed. Wire feed speed can be adjusted between 75 and 700 in./min while feeding wires from 0.023 to $\frac{5}{64}$ in. in diameter. Options include a trigger-hold/digital meter that allows operators to relax their index fingers during the weld cycle. The list price for Model 12RC is $1680. *Miller Electric Mfg. Co., Appleton, Wis., (800) 426-4553, www.MillerWelds.com.*

Fig. 7 — Miller's 8RC and 12RC wire feeders feature remote voltage control and a rugged suitcase-style case.

Strong Hand Utility Clamp. Four models of the company's modular utility clamp (Fig. 8) are available: 4.5, 6.5, and 8.5 in., and a 4.5-in. "J" style clamp for stepping over I beams and other items with tall lips. The 8.5-in. model exerts 2660 lb of clamping pressure, the others 600 lb. List price of the 8.5-in. model is $56.18. A variety of accessories let users customize the clamps for specific applications. Channel brackets help turn the clamp into a vise, the V-pad attachment allows it to be used on round stock, the "Sidekick" attachment allows users to clamp items either horizontally or vertically. Accessories are added using the threaded hole on the bottom jaw. *Valtra, Inc., Pico Rivera, Calif., (800) 989-5244, www.valtrainc.com.*

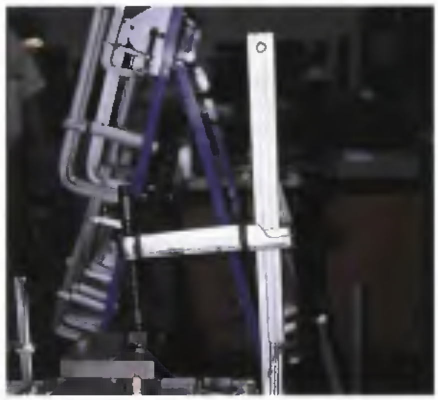

Fig. 8 — A variety of accessories customize Valtra, Inc.'s, Strong Hand utility clamps for use on a wide range of applications.

Monograph Millennium. A major priority of Jerry Leahy, president, Koike Aronson, is to promote the company as a total source for welding, cutting, and positioning for the small fab shop to the large corporation. The introduction of the Monograph Millenium (Fig. 9) is a step in that direction. This plasma cutting machine offers the latest in control technology in an affordable package for small operations. It features a $\frac{5}{8}$-in. maximum cutting capacity with a 5- x 10-ft effective cutting area. Rack and pinion drive system maintains traverse speeds up to 1400 in./min. Arc voltage feedback position control and initial height sensing are standard features. The control system features Microsoft Windows ®, a graphics interface, color panel display, 10-GB hard drive, and CNC profiler. This product fits Leahy's philosophy of "take out unnecessary costs and add value through people and processes." *Koike Aronson Inc., Arcade, N.Y., (585) 492-2400, www.koike.com.*

Fig. 9 — To make plasma cutting affordable for small operations, Koike Aronson introduced the Monograph Millennium.

Nextweld ™. Welding operations can be integrated through a 100% digital network with Nextweld™ technology. Multiple welding stations can be tied together by Ethernet and a central monitor (Fig. 10) can show live as well as historical data. The system utilizes digital communication, which transmits a large amount of data to components accurately and at high speed. By monitoring parameters, weld performance at each station can be optimized. The network integrates Lincoln's Waveform Control with power electronics to provide the ability to adjust arc characteristics to the specific job and to use power at high densities but with efficiency. *The Lincoln Electric Co., Cleveland, Ohio, (216) 481-8100, www.lincolnelectric.com.*

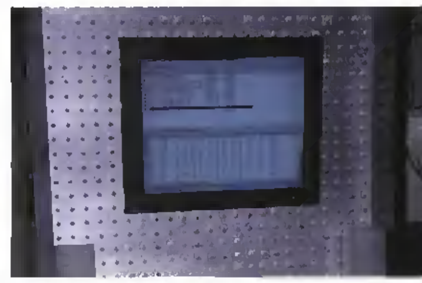

Fig. 10 — Nextweld™ from Lincoln offers arc control, efficient power consumption, and reliable data transfer across a network of welding stations.

INV-PED. This new pedestal resistance welding machine (Fig. 11) was getting a lot of attention because of its affordability (under $8000) and features. Its steel frame doesn't visibly deflect through a weld force range of 250 to 1500 lb. It has a weld head stroke of 1 to 3 in., a throat depth of 6 to 8 in., and a secondary current up to 13,500 A. It claims precise and smooth movement throughout the welding cycle. It can handle spot, projection, and seam welding, and it is configured to require minimal floor space for a pedestal welding machine. *The Taylor-Winfield Corp., Brookfield, Ohio, (330) 448-4464, www.taylor-winfield.com.*

Fig. 11 — The INV-PED pedestal resistance welding machine was getting a lot of attention at the Show.

Motion and Machine Controller. Multitasking control of an automated welding system can be performed with the BX2, a 64-bit RISC processor — Fig. 12. It offers the advantage of a single processor in the welding system controlling all the motion and welding parameters including wire feeding, current and voltage, positioning of the welding head, prepurge and postpurge, and oscillation synchronization. The controller is industrial hardened and has operated effectively in a variety of applications including offshore pipe welding, weld sealing of nuclear waste canisters, automotive tube welding, and laser joint tracking. The compact unit has the capability of 14 digital outputs and 32 inputs; Windows NT® interface; expandable through Ethernet modules; point-to-point, trapezoidal and s-curve motion; and operation in temperatures from 0 to 40°C. *Berkeley Process Control, Inc., Richmond, Calif., (510) 222-8004, www.berkleyprocess.com.*

Fig. 12 — The BX2 processor can control multitasks in an automated welding setup.

Variable Angle Clamps. The introduction of a unique clamping system for holding parts at various angles (Fig. 13) generated a lot of interest. The clamps can hold flats or rounds at multiple angles through an ingenious ratcheting mechanism. Both models C1-100 and C2-200 are made of lightweight aluminum with an anodized finish. The C1-100 has an opening up to 0.875 in., is 6.5 in. long, and costs $129. The C2-200 is 14 in. long with a 2-in. opening and has a price tag of $189. *Heck Industries, Inc., Hartland, Mich., www.heckind.net.*

Fig. 13 — This lightweight aluminum clamp holds parts in place at a variety of angles.

Heat Treating. For on-site heat treating, the 75 KVA power source has the flexibility to be used manually, remotely, or by program. The unit has six-channel capability and one or all can be run by its autoprogrammer either locally or remotely. Data acquisition and supervisory control are built-in. Made of heavy-gauge sheet steel, the unit is ready for industrial use. It is encased in a wheeled cabinet to provide mobility. The power source has capacity for 18 heaters, 80 V at 3.6 kW, or 24 heaters, 60 V at 2.7 kW. It has two 110-V auxiliary outlets and six dual panel mounted thermocouple jacks. *Manning USA, Dover, N.J., (800) 447-4473, www.manningusa.com.*

HeatShield. One way to stay cool in a hot job is to try a vest that contains a synthetic cooling medium. Place the vest into a freezer overnight, put it on for work, and the claim is it will provide body cooling for up to 3½ hours. It also has a design that channels condensed moisture out of the vest for added cooling potential. The vest can be refrozen multiple times and retain its effectiveness. The HeatShield vest weighs 4 lb and costs $199.95. *ClimaTech Safety, Inc., White Stone, Va., (800) 266-5440, www.climatechsafety.com.*

Coreshield 6. Developed to meet FEMA 353 specification for use in earthquake-prone areas, Coreshield 6 is an E70T-6 self-shielded flux cored wire (Fig. 14) for flat and horizontal position welding. This new welding wire is designed to have low spatter, low fume levels, and stable arc characteristics. It is classified under the AWS A5.20 specification, and it is a good selection for outdoor bridge and construction welding. It comes in a variety of diameters. *ESAB Welding and Cutting Products, Hanover, Pa., (717) 637-8911, www.esabna.com.*

Fig. 14 — Self-shielded flux cored Coreshield 6 meets specifications for welds on structures in earthquake regions.

TrueFit. Need an industrial glove that fits snugly but is comfortable? Tillman introduced one at the Show, and it was getting attention. Although not meant to be worn for welding, the TrueFit glove affords good protection for many jobs. The gripping part of the glove is constructed of either goatskin, cowhide, or deerskin, with extra reinforcement in the thumb and palm areas. A flexible Spandex® material is on the back, and an elastic cuff is tightened by a hook-and-loop closure. The deerskin, cowhide, and goatskin models are reasonably priced at $10.95, $8.95, and $7.50, respectively. *Tillman, Compton, Calif., (800) 255-5480, www.jtillman.com*

Head-Turners. American patriotic hard hats have been popular since they came on the market a few years ago, but the concept is now going international with the introduction of the Mexican flag model — Fig. 15. It is made of a durable material that withstands temperature fluctuations, humidity, and UV light. It is fully dielectric, has a replaceable sweatband, and the suspension is adjustable for a variety of head sizes. *Jackson Products, Inc., Belmont, Mich. (800) 253-7281, www.jacksonproducts.com.*

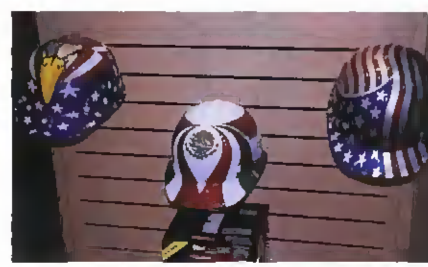

Fig. 15 — Patriotic pride goes international with the introduction of a Mexican flag hard hat, flanked here by two popular American-pride hard hats.

What's Ahead for the Welding Show

The AWS Welding Show will return to Chicago's McCormick Place April 6–8, 2004. There, showgoers will once again get the opportunity to view new developments in welding equipment and accessories, learn the latest information researchers have discovered, and mix with their peers from throughout industry.◆

AWS WELDING SHOW 2004

American Welding Society

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

(please type or print in black ink)

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:*

The candidate's accomplishments under areas identified below (use separate sheet for each category):

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

NJC Demonstrates Adaptive Mechanized Welding System at Shipyard

The Navy Joining Center (NJC) and Edison Welding Institute (EWI) have developed a system for real-time adaptive fill of multipass groove welds in U.S. Navy ship structures. The system was recently demonstrated at the General Dynamics Electric Boat Facility in Groton, Conn. The system includes a portable welding tractor, laser vision system, and gas metal arc welding equipment. This activity was in response to the Navy's need to reduce the construction cost of ships and submarines through the increased use of automated welding.

While current applications typically require the continuous supervision of an operator for welding parameter and welding gun position adjustment, the emphasis of this project was to give the welding system more intelligence so that it can function autonomously. This would free the operator to perform other duties, including the operation of multiple systems.

Since the system is based on commercially available equipment, the transition to the production floor only required upgrading software, minor hardware changes to the existing equipment, and a single day of operator training. A successful demonstration of the system was conducted by a production welder at Electric Boat. The demonstration verified that the mechanized adaptive welding system performed as intended and the system is now slated to be demonstrated at a second shipyard and for transition into production.

For further details, please contact Doug Ketron, Arc Welding and Material Automation Group, Edison Welding Institute, (614) 688-5150 or via e-mail at *doug_ketron@ewi.org*. ♦

Navy Joining Center Fellowships Awarded at AWS Welding Show 2003

Two Navy Joining Center (NJC) graduate fellowships for the 2003–2004 academic year were announced at the AWS Welding Show 2003 in Detroit. Each year, the Navy Joining Center supports two graduate fellowships as part of its commitment to further technical education and the advancement of materials joining technology. These fellowships are awarded through the American Welding Society Foundation and support graduate students whose research addresses materials joining topics of interest to the U.S. Navy.

The NJC Fellowships for the upcoming academic year have been awarded to Matthew J. Perricone of Lehigh University and Raymundo Arroyave of Massachusetts Institute of Technology. Perricone has been a previous recipient of an NJC fellowship and is pursuing both master's and doctorate degrees in material science and engineering with studies in "A Fundamental Study of the Rapid Solidification Behavior of Super-Austenitic Stainless Steels in Laser Welds for Advanced Naval Applications." Arroyave is also a past recipient of an NJC fellowship and is pursuing a doctorate degree in materials science and engineering with studies in "Thermochemical and Kinetic Phenomena at Ceramic-Metal Interfaces, Application to the Zirconia/Cu-based Active Braze System."

Please contact the American Welding Society Foundation at (800) 443-9353 ext. 689 for more information on NJC Fellowships.

Mark Your Calendar

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.

NJC Operated by EWI
The Navy Joining Center
1250 Arthur E. Adams Dr.
Columbus, OH 43221
Phone: (614) 688-5010
FAX: (614) 688-5001
e-mail: *NJC@ewi.org*
www: *http://www.ewi.org*
Contact: Larry Brown

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

Conferences and Exhibitions

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: *claundon@epri.com*. For more information, visit *www.epri.com* and click on "Events."

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*.

♦ **4th Conference on Weld Cracking Causes and Cures.** September 9–10, New Orleans, La. Sponsored by the American Welding Society. Contact: AWS Conferences, 550 NW LeJeune Rd., Miami, FL 33126, (800) 443-9353 ext. 449 or, outside the U.S., (305) 443-9353 ext. 449, FAX: (305) 443-1552; *www.aws.org*.

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: *CustSrv@asminternational.org*;*www.asminternational.org*.

2003 International Construction and Utility Equipment Exposition (ICUEE). September 23–25, Kentucky Fair and Exposition Center, Louisville, Ky. Owned and produced by the Association of Equipment Manufacturers. Contact: ICUEE, (866) 236-0442, FAX: (414) 272-1170, e-mail: *info@icuee.com*; *www.icuee.com*.

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: Ernest 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*.

♦ **Welding in the Oil and Gas Industries.** October 7–8, Hilton Garden Inn Houston, Houston, Tex. Sponsored by the American Welding Society. Contact: AWS Conferences, 550 NW LeJeune

Rd., Miami, FL 33126, (800) 443-9353 ext. 449 or, outside the U.S., (305) 443-9353 ext. 449, FAX: (305) 443-1552; *www.aws.org*.

ASM International's Materials Solutions Conference and Exposition. October 13–16, Pittsburgh, Pa. Contact: ASM Customer Service, (440) 338-5151 ext. 6, FAX: (440) 338-4634, e-mail: *Cust-Srv@asminternational.org*; *www.asminternational.org/materialssolutions*.

Friction Stir Welding Technology for Defense Applications. October 14–15, Living/Learning Center, University of Pittsburgh at Johnstown, Johnstown, Pa. Hosted by Concurrent Technologies Corp. (*CTC*) and the National Center for Excellence in Metalworking Technology (NCEMT); organized by NCEMT and Navy Joining Center; and sponsored by the Navy Manufacturing Technology Program, Office of Naval Research. Contact: Tricia Wright, NCEMT, (814) 269-2567, e-mail: *wrightt@ctcgsc.org*.

7th Welding Week 2003. Benelux Exhibition on Welding, Joining, and Cutting. October 14–17, Bouwcentrum, Antwerp, Belgium. Supported by the Belgian Welding Institute, Netherlands Welding Institute, and European Federation for Welding, Joining, and Cutting. Contact: Steven Duytschaever, Project Coordinator, 32 3-354-08-80, FAX: 32 3-354-08-10, e-mail: *weldingweek@fairtec.com*; *www.weldingweek.be*.

China International Metals Industry Fair — MetalsFair. November 6–9, Guangzhou International Convention and Exhibition Centre, Guangzhou, Guangdong Province, China. Sponsored by the China Iron and Steel Association, the China Non-Ferrous Industry Association, and the Metallurgical Council of CCIT. Running simultaneously to MetalsFair will be the International Forum on Steel Market and Trade 2003, the International Forum on Non-Ferrous Market and Trade 2003, the International Conference on Metal Production and Processing Technology 2003, and the International Ferroalloy and Refractory Industry Expo. Contact: Zhang Lingyun, Metallurgical Council of CCPIT, 86-10-65131905, FAX: 86-10-65248384, e-mail: *mail@metalsfair.com*; *www.metalsfair.com*.

♦ **Weldex 2003.** November 11–14, National Exhibition Centre, Birmingham, U.K. Weldex 2003 will run concurrently with the Manufacturing Week, INSPEX, Tooling, DES, DMC, and CIM exhibitions. Sponsored by the American Welding Society, Association of Welding Distributors, and the European Welding Federation. Contact: Karin Allfree or Isobel Roberts, 44 1322 660070, FAX: 44 1322 616350; *www.weldexpo.com/modules/serve.cgi*.

14th IAS Steelmaking Conference and the **Ironmaking Conference.** Hotel Colonial, San Nicolas, Argentina. Contact: Cristian Genzano, Institutional Services, Instituto Argentino de Siderurgia, Av. Central y Calle 19 Oeste, 2900 San Nicolas, Buenos Aires, Argentina, 54 3461 460803, FAX: 54 3461 40803, e-mail: *genzano@siderurgia.org.ar*; *www. siderurgia.org.ar/semiaceria/anuncio–eng.htm*.

Current Problems in Welding and Life of Structures. November 24–26, Kiev, Ukraine. Sponsored by the National Academy of Sciences (NAS) of Ukraine, Ministry of Education and Science of Ukraine, E. O. Paton Electric Welding Institute of the NAS of Ukraine, the Interstate Scientific Council on Welding and Related Technologies, International Association of Welding. Contact: Organizing Committee, 11, Bozhenko str., Kiev, 03680, Ukraine, 380-44 227-67-57, FAX: 380-44 268-04-86; e-mail: *office@paton.kiev.ua*; *www.nas.gov.ua/pwj*.

Educational Opportunities

Lincoln Electric Welding Design Seminars. Blodgett's Design of Welded Structures, September 16–18; Fracture and Fatigue Control in Structures, October 28–30; and Blodgett's Design of Welded Structures, November 11–13. Seminars are led by Lincoln Electric Senior Design Consultant Omer W. Blodgett and Duane K. Miller and conducted by an additional team of experts. Each seminar has an equivalent value of 2.0 CEUs and the tuition for each is $595. To register or for futher information, contact The Lincoln Electric Comany, attn: Registrar, Professional Programs, 22801 St. Clair Ave., Cleveland, OH 44117-1199, (216) 383-2240, FAX: (216) 383-8025, Web site: *www.lincolnelectric.com/knowledge/training/seminars/professional.asp*.

Fundamentals of Corrosion and Its Control. July 16–19, LaQue Center for Corrosion Technology, Wrightsville Beach, N.C. LaQue Center for Corrosion Technology Inc., 702 Causeway Dr., P.O. Box 656, Wrightsville Beach, NC 28480, (910) 256-2271, FAX: (910) 256-9816, e-mail: *info@laque.com*; *www.laque.com*.

Pipeline Process Solutions. September 30–October 2, The Lincoln Electric Co., Cleveland, Ohio. This seminar covers the latest pipeline welding technologies and consumables. Contact: (216) 383-4718; *www.lincolnelectric.com*.

EPRI NDE Training Seminars. EPRI offers NDE technical skills training in Visual Examination, Ultrasonic Examination, ASME Section XI, UT Operator Training, and more. For specific information, contact Sherryl Stogner, (704) 547-6174, e-mail: *sstogner @epri.com*.

Victor 2003 Training Seminars. Victor Equipment Co. will be conducting training programs for gas apparatus and service repair technicians, end users, and sales personnel in 2003. For a complete schedule, contact: Aaron Flippen, (940) 381-1217; *www.victorequip.com*.

The Fabricators & Manufacturers Association, International (FMA), and the Tube and Pipe Association, International (TPA) Courses. A course schedule is available by calling (815) 399-8775; e-mail: *info@fmametalfab.org*; *www.fmametalfab.org*.

Malcom Plastic Welding School. A comprehensive two-day, hands-on course that leads to certification in accordance with the latest European DVS-approved plastic welding standards for hot gas and extrusion welding techniques. Contact: Sheila Carpenter, Administration, Malcom Hot Air Systems, 1676 E. Main Rd., Portsmouth, RI 02871, (888) 807-4030, FAX: (401) 682-1904, e-mail: *info@malcom.com*; *www.plasticweldingtools.com*.

Hellier NDT Courses. A course schedule is available from Hellier, 277 W. Main St., Ste. 2, Niantic, CT 06357, (860) 739-8950, FAX: (860) 739-6732.

Shielded Metal Arc Welding of 2-In. Pipe in the 6G Position — Uphill. Hobart Institute of Welding Technology, Troy, Ohio. This course is designed to develop welding skills necessary to produce quality multipass welds on 2-in.-diameter, schedule 160 mild steel pipe (0.436-in. wall thickness) in the 6G position using E6010 and E7018 electrodes. For further information, contact: Hobart Institute of Welding Technology, 400 Trade Square East, Troy, OH 45373, (800) 332-9448, FAX: (937) 332-5200; *www.welding.org*.

2003 Motor Sports Welding School. Classes are scheduled at

Lincoln Electric headquarters in Cleveland, Ohio. For more information and a complete schedule, contact: Lincoln Electric Motor Sports Welding School, 22801 St. Clair Ave., Cleveland, OH 44117, (216) 383-2461, FAX: (216) 383-8088, e-mail: *lori_bollas@lincolnelectric.com*; *www.lincolnelectric.com*.

Boiler and Pressure Vessel Inspectors Training Courses and Seminars. Courses and seminars cover such topics as ASME Code Sections I, IV, V, VIII (Division 1), IX, and B31.1; Writing Welding Procedures; Repairing Pressure Relief Valves; Understanding How Boilers and Pressure Vessels Are Constructed and Inspected; and more. To obtain a 2003 schedule of training courses and seminars conducted by the National Board of Boiler and Pressure Vessel Inspectors at its Training and Conference Center in Columbus, Ohio, contact: Richard McGuire, Manager of Training, (614) 888-8320, e-mail: *rmcguire@nationalboard.org*; *www.nationalboard.org*.

Welding Skills Training Courses. Courses include weldability of ferrous and nonferrous metals, arc welding inspection and quality control, preparation for recertification of CWIs, and others. For a complete schedule, contact: Hobart Institute of Welding Technology, 400 Trade Square E., Troy, OH 45373, (800) 332-9448 or, outside the U.S., (937) 332-5000, FAX: (937) 332-5200; *www.welding.org*.

Structural Welding: Design and Specification Seminars. Conducted by the Steel Structures Technology Center (SSTC). For 2003 schedule and locations, contact: SSTC, (248) 344-2910, FAX: (248) 344-2911; *www.steelstructures.com*.

Machine Safeguarding Seminars. Conducted by Rockford Systems, Inc. For schedule and more information, contact: Rockford Systems, P.O. Box 5525, Rockford, IL 61125, (800) 922-7533 or, outside the U.S., (815) 874-7891, FAX: (815) 874-6144; *www.rockfordsystems.com*.

ASME International — Section IX Welding Guide. Course #ZCD996. Introduction and review of Section IX welding information including welding documentation forms, review of Articles I and IV, sample WPS and review; sample PQR and review; testing and examination requirements for performance qualification; and other issues relating to Section IX. For information, visit *www.asme.org/pro_dev*.

AWS International Schedule — CWI/CWE Prep Courses and Exams

CWI Training: November 3–7;
Examination: November 8
Location: DALUS, S.A., Monterrey, N.L.
Contact: Lorena Garza
Telephone: 52 (81) 8386 4780
E-mail: *info@dalus.com*

Educational Opportunities

AWS Schedule — CWI/CWE Prep Courses and Exams

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
Anchorage, Alaska	September 7–12 (API 1104 Clinic also offered)	September 13
Baton Rouge, La.	July 13–18 (API 1104 Clinic also offered)	July 19
Charlotte, N.C.	August 24–29 (API 1104 Clinic also offered)	August 30
Columbus, Ohio	August 4–8 (API 1104 Clinic also offered)	August 9
Dallas, Tex.	September 21–26 (API 1104 Clinic also offered)	September 27
Houston, Tex.	August 17–22 (API 1104 Clinic also offered)	August 23
Houston, Tex.	September 15–20 9-YEAR RECERTIFICATION COURSE	
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 9-YEAR RECERTIFICATION COURSE	
Long Beach, Calif.	EXAM ONLY	July 26
Memphis, Tenn.	August 10–15 (API 1104 Clinic also offered)	August 16
Miami, Fla.	EXAM ONLY	July 17
Miami, Fla.	EXAM ONLY	August 14
Miami, Fla.	EXAM ONLY	September 18
Minneapolis, Minn.	September 14–19 (API 1104 Clinic also offered)	September 20
Mobile, Ala.	EXAM ONLY	July 19
New Orleans, La.	September 7–12 (API 1104 Clinic also offered)	September 13
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.	October 19–24 (API 1104 Clinic also offered)	October 25
Rochester, N.Y.	August 24–29 (API 1104 Clinic also offered)	August 30
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
San Diego, Calif.	September 14–19 (API 1104 Clinic also offered)	September 20
Seattle, Wash.	July 27–August 1 (API 1104 Clinic also offered)	August 2

BY SUSAN CAMPBELL

VOLUME 82 • NUMBER 7• JULY 2003

TransAlaska Pipeline Declared an Outstanding Development in Welded Fabrication

Presenting the AWS Outstanding Development in Welded Fabrication Award to Alyeska Pipeline Service Company Sr. Welding Engineer Alan Beckett, left center, and Vice President of Engineering and Projects Lee Monthei, right center, are AWS District 19 Director Philip Zammit, left, and Alaska Section Chairman Bruce Weisman.

Only two weeks after the fourth-largest earthquake in recorded history tested the structural design and the welds of the TransAlaska Pipeline, employees and guests of the Alyeska Pipeline Service Company gathered together at the Westmark Hotel in Fairbanks to celebrate the pipeline's 25th anniversary and its designation by the American Welding Society (AWS) as an Outstanding Development in Welded Fabrication.

"The pipeline's reliability, even when severely tested by a 7.9 earthquake, is a significant testimony to the outstanding technological advances achieved in welding. It also reaffirms the accomplishments of [those] that welded this Arctic pipeline," said Senior Welding Engineer Alan Beckett while accepting the award.

The plaque, which will be displayed in a visitor's center near the pipeline, was presented by Phil Zammit, AWS District 19 director, and Bruce Weisman, chairman of the AWS Alaska Section, and accepted by Beckett and Lee Monthei, vice president of engineering and projects, on behalf of Alyeska Pipeline Service Company, the organization responsible for the operation and maintenance of the pipeline.

Construction of the TransAlaska Pipeline was completed in May 1977 and the first of more than 13 billion barrels of oil began to move through the 800 miles of pipeline on June 20, 1977.

TransAlaska Pipeline Quick Facts

- The TransAlaska Pipeline System was designed and constructed to move oil from the North Slope of Alaska to the northernmost ice-free port — Valdez, Alaska.
- Length: 800 miles.
- Diameter: 48 inches.
- Crosses three mountain ranges and more than 800 rivers and streams.
- Cost to build: $8 billion in 1977, largest privately funded construction project at that time.
- Construction began on March 27, 1975, and was completed on May 31, 1977.
- First oil moved through the pipeline on June 20, 1977.
- More than 13 billion barrels have moved through the TransAlaska Pipeline System.
- First tanker to carry crude oil from Valdez: ARCO Juneau, August 1, 1977.
- Tankers loaded at Valdez: 16,781 through March 2001.
- Storage tanks in Valdez: 18 with total storage capacity of 9.1 million barrels.
- The mission of Alyeska's Ship Escort Response Vessel System is to safely escort tankers through Prince William Sound.
- 52 mainline girth welds.
- 66,000 manual welds.
- 42,000 automatic double-joint welds.

The Outstanding Development in Welded Fabrication Award

The award is part of the AWS Extraordinary Welding Awards program, which also includes the AWS Historical Welded Structure Award. The Outstanding Development in Welded Fabrication Award is presented to structures that symbolize advanced engineering and welding technology. The Historical Welded Structure Award honors structures at least 35 years old that have had a significant impact on history. Extraordinary Welding Awards can be nominated by any AWS member for consideration by the Past Presidents Committee.

To nominate a structure, ship, bridge, or other feat of engineering that has led to advances in welding design and processes, please contact AWS Communications/Public Relations Manager Amy Nathan at the American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126, telephone (800) 443-9353 ext. 308, outside the U.S. dial (305)

Errata for AWS Specifications

The following errata items apply to ANSI/AWS A5.16-90, *Specification for Titanium and Titanium Alloy Welding Electrodes and Rods*; ANSI/AWS A5.2-92, *Specification for Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding*; ANSI/AWS A5.24-90, *Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods*; ANSI/AWS A5.28-96, *Specification for Low Alloy Electrodes for Gas Shielded Metal Arc Welding*. The table number is followed in parentheses by the Code page number and any other information needed.

Errata for ANSI/AWS A5.2-92, *Specification for Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding*

Table 4 (page 4) - Change the first entry under the fourth column (Mn) to "0.50" in place of "0.05."

Errata for ANSI/AWS A5.16-90, *Specification for Titanium and Titanium Alloy Welding Electrodes and Rods*

Table 1 (page 2) - For ERTi-12 under "Oxygen," change "0.25" to "0.12."

Errata for ANSI/AWS A5.24-90, *Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods*

Table 1 (page 2) - In the seventh column, under "Oxygen," change all three entries from "0.16" to "0.016."

Errata for ANSI/AWS A5.28-96, *Specification for Low Alloy Electrodes for Gas Shielded Metal Arc Welding*

Table 3 (page 4) - The shielding gas for the ER90S-B9 is incorrectly shown as "Argon/5% O_2," correct to "Argon5% CO_2," which is the gas shown throughout the approval process.

Errata for Welding Journal

The following errata item applies to the article "Welding Stainless Steel Piping with No Backing Gas," by Barry Messer, Greg Lawrence, Vasile Oprea, Charles Patrick, and Terry Phillips in the December 2002 *Welding Journal*.

Figure 2 (page 33) - The images for Fig. 2A and Fig. 2B have been reversed. Image "A" shows the weld root pass without backing gas and "B" shows the weld root pass with backing gas.

Table 3 (page 33) - The 364 MPa tensile test value shown for the testing performed without backing gas is incorrect, the correct value should be 560 MPA. ♦

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.

August 5–6, B4 Committee on Mechanical Testing of Welds. Chantilly, Va. Standards preparation meeting. Staff contact: A. Davis, ext. 466.

August 14–15, Technical Activities Committee. Columbus, Ohio. General Meeting. Staff contact: L. Connor, ext. 302. ♦

Standards Notices

Standards for Public Review

***AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require all standards be open to public review for comment during the approval process. This column alsa advises of ANSI approval of documents. The following standards are submitted for public review. A draft copy may be obtained by contacting Rosalinda O'Neill at AWS, Technical Services Business Unit, 550 NW LeJeune Rd., Minmi, Fl 33126; (800/305) 443-9353, ext. 451, e-mail:* roneill@aws.org.**

C5.10/C5.10M:200X, *Recommended Practices for Shielding Gases for Welding and Cutting*. Revised standard. $17.50. [ANSI Public Review Expires July 22, 2003.]

New Standard Approved by ANSI

B5.1:2003, *Specification for the Qualification of Welding Inspectors*. Approval date: April 29, 2003. ♦

District 18 Director Presents Awards

The District Director Award provides a means for District Directors to recognize individuals who have contributed their time and effort to the affairs of their local Section and/or District.

District 18 Director **John L. Mendoza** has nominated the following with this award for 2002–2003.

Tommy Campbell
Corpus Christi

Morris Weeks
Mark Clark
Sabine

Jimmy Veillon
Nicholette Savoy
Lake Charles

Dan Jones
Dave Mason
Asif Latif
Kim Smith
Houston

Frances Guerrero
Nora Mendoza
Juseph Guerrero
Judy Lynn
San Antonio

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
telephone: (800) 443-9353, ext. 244
e-mail: *campbell@aws.org*

American Welding Society Memorial Resolution

The AWS board of directors has moved to honor the memory of **Dr. Nelson C. Wall**, AWS deputy executive director emeritus, by placing a memorial resolution in the permanent records of the Society. His contribution to the Society shall be missed.

The AWS board of directors observes with deep regret the death of former AWS Deputy Executive Director Dr. Nelson C. Wall on May 12, 2003.

Nelson C. Wall

Dr. Nelson C. Wall joined the staff of the American Welding Society in 1981 as director of education. In 1985, Dr. Wall was named to the position of deputy executive director. He retired from the American Welding Society on October 31, 1996.

Dr. Wall received a B.S. degree in mechanical engineering from the Georgia Institute of Technology and a doctorate in political science from Universidad de La Habana, Havana, Cuba.

Dr. Wall served as AWS international program manager for many years and, as a representative of AWS, was responsible for many of the International Agreements of Cooperation that AWS shares with societies around the world. He was also instrumental in the formulation of the AWS S.E.N.S.E. program.

In recognition of the many contributions of Dr. Nelson C. Wall to the Society, the board of directors wishes to record the following:

WHEREAS, the American Welding Society sustained an irreplaceable loss with the death of former Deputy Executive Director Dr. Nelson C. Wall, and

WHEREAS, Dr. Nelson C. Wall served the Society and the welding industry honorably, opening new pathways of communication and cooperation with both national and international sister societies, and

WHEREAS, Dr. Nelson C. Wall served the Society and its members with honor, dignity, and distinction, therefore

BE IT RESOLVED that the American Welding Society board of directors, in the special meeting held May 19, 2003, records its sorrow at the loss of a valued associate and expresses its appreciation for the many contributions, years of service, and loyalty of Dr. Nelson C. Wall, and

BE IT FURTHER RESOLVED that these resolutions be placed in the permanent records of the American Welding Society and that a copy be presented to his wife, Cary. ♦

AWS and Germany's DVS Sign Cooperative Agreement

Dr. Detlef von Hofe, executive director of DVS (the German Welding Society), right, and American Welding Society President Ernest Levert signing an International Cooperative Agreement betweeen the two societies during Levert's visit to DVS's headquarters in Dusseldorf, Germany, on April 23.

District 15 Director Presents Awards

The District Director Award provides a means for District Directors to recognize individuals who have contributed their time and effort to the affairs of their local Section and/or District.

District 15 Director **Jack D. Heikkinen** has nominated the following with this award for 2002-03.

Joel Johnson
Ralph Williams
Tim Schwanz
John Cox
Blake English
Mick Tronson
Jessie Hopewell
Dave Lynnes
Northern Plains

Thomas Baldwin
Loren J. Kanfola
Arrowhead

John R. Pennaz
Mace Harris
Dale Szabla
Tom Laberfa
Mark Sandvig
Northwest

The ASNT Signs Transitioning Agreement with AWS for CWIs and SCWIs

The American Society for Nondestructive Testing (ASNT) and AWS signed an agreement, effective May 28, 2003, permitting Certified Welding Inspectors (CWIs) and Senior Certified Welding Inspectors (SCWIs) to transition to the ASNT Central Certification Program (ACCP) without additional examination. All AWS Certified Welding Inspectors and Senior Certified Welding Inspectors holding valid certificates are eligible to apply for transitioning through the September 30 application deadline.

The ASNT Central Certification Program provides visual inspection certification in accordance with ASNT *Recommended Practice No. SNT-TC-1A*. It is the most widely referenced NDT program document and is specified in codes worldwide, most notably by ASME. Significantly, the ACCP certificate permits the holder to work under numerous codes, standards, and specifications.

Certified Welding Inspectors and SCWIs who transition will be issued ACCP VT Level II in the Visual Testing for the Direct Visual Inspection technique under the ACCP General Industry (GI) Sector. A Remote technique may be applied for as well. The Remote technique covers fiber optics, borescopes, and computer-assisted and other remote viewing equipment. To add the technique, applicants must provide additional documentation. The GI Sector is for personnel performing general inspection tasks in multiple industries.

If they can satisfy additional requirements, CWIs and SCWIs can apply for Level II certification in the ACCP Pressure Equipment (PE) Sector. The PE Sector is designed for those personnel that have documented experience in pressure-related work.

Prior to approving the AWS programs for transitioning, the ASNT Certification Management Council (CMC) did a thorough review of the requirements for CWI and SCWI certification. The CMC determined that the CWI experience and examination requirements satisfy the requirements of the ACCP for VT Level II in the Direct viewing test technique. It was determined that the SCWI examinations did not cover the full scope of the Basic and Method tests that are a required part of the ACCP Level III certification requirements; however, SCWIs are eligible to transition to ACCP VT Level II.

The cost for transitioning, regardless of type of certification, is $150, which must be submitted with the completed application by the Septmber 30 application deadline.

Applicants must complete an ACCP transitioning application, submit a copy of current CWI or SCWI certificate, and a valid vision test. The ACCP requires that the vision test document the applicant's ability to read a Jaeger J-1 text.

All successful applicants will receive certification as an ACCP VT Level II in the Direct testing technique. Those applicants applying for the additional Remote technique must document experience with remote viewing equipment and have their employer attest to that experience as well.

Applications and more information may be found at the ASNT Web site at *www.asnt.org/certification/accp/transition.htm*.♦

SECTION NEWS

ABC Disposal Service Plant Manager Chris Ross, center, showing Central Massachusetts/Rhode Island Section members a grate through which materials to be hardfaced are crushed.

DISTRICT 1

Director: Russell L. Norris
Phone: (800) 559-9353

MAINE

OCTOBER 12, 2002
Speaker: **Jim Reid**, stainless welding technician.
Affiliation: Consultant to Red Hook Brewing.
Topic: The use of stainless steel in the modern brewing process.

CENTRAL MASSACHUSETTS/ RHODE ISLAND

FEBRUARY 22
Speaker: **Chris Ross**, plant manager and foreman.
Affiliation: ABC Disposal Service.
Topic: Operation of materials recycling.

MARCH 20
Speakers: **Bruce Richardson** and **Jim Harrington**.
Affiliation: ABC Testing.
Activity: Certification Night was held at Old Colony Regional Vocational Technical High School.
Activity: Members took a welding test to become certified under the Massachusetts Highway Department using AWS D1.5, *Bridge Welding Code*.

GREEN & WHITE MOUNTAINS

MARCH 2
Activity: The Section organized and operated the Vermont SkillsUSA Weld Trials. Ten students competed in the contest.

Stopping for a photograph are six of the ten student competitors in the Vermont SkillsUSA weld trials held by the Green & White Mountains Section.

Central Massachusetts/Rhode Island Section member Steve St. John, left, observing George Bumiha, Jr., taking his 3-G test.

From left at the Boston Section's May tour of the Iron Workers Local #7 training facility are Section Chairman Tom Free, Larry Harganon, guest speaker Steve Flowers, and Tom Frazier.

CONNECTICUT

MARCH 11
Speaker: **John Gullotti**, principal welding engineer.
Affiliation: Electric Boat Division, General Dynamics Corp., Groton, Conn.
Topic: Welding process and filler metal selection.
Activity: This was a joint meeting with the ASM Hartford Chapter.

BOSTON

MAY 12
Speakers: **Steve Flowers**, welding instructor and member of Iron Workers Local #7, and **Brendan McLellan**.
Affiliation: Southeast Regional Vocational High School, South Easton,

Mass., and The Lincoln Electric Co.
Topic: McLellan gave a slide presentation on self-shielded FCAW electrodes.
Activity: Flowers guided members on a tour of Local #7's state-of-the-art training facility.

DISTRICT 2

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

READING

MARCH 5
Speaker: **Bob Sommer.**
Affiliation: The Lincoln Electric Co., Philadelphia, Pa.
Topic: Controlling weld distortion.
Activity: This was the first session of the Section's Welding Seminar.

MARCH 12
Speakers: **Roger Bushey** and **Jerry Doherty.**
Affiliation: ESAB Group, Hanover, Pa.
Topic: Maintenance welding and cast-iron repair.
Activity: Session two of the Section's Welding Seminar.

MARCH 15
Activity: The Section held its Annual Vo-Tech Welding Contest at Lancaster County Career and Technical Center. Twenty-six students participated. Acting as judges for the contest were **Dave Hibshman**, **Gene Henry**, **Dave Ochs**, and **Frank Roberts**.

MARCH 19
Speaker: **Dave Colwell**, senior technical representative and AWS CWI.
Affiliation: J. W. Harris Co., Inc., Mason, Ohio.
Topic: Soldering and brazing.
Activity: The Section held the third session of its Welding Seminar.

APRIL 17
Speaker: **George Bottenfield,** District 3 Deputy Director and York-Central Pennsylvania Section chairman.

Guest speaker Bill Campbell, seated at center, and members of the New York Section.

NEW YORK

MARCH 18
Speaker: **Bill Campbell**, welding instructor.
Affiliation: New York District Council of Carpenters Technical College.
Activity: Hands-on welding demonstrations.

DISTRICT 3

Director: Alan J. Badeaux, Sr.
Phone: (301) 449-4800, ext. 286

Jerry Doherty demonstrating the proper technique of repair welding on cast iron at the second session of the Reading Section's Welding Seminar.

Reading Section Treasurer and Foundation Representative Dave Hibshman, left, presenting David Butkis with a Section scholarship.

Guest Speaker Dave Colwell, second from left, during his presentation at the Reading Section's third session of its Welding Seminar.

Reading Section Treasurer and Seminar Chairman Dave Hibshman, left, presenting a speaker's gift to Bob Sommer.

Reading Section members and students at the Section's Annual Vo-Tech Welding Contest. Holding the banner is welding instructor John Boyer.

South Carolina Section Chairman Gale Mole, left, with guest speaker Dave Lackey at the Section's April meeting.

Reading Section Chairman John Miller, right, presenting District 3 Deputy Director George Bottenfield with a speaker's gift.

Attending the Southwest Virginia Section's April meeting are, from left, Incoming District 4 Director Ted Alberts, guest speaker David McQuaid, and Incoming Chairman Bill Rhodes.

New River Valley Plant Technical Leader Wayne Johnson, left, accepting an Appreciation Plaque from Southwest Virginia Section Secretary Bill Rhodes.

Affiliation: American Welding Society.
Activity: The Section presented District 3 Director Awards and **David Butkus** received a $500 scholarship toward his expenses at the Hobart Institute of Welding. **Merrie Butkus** received the Exemplary Service Award for her dedication to the Section.

DISTRICT 4

Director: Ted Alberts
Phone: (540) 674-3600, ext. 4314

SOUTHWEST VIRGINIA

April 23
Speaker: **David L. McQuaid.**
Affiliation: D. L. McQuaid and Associates.
Topic: The Northridge earthquake.

May 15
Activity: Members toured the New River Valley Plant, which produces both Volvo and Mack road tractors.

DISTRICT 5

Director: Wayne J. Engeron
Phone: (404) 501-9185

SOUTH CAROLINA

April 17
Speaker: **Dave Lackey**, district manager.
Affiliation: The Lincoln Electric Co., Charlotte, N.C.
Topic: The importance of AWS Certified Welding Inspector credentials.

DISTRICT 6

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

DISTRICT 7

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

COLUMBUS

April 17
Speaker: **Jerry Van Meter**, product development engineer.

Columbus Section Chairman John Lawmon, center right, presenting the Section's Welding Helmet Clock to guest speaker Jerry Van Meter, center left.

Columbus Section Chairman John Lawmon, with his Distinguished Service Award and friends, during the May meeting.

Patrick Gootee, president of Gootee Construction, left, and New Orleans Section Chairman Lenis Doiron, center, presenting a host's plaque to Gootee Construction Vice President Dwayne Hammer.

Showing off some of the prize-winning redfish at the New Orleans Redfish and Speckled Trout Rodeo are, from left, Vincent Todaro, Sr., Rodeo Chairman Mike Skilea, and Vincent Todaro, Jr.

Affiliation: Nippert Co.
Activity: Members toured the two Nippert Company plants in Delaware, Ohio.

MAY 8
Speaker: **John Lawmon**, chairman.
Affiliation: AWS Columbus Section.
Activity: Members voted on officers for the 2003–2004 year and discussed possible meeting topics and plant tours. Lawmon was presented with a Distinguished Service Award.

DISTRICT 8

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

NASHVILLE

MAY 3
Activity: The Section held its annual picnic at Long Hunter State Park. Scholarships were presented to students from the Tennessee Technology Center at Crossville.

CHATTANOOGA

MAY
Activity: **Josh Harvey**, the first place winner in the secondary school category of the Tennessee SkillsUSA welding contest, and his instructor, **Dave Hamilton**, spoke to members.

DISTRICT 9

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

NEW ORLEANS

APRIL 15
Activity: Section members toured the Gootee Construction facility and viewed demonstrations of orbital welding. **Emile Miller** won the night's 50/50 drawing.

MAY 3
Activity: The Section held its Annual Redfish and Speckled Trout Rodeo. The

New Orleans Redfish and Speckled Trout Rodeo Chairman Mike Skiles, left, with Rodeo Weight Master Ivy Bernard, right, and first place speckled trout winner Butsie Duhon, left center, and first place redfish winner Bluir Duhon, right center.

winners in the redfish category were **Blair Duhon** in first place with 8.3 lb, **Vincent Todaro, Jr.**, in second with 6.9 lb, **Ken Ashworth** in third with 6.3 lb, and **Butsie Duhon** in fourth with 6.1 lb. Vincent Todaro, Jr., won the Redfish Calcutta with 27.1 lb. Winners in the speckled trout category were Butsie Duhon in first place with 3.4 lb, **Sherman Sanchez** in second with 2.9 lb, and **Blair Duhon** and **Raymond Birdsall** in a tie for third place with 2.4 lb each. Butsie Duhon won the Speckled Trout Calcutta with 11.6 lb. Corporate sponsors of the event were ConocoPhillips – Alliance Refinery; Owensby and Kritikos, Inc.; and Inspection Specialists. Proceeds from the event benefit the Section's scholarship fund.

MOBILE

APRIL 17
Speaker: **Jackie Morris**, QA manager.
Affiliation: Bender Shipbuilding and

The ConocoPhillips fishing team at the New Orleans Redfish and Speckled Trout Rodeo. ConocoPhillips is the Section's first Titanium Sponsor for the event.

Mobile Section Treasurer Eleanor Ezell presenting a speaker's plaque to Jackie Morris.

District 9 Director John Bruskotter, left, presenting the Section Meritorious Award to Pascagoula Section Chairman Darren Haas.

Pascagoula Section Chairman Darren Haas, right, presenting a speaker's plaque to Bill Stone.

Repair Co., Mobile, Ala.
Activity: Members toured Bender Shipbuilding and Repair Co.'s laser shop and panel line.

PASCAGOULA
April 22
Speaker: **Bill Stone**, welding inspector.
Affiliation: Halter Marine, Moss Point, Miss.
Topic: Welding inspections.
Activity: **Gerald Shepard** received the Distinguished Service Award, and **Darren Haas** was presented with the Section Meritorious Award.

Student participants in the Birmingham Section's Secondary School Welding Competition pose for a photograph.

BIRMINGHAM
May 3
Activity: The Section held the Secondary School Welding Competition at Bessemer State Technical College. Eighteen students participated from four high school welding programs. Students were required to fabricate a weldment and perform SMA, GMA, and/or FCA welding. Winners received a scholarship for Bessemer State's welding technology program.

DISTRICT 10
Director: Victor Y. Matthews
Phone: (216) 383-2638

DISTRICT 11
Director: Eftihios Siradakis
Phone: (989) 894-4101

WESTERN MICHIGAN
April 22
Activity: District 11 held its Annual Quiz the Experts Night. The night was hosted by the Western Michigan Section. Members of the Western and Central Michigan Sections and the Ferris State University Student Chapter attended the event.

May 19
Activity: Members toured the Western Michigan Fifth Third Ballpark in Comstock Park, Mich. The tour included the inside of the ballpark, the clubhouse, luxury suites, and the press boxes.

AWS President Ernest Levert, left, congratulating Michael Karagoulis, center, upon District 11 Director Scott Chapple's presentation of the District Meritorious Award.

NORTHWEST OHIO
May 8
Speaker: **Richard West**, chairman.
Affiliation: AWS Northwest Ohio Section.
Topic: Highs and lows of the past year's meetings and meeting topics for the 2003–2004 year.

DETROIT
May 2
Activity: More than 700 members and guests of the Section took part in its annual Ladies' Night celebration at Detroit's Cobo Conference/Exhibition Center. AWS President **Ernest Levert** was on hand to assist District 11 Director **Scott Chapple** in awarding the District Meritorious Award to **Michael Karagoulis** for his efforts in chairing the Detroit Section's Sheet Metal Conferences 9, 10, and 11 (scheduled for May 2004). Proceeds from the event benefit the Section's scholarship fund.

Receiving scholarships from the Milwaukee Section are, from left, John Schneider, Steve Gapp, Kory Satka, Cheryl Wirkus, and Lonnie Czapiewski.

Inside the Lincoln Welding Garage at the Indianapolis 500 are, from left, St. Louis Section First Vice Chairman Kevin Corgan, Wyatt Swaim, Gay Cornel, Jeremy Nawyen, and Jerry Simpson. Cornel and Simpson are St. Louis Section members.

Fox Valley Section Chairman Sean Moran, left, presenting Dave Hoffman with the AWS District 12 Educator of the Year Award.

DISTRICT 12

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

MILWAUKEE

April 15

Speaker: **Richard Arn**, president and past AWS president.
Affiliation: WELDtech International.
Topic: Reclamation of steel and aluminum mill rolls.
Activity: This was a joint meeting with the ASM Milwaukee Chapter. Scholarships were awarded to **John Schneider** and **Steve Gapp** of Waukesha Community Technical College and **Kory Satka**, **Cheryl Wirkus**, and **Lonnie Czapiewski** of Milwaukee Area Technical College.

FOX VALLEY

April 17

Speakers and Affiliations: **Sean Moran**, **Eric Young**, and **Dennis Tiedt**, Miller Electric Mfg. Co.; **Dave Hoffman**, Fox Valley Technical College; **Tom Trieber**, Interstate Welding Supply; and **Scot Forbes**, Tech Aid.
Topic: Careers in welding, education options, and live welding and cutting demonstrations.
Activity: The Section held Student Night at the Fox Valley Technical College in Appleton, Wis. **Dave Hoffman** was presented with the AWS District 12 Educator of the Year Award.

DISTRICT 13

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

DISTRICT 14

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

Brandon Lester, left, accepting the first-place award in the state SkillsUSA Welding Contest from Lexington Section Chairman Frank McKinley.

ST. LOUIS

April 15

Activity: Members **Gay Cornel** and **Jerry Simpson** organized a chartered bus to take members to the Indianapolis 500 Time Trials. Despite being rained out, members still had a fun trip that included passes to Gasoline Alley and the Indy-500 Museum. **Wyatt Swaim** of High Tech Welding/Lincoln Electric and **Jeremy Nawyn** took members on a tour of the Lincoln Electric Welding Garage.

INDIANA

April 21

Speaker: **Bob Evans**, past chairman (1954).
Affiliation: AWS Indiana Section.
Topic: Personal experiences in the field of welding.
Activity: AWS Past President **Harry Prah** was awarded for 50 years of AWS membership.

The 2003-2004 AWS Member-Get-A-Member Campaign*

RECRUIT NEW MEMBERS... WIN GREAT PRIZES

A simple way to give back to your profession, strengthen AWS and win great prizes is by participating in the 2003-2004 Member-Get-A-Member Campaign. By recruiting new members to AWS, you're adding to the resources necessary to expand your benefits as an AWS Member. Plus, you become part of an exclusive group of AWS Members who get involved. Year round, you'll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is. Who better than you to encourage someone to join AWS?

AWS MEMBER BENEFITS CHECKLIST:

- Annual subscription to the *Welding Journal*.
- A 25% discount on hundreds of first-rate AWS technical publications and 140+ industry codes.
- Deep discounts on 120+ technical training events every year.
- Access to widely recognized AWS Certification programs.
- New Members can save nearly 90% off an AWS publication. Choose from four of our most popular titles (see reverse).
- AWS Membership Certificate and Card.
- Networking opportunities through local Section meetings, the AWS Welding Show and an on-line bulletin board on the AWS website at <www.aws.org>.
- Members'-only discounts on auto insurance, car rentals, credit cards and more.
- Connection to career opportunities through AWS JobFind – at www.aws.org/jobfind
- *The American Welder* section of the *WJ* geared toward front-line welders.
- And much more!

GET INVOLVED TODAY, AND WIN!

PRIZE CATEGORIES

President's Honor Roll:
Recruit 1-5 new Individual Members and receive a welding ball cap.

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 2004).

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 2005 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 a welding ball cap.

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 2003, as well as in February and June 2004.

Prizes Include:

- American Welder™ T-shirt
- one-page, black/white ad in the *Welding Journal*
- 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 2004 deadline will receive special recognition in the *Welding Journal*.

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

**The 2003-2004 MGM Campaign runs from June 1, 2003 to May 31, 2004. Prizes are awarded at the close of the campaign.*

American Welding Society
550 N.W. LeJeune Rd. • Miami, FL 33126
Visit our website http://www.aws.org

Lexington Section Chairman Frank McKinley with his wife, Mary.

LEXINGTON

APRIL 24
Speaker: **Bill Cross.**
Affiliation: Scot-Gross Welding.
Topic: Gases.
Activity: **Brandon Lester** received an award for taking first place in the state SkillsUSA Welding Contest. Chairman **Frank McKinley** was awarded with a three-day trip to the Smoky Mountains for his outstanding service to the Section for the past ten years.

DISTRICT 15

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

DISTRICT 16

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

DISTRICT 17

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

CENTRAL TEXAS

APRIL 22
Speaker: **Andy Divin.**
Affiliation: The Lincoln Electric Co.
Topic: Robotic welding.

DISTRICT 18

Director: John Mendoza
Phone: (210) 860-2592

HOUSTON

APRIL 28
Activity: The Section held its Annual Golf Outing. Eighty-three golfers participated in the event, which benefits the Section's scholarship fund.

Houston Section member and past District 18 Director Ron Thiess with Kim Smith, left, and Sarah Wood at the Houston Section's Annual Golf Outing.

Sabine Section members check out the World War II artillery piece on display at the Section's Annual Crawfish Boil.

Incoming Sabine Section Chairman Morris Weeks, right, presenting outgoing Chairman Carey Wesley with a chairman's pin and a Certificate of Appreciation.

SAN ANTONIO

MAY 13
Speaker: **Martin Landgraf.**
Affiliation: San Antonio Police Department.
Topic: Protection against identity theft.
Noted: Honorable Governor **Rick Perry** proclaimed April 2003 "Welding Month" in the state of Texas and Mayor **Edward Garza** proclaimed the same in San Antonio.

San Antonio Section members at the May meeting.

SABINE

MAY 20
Activity: The Section held its Annual Crawfish Boil at the Weeks Welding Labs in Nederland, Tex. Officers for the 2003–2004 year were voted in. Elected are **James Amy** as chairman; **Tom Holt**, first vice chairman; **Matthew Jowett**, second vice chairman; **Mark Clark**, secretary; **Ruel Riggs**, treasurer; and **Kim McKensie, Ken Sennett, David Morgan, Carey Wesley, Sudhanshu Ogale, Morris Weeks, Alton Wolf,** and **Pat Becker** as directors.

DISTRICT 19

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

Puget Sound Section guest speakers, from left, Steve Carter, Chris Sundberg, Steve Pollard, Blaine Maki at the Section's May meeting.

PUGET SOUND

MAY 9
Speakers and Affiliations: **Steve Carter,** PC & welding engineer, PRECOR; **Chris Sundberg,** PC and engineering manager, CH2M-Hill; **Steve Pollard,**

Attending the Lake Washington Technical College Welding Advisory Committee meeting from the Puget Sound Section are, front row from left, Jim Agnew, Steve Nielson, Steve Pollard, Chuck Daily, back row left to right, Ben Paves, Phil Proctor, Jerry Hope, Frank Drumm, Rick Forster, Ron Bart, Shawn McDaniel, and Dave Cunningham.

PC and engineering manager, M. Inc.; and **Blaine Maki**, manager, Metal Test, Inc.
Topic: Pros and cons of welding procedures specifications (WPSs) and PQRs.

MAY 15
Activity: Members of the Section's Welding Advisory Committee meeting met at Lake Washington Technical College. The committee requested two welding instructors for 7 to 15 students. Attending the meeting were **Jim Agnew, Steve Nielson, Steve Pollard, Chuck Daily, Ben Paves, Phil Proctor, Jerry Hope, Frank Drumm, Ron Bart, Shawn McDaniel**, and **Dave Cunningham. Rick Forster**, owner/manager of Rainier Welding, Inc., was presented with a Certificate of Appreciation by **Dave Cunningham**, dean of Lake Washington Technical College.

ALASKA

MAY 17
Activity: Section members enjoyed the Annual Picnic.
Activities: The Section awarded a $500 travel allowance and a one-year AWS membership to **Neal Miner**, winner of the state high school welding competition.

Officers for the 2003–2004 year are **Bruce Weisman**, chairman; **Dan Rogers**, first vice chairman; **Brian Walsh**, second vice chairman; **Bob McCauley**, treasurer; **Creighton Moore**, treasurer; and **Duane Goodrich, Jack Simpson**, and **Mark Wood** as members-at-large.

DISTRICT 20

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

DISTRICT 21

Director: Les Bennett
Phone: (805) 929-2356

DISTRICT 22

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

American Welder Gear Available on the AWS Web Site

The American Welding Society proudly introduces a new line of American Welder™ Gear. The line carries more than 60 products ranging from pens to apparel to watches. AWS members receive a 10% discount on purchases. To check out the full line of Gear, visit *www.aws.org/gear/* or call (800) 443-9353 to request a catalog. ♦

Kansas City Section Promotes Education

Kansas City Section member Dave Kopek, left, and Chairman Bob Worthington during their presentation to students at the Fifth Annual Middle School Design-Build Competition in March.

Recent studies conducted by the U.S. government show that the nation's construction force is dwindling and fewer high school and college students are interested; nor do they have the skills necessary to pursue this field as their career.

In order to combat this predicted shortage, many organizations across the United States. have begun to take action, primarily in the form of early education that targets young students to spark their interest. One such organization engaged in these activities is the Center for Construction Excellence (CCE) at the University of Missouri-Kansas City's (UMKC) School of Interdisciplinary Computing and Engineering.

The CCE exists to raise awareness of the construction industry for Missouri and Kansas students, from grade school to high school. The CCE emphasizes the importance of math, science, English, and technology and how each applies to the construction industry.

Putting their words into action, on March 4 the CCE, along with cosponsor Black & Veatch, held the Fifth Annual Middle School Design-Build Competition in Kansas City, Mo. More than 2400 students attended and demonstrated their skills.

The Kansas City AWS Section participated in order to promote and improve educational opportunities in welding for young people in Kansas and Missouri middle schools. ♦ — *Information provided by Bob Worthington, AWS Kansas City Section*

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***
J. Merzthal, *Peru***
B. A. Mikeska, *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.)

J. Compton, *San Fernando Valley* — 38
S. McGill, *Northeast Tennessee* — 20

President's Round Table

(AWS Members sponsoring 11–19 new Individual Members between June 1, 2002, and May 31, 2003.)

G. W. Taylor, *Pascagoula* — 15
G. Fairbanks, Jr., *Baton Rouge* — 13
E. Levert, *North Texas* — 13
T. Ferri, *Boston* — 11
J. Grantham, *Colorado* — 11

President's Club

(AWS members sponsoring 6–10 new Individual Members between June 1, 2002, and May 31, 2003.)

R. Purvis, *Sacramento* — 10
J. Hope, *Wyoming* — 9
B. McGuire, *East Texas* — 9
T. Fleckenstein, *North Texas* — 8
J. Hannahs, *Dayton* — 8
J. Scott, *Houston* — 8
M. Kincheloe, *Holston Valley* — 7
D. Wright, *Kansas City* — 7
C. Dynes, *Kern* — 6

President's Honor Roll

(AWS members sponsoring 1–5 new Individual Members between June 1, 2002, and May 31, 2003. Only those sponsoring 2 or more AWS Individual Members are listed.)

J. Carney, *Western Michigan* — 5
F. Luening, *Houston* — 5
T. Skaff, *LA/Inland Empire* — 5
R. Fontenot, *Oklahoma City* — 4
W. Galvery, Jr., *Long Bch./Orange Cnty.* — 4
S. Giese, *East Texas* — 4
G. Huegin, *Central Mass./R.I.* — 4
G. Baum, *Detroit* — 3
F. Brieden, *Lehigh Valley* — 3
R. Corsaro, *Niagara Frontier* — 3
R. Howard, *Louisville* — 3
F. Juckem, *Madison-Beloit* — 3
G. Mulee, *Rochester* — 3
G. O'Connor, *New Jersey* — 3
R. Robles, *Corpus Christi* — 3
J. Ruiz-Castro, *New Jersey* — 3
D. Scott, *Peoria* — 3
K. Tebeau, *Detroit* — 3
R. Tupta, *Milwaukee* — 3
C. Wesley, *NW Pennsylvania* — 3
P. Zammit, *Spokane* — 3
G. Atherton, *Philadelphia* — 2
J. Biegas, *Rochester* — 2
F. Bonifatti, *International* — 2
C. Casey, *Arizona* — 2
C. Daily, *Puget Sound* — 2
J. Dolfi, *Detroit* — 2
A. Duschere, *Long Island* — 2
T. Erichsen, *Santa Clara Valley* — 2
E. Ezell, *Mobile* — 2
M. Fedoruk, *Maryland* — 2
R. Fitch, *Southwest Virginia* — 2
N. Goel, *Long Island* — 2
S. Harville, *Mobile* — 2
J. Heinbigner, *Fox Valley* — 2
S. Hunt, *Shreveport* — 2
W. Kielhorn, *East Texas* — 2
F. Langs, *Central Mass./R.I.* — 2
L. Lenker, *Oklahoma City* — 2
D. Lockman, *Alaska* — 2
A. Lynch, *Pittsburgh* — 2
S. Mackenzie, *Northern Michigan* — 2
M. Marcum, *Johnny Appleseed* — 2
D. Moulton, *Saginaw Valley* — 2
F. Nguni, *New Jersey* — 2
J. Norrish, *International* — 2
M. Perry, *Tulsa* — 2
M. Powell, *Lehigh Valley* — 2
D. Roskiewich, *Philadelphia* — 2
R. Smith, *Tri-State* — 2
G. Spengler, *Chicago* — 2
R. Stobaugh, Jr., *Carolina* — 2
J. Wells, *Central Texas* — 2
B. Worley, *Dayton* — 2

Student Sponsors

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

D. Scott, *Peoria* — 130
C. Wesley, *Northwestern Pa.* — 62
W. Galvery, Jr., *Long Bch./Orange Cnty.* — 37
A. Lynch, *Pittsburgh* — 34
S. Caldera, *Portland* — 30
B. Huff, *Sangamon Valley* — 26
J. Sullivan, *Mobile* — 26
T. Geisler, *Pittsburgh* — 24
S. Siviski, *Maine* — 24
R. Grays, *Kern* — 23
D. Combs, *Santa Clara Valley* — 22
H. Browne, *New Jersey* — 21
R. Durham, *Cincinnati* — 21
F. Mong, *Pittsburgh* — 21
J. Cox, *Northern Plains* — 20
W. Harris, *Pascagoula* — 20
K. Langdon, *Johnny Appleseed* — 19
R. Boyer, *Nevada* — 18
G. Euliano, *Northwestern Pa.* — 18
G. Woomer, *Johnstown/Altoona* — 18
V. Hunter, *Blackhawk* — 17
D. Marks, *Lehigh Valley* — 17
R. Robles, *Corpus Christi* — 17
F. Juckem, *Madison-Beloit* — 16
W. Kielhorn, *East Texas* — 16
M. Anderson, *Indiana* — 15
J. Hayes, *Oklahoma City* — 15
R. Norris, *Maine* — 15
D. Roskiewich, *Philadelphia* — 15
F. Wernet, *Lehigh Valley* — 15
S. Zwilling, *Louisville* — 15
L. Davis, *New Orleans* — 14
R. Fulmer, *Twin Tiers* — 14
B. Lavallee, *Northern New York* — 14
E. Soto Ruiz, *Puerto Rico* — 14
D. Zabel, *Southeast Nebraska* — 13
A. Badeaux, *Washington, D.C.* — 12
A. DeMarco, *New Orleans* — 12
C. Kipp, *Lehigh Valley* — 11
F. Madrid, *Arizona* — 11
R. Shrewsbury, *Tri-State* — 11
R. Hilty, *Pittsburgh* — 10
T. Strickland, *Arizona* — 10
K. Geist, *Olympic* — 9
D. Hatfield, *Tulsa* — 9
S. Hoff, *Sangamon Valley* — 9
C. Jones, *Houston* — 9
D. Ketler, *Williamette Valley* — 9
J. Pelster, *Southeast Nebraska* — 9
M. Pointer, *Sierra Nevada* — 8
P. Walker, *Ozark* — 8
J. Livesay, *Nashville* — 7
R. Rux, *Wyoming* — 7
D. Smith, *Niagara Frontier* — 7
R. Tupta, *Milwaukee* — 7

— continued on page 74

Columbia Section Sponsors SkillsUSA Welding Contest

Florence Darlington Technical College hosted the South Carolina SkillsUSA/VICA State Welding Competition on March 7 and 8. The American Welding Society's Columbia Section was a major sponsor of the event. Pictured at the event are, from left, South Carolina SkillsUSA Welding Chairperson and Columbia Section Education Chairperson Sue Benton, third-place winner Melvin Jackson, second-place winner Shelly Matheson, and first-place winner Jeremy VanPut.

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, AWS, 550 NW LeJeune Rd., Miami, FL 33126; FAX: (305) 443-7404; e-mail: *campbell@aws.org*. ♦

2002–2003 Member-Get-A-Member Campaign

— continued from page 73

J. Boyer, *Lancaster* — 6
J. Ciaramitaro, *North Central Florida* — 6
A. Vidick, *Wyoming* — 6
R. Ledford, Jr., *Birmingham* — 5
J. Smith, *Mobile* — 5
P. Baldwin, *Peoria* — 4
T. Buchanan, *Mid-Ohio Valley* —4
A. Honegger, *LA/Inland Empire* — 4
T. Kienbaum, *Colorado* — 4
D. Kowalski, *Pittsburgh* — 4
G. Menser, *L.A./Inland Empire* — 4
E. Norman, *Ozark* — 4
D. Parker, *East Idaho/Montana* — 4
J. Smith, *Greater Huntsville* — 4
S. Strader, *Portland* — 4
J. Yochum, *South Florida* — 4
R. Brown, *L.A./Inland Empire* — 3
J. Compton, *San Fernando Valley* — 3
R. Felix, *Long Bch/Orange County* —3
L. Frechette, *San Francisco* — 3
J. Goodson, *New Orleans* — 3
J. Greer, *Chicago* — 3
R. Huston, *Olympic* — 3
M. Koehler, *Milwaukee* — 3
D. Marquis, *Ozark* — 3
A. Mattox, *Lexington* — 3
J. McCarty, *St. Louis* — 3
W. Miller, Jr., *New Jersey* — 3
F. Ramos, *Sacramento* — 3
M. Rice, *North Texas* — 3
H. Riviere, *South Florida* — 3
T. Shirk, *Tidewater* — 3
R. Vann, *South Carolina* — 3♦

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*. ♦

Sustaining Member Company

CESOL
Gabino Jimeno 5B
Madrid 28026 Spain
34-91-4758307
FAX: 34-91-5005377
e-mail: *cesol@cesol.es*
www.cesol.es

CESOL, the Spanish Association of Welding and Joining Technologies, is a nonprofit, independent association that serves welding and joining technologies and welcomes the participation of persons and firms interested in the objectives of the same.

The association's main activities are assessment; technical assistance; education, training, and qualification; standardization and certification; and information and publications. ♦

AWS Welcomes New Affiliate Member Companies

UMS Steel Fabricators, Inc.
P.O. Box 3455
Lantana, FL 33465

Carolina Industrial & Welding, Inc.
P.O. Box 508
Oak Island, NC 28465

Ind. Maint. Welding & Machining Co.
P.O. Box 385
Kingsbury, IN 46345

Beller Fabrication Corp.
66 N. Research Dr.
Pueblo West, CO 81007

JMF Precision Welding, Inc.
2415 Harvin Springs Cove
Dacula, GA 30019

Mag Welding, Inc.
925 S. 7th St.
Cousil Bluffs, IA 51501

Rescom Management, Inc.
P.O. Box 348
Washington, IN 47501

Van Win Corp.
N. 8980 Oneida Rd.
Menasha, WI 54952

AWS Welcomes New Supporting Companies

New Educational Institutions

Attleboro Vocational Technical High School
100 Rathbun Willard Dr.
Attleboro, MA 02703

Bristol-Plymouth Regional Technical High School
940 County St.
Taunton, MA 02780-3799

Champlain Valley Educational Services CV-TEC Division
1585 Military Turnpike
Plattsburgh, NY 12901

East Mississippi Community College
8731 S. Frontage Rd.
Mayhew, MS 39753

Northeast Metropolitan Regional Vocational High School
100 Hemluck Rd.
Wakefield, MA 01880

Texas A&M University Systems
Texas Engineering Extension Service
2002 South Wayside
Houston, TX 77023-3905

Welding Research Institute
Bharat Heavy Electrical Limited
Tiruchirappalli
Tamil Nadu 620 014
India

District 5 Director Presents Awards

The District Director Award provides a means for District Directors to recognize individuals who have contributed their time and effort to the affairs of their local Section and/or District.

District 5 Director **Wayne J. Engeron** has nominated the following with this award for 2002–2003.

Greg Engeron
Atlanta

Lee Clemens
Florida West Coast

Gregory Hofmann
North Central Florida

Bill Strate
North Florida

Gale Mole
South Carolina

Angel Castro
Puerto Rico

H. G. Riviere
South Florida

George Bower
Columbia

Srikanth Kottilingam
Florida Space Coast

Neil Prager
Palm Beach Section

AWS Membership

Member Grades	**As of June 1, 2003**
Sustaining Companies	424
Supporting Companies	204*
Educational Institutions	325
Affiliate Companies	122
Welding Distributor Companies	53
Total Corporate Members	**1,128**

**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	44,232
Student Members	4,182
Total Members	**48,414**

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
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Ray W. Shook. ....(210)

Deputy Executive Directors
Jeffrey R. Hufsey ....(264)
John J. McLaughlin ....(235)

Corporate Director Volunteer Services
Debbie A. Cadavid ....(222)

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

Chief Financial Officer
Frank R. Tarafa ....(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) 835-0243

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

WELDING EQUIPMENT MANUFACTURERS COMMITTEE
Associate Executive Director
Richard L. Alley ....(217)

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 Ospina...(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 Saltzstein ....(243)

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

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

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.

COMMUNICATIONS/PUBLIC RELATIONS
Manager
Amy Natban ....(308)

MARKET RESEARCH AND DEVELOPMENT
Corporate Director
Debrah C. Weir ....(482)

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

MEMBER SERVICES
Department Information ....(480)

Associate Executive Director
Cassie R. Burrell ....(253)

Director
Rhenda 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
Giselle I. Hufsey ....(278)

Responsible for national and local conferences/exhibitions and seminars on industry topics ranging from the basics to the leading edge of technology. Organizes CWI, SCWI, and other seminars designed for preparation for certification.

CERTIFICATION OPERATIONS
Managing Director
Wendy S. Reeve.......................................(215)

Director
Terry Perez...(470)

Information and application materials on certifying welders, welding inspectors, and educators.
....(273)

INTERNATIONAL BUSINESS DEVELOPMENT
Director
Walter Herrera ....(475)

AWS AWARDS, FELLOWS, AND COUNSELORS
Managing Director
Wendy S. Reeve.......................................(215)

Coordinates AWS awards and AWS Fellow and Counselor nominees.

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

Engineers
John L. Gayler ....(472)
Structural 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 ....(299)
Resistance Welding, High-Energy Beam Welding and Cutting, Oxyfuel 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 Jenney ....(304)
Definitions & Symbols, Brazing & Soldering, Filler Metals for Brazing and Braze Welding, Technical Editing

Senior Manager of Publications, Technical
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 particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

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 be frequently available to the National Office, and should be of executive status in business or industry with experience in financial affairs.

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

Interested 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. Arn, 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 contributions to the worldwide welding industry. This award should reflect "Service to the International Welding Community" in the broadest terms. The awardee is not required to be a member of the American Welding Society. Multiple awards can be given per year as the situation dictates. The award consists of a certificate to be presented at the award's luncheon or at another time as appropriate in conjunction with the AWS President's travel itinerary, and, if appropriate, a one-year membership to AWS.

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

TELEWELD
FAX: (305) 443-5951

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REPRINTS
To order custom reprints of articles in the *Welding Journal*, contact Denis Mulligan at (800) 259-0470

It is the intent of the American Welding Society to build the Society to the highest quality standards possible. We welcome any suggestions you may have.

Please contact any of the staff listed on the previous page or AWS President Thomas M. Mustaleski, BWXT Y-12 LLC, P.O. Box 2009, Oak Ridge, TN 37831-8096.

AWS MISSION STATEMENT

The mission of the American Welding Society is to provide quality products and services to our members and the industry which will advance the science, technology and application of materials-joining throughout the world.

AWS FOUNDATION, INC.
550 NW LeJeune Rd.
Miami, FL 33126
(305) 445-6628
(800) 443-9353, ext. 293
Or e-mail: *bobw@aws.org*
General Information
(800) 443-9353, ext. 689

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

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Magnetic Work Holding Tools Featured in Catalog

An eight-page catalog features a variety of magnetic chucks, vises, clamps, holders, grounds, and pickup tools for welding, metalworking, and parts handling.

Bunting Magnetics Co. 115
P.O. Box 468, Newton, KS 67114

Brochure Describes Handheld Ferrite Probe

The Ferritscope® MP30 is portrayed in a full-color, four-page brochure. Using magnetic induction, the LED-equipped handheld device measures ferrite content from 0 to 80% Fe (0–120 WRC number) in construction steels, welded claddings, austenitic stainless steels, and duplex steels.

Fischer Technology, Inc. 116
750 Marshall Phelps Rd., Windsor, CT 06095

Catalog Features Welding Reels

A variety of welding reels are described in catalog format. Products include power and manual rewind reels handling cables up to 400 A, as well as dual arc welding reels and welding gas hose reels.

Hannay Reels 117
553 State Rte. 143, Westerlo, NY 12193

Catalog Describes V-Twin Engines

The 16-page, full-color catalog includes Aegis 20- to 27-hp liquid-cooled V-twin engines. Both vertical- and horizontal-shaft models are included, with detailed photographs, blueprints, and performance specifications.

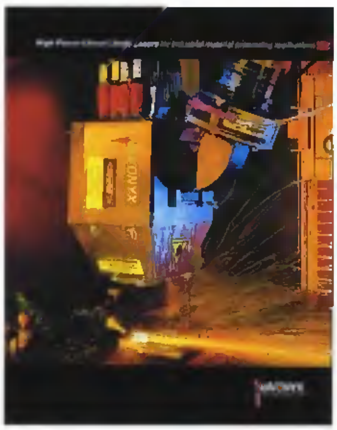
Kohler Engines 118
444 Highland Dr., Kohler, WI 53044

CD-ROM Presents Hardfacing Information

The third edition of a free interactive guide to hardfacing has been released. The *Express 3 CD* now includes stainless steel, nickel, and cobalt alloys, with a guide to their selection, cost calculations, and application tips.

Stoody Company 119
101 S. Hanley Rd., St. 600, St. Louis, MO 63105

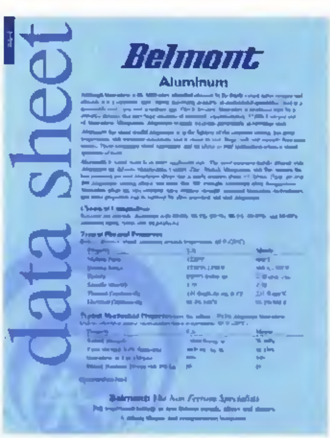
Brochure Describes Laser Applications



A full-color, four-page brochure outlines material processing applications of high-power, direct diode lasers, including welding, heat treating, cladding, brazing, metal bending, curing, and paint stripping.

Nuvonyx Inc. 120
3753 Pennridge Dr., Bridgeton, MO 63044

Aluminum Data Sheet Published



Data Sheet Al-1 describes the benefits and general applications of aluminum, as well as its mechanical, physical, and chemical properties. It also offers information on casting, melting, joining, fabricating, and available forms and shapes.

Belmont Metals Inc. 121
330 Belmont Ave., Brooklyn, NY 11207

Specifications Sheet for Welding Blanket Published

A color flyer describing Velvet Shield® welding blankets includes sizes and performance data on a fabric that can withstand temperatures up to 3000°F.

Steiner Industries 122
5801 N. Tripp Ave., Chicago, IL 60646

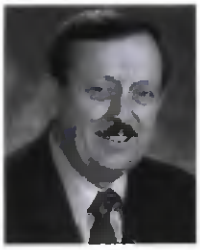
Industry Manual on Portable Pump Safety Available in Spanish

An illustrated manual on safe operation of submersible and motor-driven contractors' pumps at job sites has been translated into Spanish and published by a manufacturers' organization, in order to reduce injuries among Hispanic workers.

Association of Equipment Manufacturers 123
111 E. Wisconsin Ave., Ste. 1000, Milwaukee, WI 53202

— *continued on page 81*

Hobart Institute Names Scott to Board of Directors



Ron Scott

The Hobart Institute of Welding Technology has named **Ron Scott** to the board of directors. Scott has been with the institute since 1975 and currently serves as vice president and general manager. This appointment serves to provide the seven-member board with a balance shared by operating and nonoperating members.

ProMotion Controls Appoints CFO

ProMotion Controls Inc., Medina, Ohio, has appointed **John P. Neal** as chief financial officer for the company's western operations, including North America, Central America, and South America. Over the past two decades, Neal has founded several companies and organizations and has worked as part of several successful turnaround teams. Most recently, he formed CXO Associates. Neal holds a bachelor of science degree in accounting from San Diego State University.

Battelle Announces Executive Vice President

Battelle announced that **Bill Madia**, director of Oak Ridge National Laboratory (ORNL) for the past three years, will leave Oak Ridge and return to Battelle's world headquarters in Columbus, Ohio, as executive vice president of laboratory operations. Battelle and the University of Tennessee operate ORNL for the Department of Energy.

Madia began his Battelle career in 1975 as a nuclear chemistry researcher and has held numerous important positions including president of Battelle Technology International, general manager of the Battelle Project Management Division, director of Pacific Northwest National Laboratory, and director of ORNL. Madia, who in 1999 was named Laboratory Director of the Year by the Federal Laboratory Consortium, received his B.S. and M.S. degrees in chemistry from Indiana University of Pennsylvania and his Ph.D. in nuclear chemistry from Virginia Tech.

Bosch Rexroth Announces Leadership Changes

Steven D. Roberts

Bosch Rexroth Corp., Hoffman Estates, Ill., announced three changes in its leadership.

Steven D. Roberts was named senior vice president-corporate finance. Roberts joined the company as divisional controller in 1994. He most recently served as vice president and general manager of the Linear Motion and Assembly Technologies business unit.

Ernst Iseli assumed the role of vice president and general manager of the company's Linear Motion and Assembly Technologies business unit. Earlier this year, he was named vice president-marketing for the business unit and previously served as its director-sales and marketing.

Ernst Iseli

Bill Demuth

Bill Demuth was named director of controlling and administration. Demuth, who joined the company in 1998, will add human resources and overall commercial responsibility to his current role as division controller for the Linear Motion and Assembly Technologies business unit.

SAW Pipes Names General Manager

SAW Pipes, USA, Inc., has named **C. P. "Chuck" Woodruff** corporate general manager. In this position, Woodruff is responsible for the operations of the facility located in Baytown, Tex.

Magnatech Appoints Sales Manager

Don Brown

Don Brown [AWS] has joined Magnatech Limited Partnership, East Granby, Conn., as East Coast regional manager. Prior to joining Magnatech, Brown had spent three years in sales at Liburdi Dimetrics and ten years at Applied Energy Systems.

Steiner Industries Names Manager

Steiner Industries, Inc., Chicago, Ill., has named **Debbie Ralson-McHugh** sales and marketing manager responsible for the welding distribution market channel. Ralson-McHugh's previous experience includes 12 years with Singer Safety Company.

Lepel Appoints Sales Manager

Lepel Corp., Edgewood, N.Y., has announced the appointment of **Richard Detty** [AWS] to induction sales manager for its induction heating division. Detty brings to the position more than 20 years of induction heating experience. His previous employers include Lindberg/Cycle-Dyne and Ameritherm Inc. He is a member of the American Welding Society, Society of Manufacturing Engineers, and the American Society of Materials.

Obituaries

Nelson C. Wall

Nelson C. Wall

Nelsnn C. Wall [AWS] died on May 12 at Baptist Hospital in Miami, Fla.

Wall received his B.S. degree in mechanical engineering from the Georgia Institute of Technology, Atlanta, Ga. He received his Ph.D. in political science from the Universidad de La Habana, Havana, Cuba. He also attended the Industrial Development Institute at the University of Oklahoma.

In 1948, Wall began his professional career with United Railways of Havana and Regia Warehouses, Ltd., Havana, Cuba, as a draftsman and junior engineer. He later joined Barrenos y Equipos as a service engineer and chief mechanical engineer. At Ferrocarriles Occidentalles, he was a consultant, chief engineer, and assistant to the president.

In 1960, Wall was owner and operator of Ma's Old Fashion Bottling Co. in Scranton, Pa. In 1964, he joined the Georgia Institute of Technology as assistant research engineer and then as research engineer. Wall remained with the Georgia Institute of Technology from 1964 to 1969, when he was named head of the International Education Services Section. From 1970 to 1976, Wall served as head of the Research Services Branch; from 1976 to 1977, he was head of the International Development Branch; and from 1978 to 1980, he served as chief of the International Program Division. From 1980 to 1981, Wall was director and principal research engineer, Engineering Experiment Station.

In 1981, Wall joined the American Welding Society as director of education. In 1985, he was named to the position of deputy executive director. Upon his retirement in 1996, Wall was named AWS deputy executive director emeritus and served as chief operations officer of AWServices.

Wall was a member of numerous professional and technical associations and has had more than 100 reports, publications, and handbooks published under the sponsorship of the United States Agency for International Development (USAID), Organization of American States (OAS), U.S. Department of State, Georgia Institute of Technology, Solar American, Hercules Powder Co., and the International Rice Research Institute.

Wall is survived by his mother, Zoila, and his wife, Cary.

Rao Kadiyala

Rao Kadiyala [AWS] died suddenly on May 18.

Kadiyala was technical vice president of Techalloy Company, Inc.'s, Welding Division. He worked for the company for almost 22 years and was well-known and highly respected throughout the welding and metals industry. Kadiyala, who was very active in and served for many years on various AWS technical committees, recently presented a technical paper he coauthored at the 2003 Interwire Trade Exposition in Atlanta.

NEW LITERATURE

— continued from page 79

High-Temperature Brazing Book Published

A primer on brazing by nickel-based brazing pioneer Rohert L. Peaslee, *Brazing Footprints: Case Studies in High-Temperature Brazing*, includes 120 case studies and is available for $130. Ordering information is available at *www.wallcolmonoy.com*.

Wall Colmonny Corp. 124
30261 Stephenson Hwy., Madison Heights, MI 48071

Mass Spectrometer Catalog Released

The *2002–2004 Mass Spectrometer Catalog* includes 116 pages of information on products as well as informative fundamentals of mass spectrometry theory and practical applications.

Pfeiffer Vacuum, Inc. 125
24 Trafalgar Sq., Nashua, NH 03063

4th AWS Conference on Weld Cracking: Causes and Cures
September 9–10
New Orleans, Louisiana
Doubletree Hotel New Orleans – Lakeside

It all started during World War II, when U.S. shipyards went wild fabricating welded ships for the war effort. A small number of these ships experienced cracks in their welds, and the newspapers and radio stations let the country know what was going on in some of these yards. Was the news blown out of proportion? Perhaps. But welding researchers looked into the matter with intensity, and much useful information was accumulated.

Those days of mass-produced ships are over, but the phenomena involving weld cracking are still apparent to some degree in many job shops, on pipelines, in pressure vessels, in offshore platforms, in aircraft engines, on truck chassis, in skyscrapers — wherever welding is used to join components together. Modern science is helping industry test for these cracks and introduce a host of preventive cures.

Welding in the Oil and Gas Industries
October 7–8
Houston, Texas
Hilton Garden Inn Houston

One of the strongest segments of the U.S. economy is the energy industry, which is best exemplified by oil and natural gas. The pressure upon industry is intense to deliver these fuels to the marketplace as efficiently and as economically as possible. Welding plays an extremely important role in this scenario.

Therefore, the pressure is also on the welding industry to keep the cross-country pipelines in continuous operation, to make sure badly needed fuels are retrieved from offshore sources, and to maintain adequate production from the refineries.

2nd Conference on Nondestructive Testing ot Welds
December 2–3
Orlando, Florida
Grosvenor Resort in the Walt Disney World Resort

New developments in nondestructive testing are rapidly being introduced. This conference will help you keep pace with new technologies such as thermographic inspection of resistance spot welds, alternating current field measurement, time-of-flight diffraction, and phased array inspection. A panel of three prominent engineers will lead a timely discussion on the "Status of NDT Certification Programs" to bring this two-day program to a close. Whether you are directly or indirectly involved with weld inspection — often described as welding's right arm — you'll benefit from this helpful, educational conference.

For further information, contact Conferences, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126. Telephone: (800) 443-9353 ext. 449 or (305) 443-9353 ext. 449; FAX: (305) 648-1655. Visit the Conference Department home page, *www.aws.org*, for upcoming conferences and registration information.

Call for Papers

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.

AN INVITATION TO AUTHORS

to present Brazing and Soldering Papers at the AWS International Brazing and Soldering Symposium

Chicago, Illinois
April 6–8, 2004

The American Welding Society's C3 Committee on Brazing and Soldering invites you to present your outstanding and unpublished work in the field of brazing and soldering development, research, or application, at the International Brazing and Soldering Symposium. This event will be held in conjunction with the Society's Annual Convention, Chicago, April 6–8, 2004.

Please submit your abstract(s) by July 15, 2003, to be screened by the C3 Papers Selection Committee for the 2004 conference.

Each extended abstract should be sufficiently descriptive to give a clear idea of the content of the proposed paper. In any case, it must contain not less than 500 — *but preferably not more than 1000* — words. Repeated references to a company and/or the use of advertisements, trade names, trademarks (or expressions considered as such by the industry) are not permitted. Suitable generic terms must be used, in accordance with those standardized by the American Welding Society, where applicable.

Papers may be considered for publication in the *Welding Journal* regardless of acceptance for presentation at the conference.

Topics of particular interest are applied technologies of (1) automotive assemblies, (2) machine tools, (3) nuclear assemblies, (4) aerospace structures, (5) electronic equipment, (6) food processing equipment, (7) pressure vessels, and (8) biomedical components. Of special interest is the application of brazing to titanium, aluminum and other base metals, including brazement strength data.

In addition, papers pertaining to new research and development on (1) brazing or soldering filler metals, (2) brazing filler metal/base metal interaction, (3) nuclear properties of brazements, (4) electronic properties of brazements, (5) corrosion of brazements, (6) strength of brazed joints, (7) active brazing fluxes, (8) industrial soldering applications, (9) testing of brazed or soldered joints, and (10) brazing and soldering of ceramics are being sought.

Finally, papers dealing with educational and informative aspects of production, engineering, research and metallurgy are welcomed if the subject falls within the scope of the session.

Please fill out the Author Application Form (reverse side), attach abstract thereto and return to AWS, 550 N.W. LeJeune Road, Miami, FL 33126. To assure your paper's consideration for the 2004 conference, your abstracts must be postmarked **no later than July 15, 2003.**

IMPORTANT: ABSTRACTS MUST BE AT LEAST 500 WORDS AND BE POSTMARKED NO LATER THAN JULY 15, 2003, TO ASSURE CONSIDERATION.

AUTHOR APPLICATION FORM
FOR
INTERNATIONAL BRAZING AND SOLDERING SYMPOSIUM

Chicago, Illinois **April 6–8, 2004**

Please complete this form legibly. This completed form is to accompany the 500–1000 word summary described on the back. Please mail to AWS, 550 N.W. LeJeune Road, Miami, FL 33126.

Author's Name____________________Check how addressed: Dr. ❐ other__________
Title or position________________Company or Organization________________
Mailing address:________________________________
City__________State____Zip/Postal Code__________Country__________
Area/Country Code______Telephone__________FAX__________e-mail__________

For joint authors, list names and ***FULL MAILING ADDRESSES*** *of all authors (attach list if necessary):*
1st Name________________Telephone: Area____Number__________FAX__________
Title or position________________Company or Organization________________
Mailing address:________________________________
City__________State____Zip/Postal Code__________Country__________
2nd Names________________Telephone: Area____Number__________FAX__________
Title or position________________Company or Organization________________
Mailing address:________________________________
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PROPOSED TITLE (10 words or less):________________________________

SUBJECT CLASSIFICATIONS:

1. Classify your paper by choosing **one** of the appropriate boxes in each of the following two groups (a) and (b):

   a. ❐ Applied Technology ❐ Education ❐ Research Oriented
   b. ❐ Original Contribution ❐ Progress Report ❐ Review ❐ Tutorial

2. Brazing process(es) used:________________________________

3. Materials used:________________________________

4. The main emphasis is more ❐ process oriented ❐ materials oriented

5. Industries this paper most applies to are:________________________________

6. **KEY WORDS: Please rank the top four in order of importance (i.e., 1 = most important; 4 = 4th):**

__Stainless Steels
__Sheet Steels
__Aluminum Alloys
__Copper Alloys
__Titanium Alloys
__Ni-Base Alloys
__Dissimilar Materials
__Structural Ceramics

__Brazing Filler Metals
__Brazing Fluxes
__Brazing Processes
__Solid-State Processes
__Soldering
__Laser Processes
__Furnace Brazing
__Diffusion Brazing

__Fixturing
__Heat Exchangers
__Wetting/Wetted Joints
__Mechanical Properties
__Brazed joint Microstructure
__Testing Methods

__Other__________

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For more information, contact Jeff Hufsey at *hufsey@aws.org*.

SERVICES

EMPLOYMENT

Director, Sales and Marketing

The American Welding Society seeks an experienced professional to oversee marketing and promotion of a broad spectrum of association products and services, including advertising and exhibition space sales, conferences and seminars, certification programs, tradeshow attendance, educational foundation fundraising, and publication sales. Must be able to develop strong customer-driven marketing programs and maintain an effective internal system for measuring program effectiveness.

Bachelor's degree and 10 years' marketing experience required. Prior association with the welding industry is a definite plus, as is familiarity with graphic design, print production, and list development and management.

Interested parties should send a resume and a letter outlining interest to:

American Welding Society
550 N.W. LeJeune Rd.
Miami, FL 33126

Attn.: Luisa Hernandez
Personnel Department
luisa@aws.org

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Large manufacturer of industrial gas apparatus and industrial flow control equipment seeks experienced reps calling on welding supply industry. Large protected territories and great commission rates. Fax resume to 909 612-1927.

WELDING INSTRUCTOR

Full-time faculty position at Sheridan College, a two–year community college at the foot of the beautiful Big Horn Mountains in northern Wyoming. Teach a variety of welding and welding–related classes. Bachelor's degree required, Master's preferred. Requires CWI/MSHA, and other professional welding certifications. Teaching experience preferred. For application, contact Sheridan College, Employee Services Office, P.O. Box 1500, Sheridan, WY 82801. (307) 674-6446, ext. 6218/6373. Duties to begin no later than August 2003. EOE

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WELDING RESEARCH

SUPPLEMENT TO THE *WELDING JOURNAL*, JULY 2003
Sponsored by the American Welding Society and the Welding Research Council

A Proposed S-N Curve for Welded Ship Structures

A hot-spot stress-based design S-N curve for fillet weld joints takes into account the effects of static cargo loads

BY S. W. KANG AND W. S. KIM

ABSTRACT. Static loads on ship structures induced by cargo loading cause relatively higher stress histories at welded joints compared with cyclic loads induced by waves. Due to these static loads, the initial tensile residual stresses at welded joints are shaken-down to a great extent by the elastoplastic deformation behavior of the material. The redistribution of initial welding residual stresses by the preload was evaluated using finite element (FE) analysis and compared with the results obtained from an ordinary sectioning method for three types of welded specimens, which were all typical fillet weld joints in ship structures. Fatigue tests were performed to evaluate the effects of shaken-down residual stresses on the fatigue strength of the fillet weld joints. The effects of the tensile mean stress on the fatigue strength of preloaded specimens were investigated as well. From the results of fatigue tests, an empirical formula of S-N curves, taking into account the effect of the arbitrary preload and mean stress associated with static loads, was derived based on the hot-spot stress range. The standard deviation between the formula and fatigue test results was calculated. With 2.35% of probability of failure, "HD S-N Curve (Hot spot-stress based Design S-N Curve)" was proposed.

Introduction

Tensile residual stresses generally exist up to the yielding point of the material around welded joints. Much research has been carried out on the effects of residual stresses on fatigue strength. Most of this research work, however, has concentrated on the effects of initial welding residual stresses. Only a few research works were performed on the effect of redistribution of residual stresses caused by the actual service condition on fatigue strength (Refs. 1, 2).

Static loads on a ship structure, induced either by water pressure before service or by cargo pressure during the first laden voyage, cause relatively higher stress history at welded joints, compared with cyclic loads induced by waves during service. Scantlings of main ship structure are generally determined under the rule requirements of classification societies (Refs. 3–5), and the values of allowable nominal stress by design static loads are in the range of approximately 50–70% of the yield points of materials. In ship structure, local stress concentration is inevitable due to structural geometry or discontinuity. In most cases, the fatigue damage occurs at these stress-concentrated points. Due to static loads, the initial tensile residual stresses at welded joints, where fatigue strength is concerned, are expected to be shaken-down to a great extent by the elastoplastic deformation behavior of the material, although the behavior of global structure is elastic. Ship structural members are subsequently exposed to cyclic loads during service. It is therefore imperative to verify the fatigue characteristics related to the redistributed residual stresses to assess the fatigue strength of the ship structure properly.

KEY WORDS

Residual Stress
Preload Effect
Mean Stress Effect
Hot-Spot Stress
S-N Curve
Fatigue Analysis

It was also reported that the effect of cyclic stress ratio (minimum stress/maximum stress) on the fatigue strength of a structure under the initial residual stress condition by welding was minor (Ref. 6). Therefore, the mean stress effect on the fatigue strength of structures is minor, based on exposure to cyclic loads under as-welded conditions. However, the effect of a certain level of mean stress associated with static loads of cargo or ballasting would not be minor in the case of ship structures with residual stresses shaken-down by fairly large static loads, when exposed to cyclic loads induced by waves.

In this research work, the redistribution of residual stresses by the static preload was evaluated using FE analysis and compared with the results obtained from an ordinary sectioning method for three types of small specimens: a non-load-carrying box fillet weldment (Model 1); a weldment with gussets on the plate edge (Model 2); and a weldment with padding plate (Model 3). These were all typical fillet weld joints in a ship structure. Fatigue tests were performed to evaluate the effect of shaken-down residual stresses on the fatigue strength of as-welded specimens and that of statically preloaded ones. The effects of the tensile mean stress on the fatigue strength of preloaded specimens were investigated as well.

Distribution of Residual Stress

Details of the specimens are illustrated in Fig. 1. The welding condition for specimens is listed in Table 1. The specimens were fabricated in accordance with actual shipbuilding workmanship and practice. The material for the specimens was ship structural mild steel of grade A. The major chemical composition and mechanical properties of the steel are listed in Table 2. Although actual yielding stresses of the material were about 300 MPa, classifica-

S. W. KANG is with Pusan National University, Pusan, South Korea. W. S. KIM is with the Hull Initial Design Department, Shipbuilding Division, Hyundai Heavy Industries Co., Ulsan, South Korea.

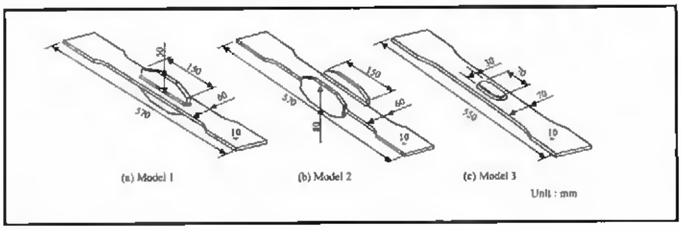


Fig. 1 — Details of specimen.

Condition	Preload (nominal stress)		Load pattern
1	As-welded	0	0
2	$0.5\sigma_o$	117.5 MPa	$0.5\sigma_o$
3	$0.85\sigma_o$	199.75 MPa	$0.85\sigma_o$

Fig. 2 — Static preload conditions.

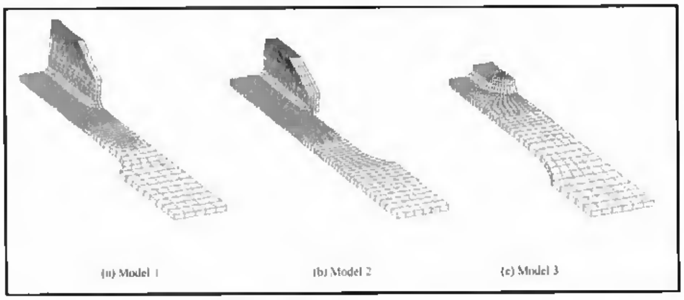


Fig. 3 — Finite element models for simulation of residual stress distribution.

Table 1 — Welding Condition

Current	250 A
Voltage	26 V
Speed	30 cm/min
Method	FCAW

Table 2 — Major Chemical Composition and Mechanical Properties of Mild Steel

Chemical Composition (%)

C	Si	Mn	P
0.13~0.17	0.15~0.18	0.46~0.65	0.012~0.019

Mechanical Properties

Yield Stress (MPa)	Tensile Strength (MPa)	Elongation (%)
290~299	427~457	34~36

tion societies define the design yield stress of σ_o as 235 MPa for ship structural mild steel. In this regard, hereinafter, the design yield stress σ_o is defined as 235 MPa according to the classification societies' specification.

Distributions of residual stresses of the specimen under three statically preloaded conditions, which are illustrated in detail in Fig. 2, were evaluated by FE analysis and measured by a sectioning method.

Condition 1 was the as-welded condition; condition 2 had a preload inducing 0.5 σ_o of tensile nominal stress; condition 3 had a preload inducing 0.85 σ_o of tensile nominal stress.

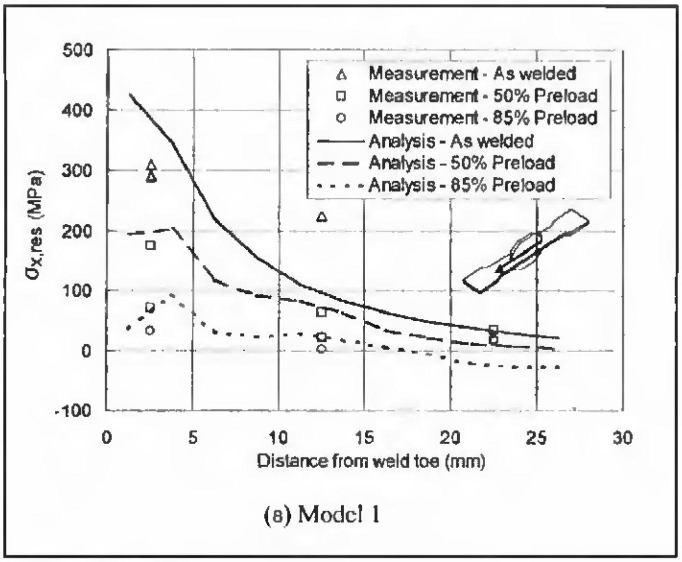
Thermo-elastoplastic FE analyses were performed using the models shown in Fig. 3 to simulate residual stress distributions by welding, and redistributions of residual stresses by preloads. One-eighth of the specimen was modeled imposing symmetric boundary conditions. Elements were 8-noded solids, and the element sizes around the weld toe were about one-fourth of the plate thickness. Mechanical properties of the stress-strain relation and material hardening due to welding were obtained from the tensile test and the hardening test. After the heat input, which was calculated from the welding condition, was fluxed to the weld bead elements, the distributions of the temperature were calculated by a transient thermal conduction analysis ignoring heat convection and radiation to the air. With the calculated distributions of the temperature with respect to time, a thermo-elastoplastic analysis was carried out to simulate initial welding residual stress distributions. From the status of the initial welding residual stresses, the static preloads depicted in Fig. 2 were applied to models to simulate redistributions of residual stresses by an elastoplastic analysis.

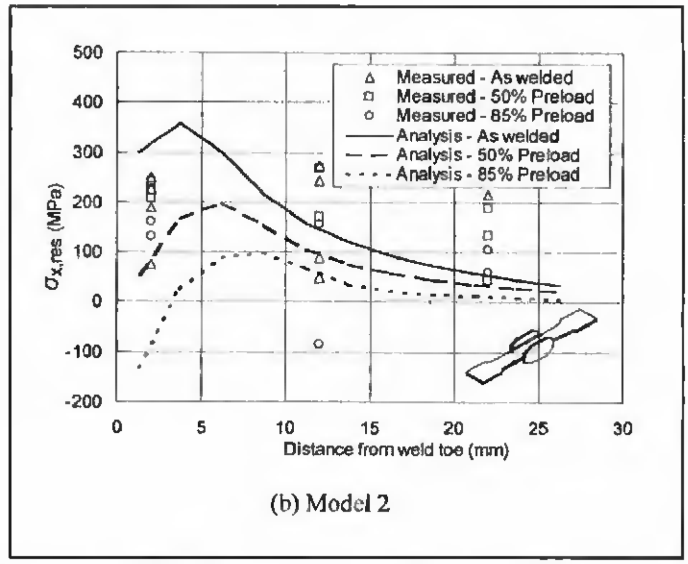
Initial residual stresses by welding and redistributed residual stresses by preloads were measured as well by using an ordinary sectioning method. Two-dimensional strain gauges with a gauge length of 1 mm were bonded on both sides of the main plates at 2-mm, 12-mm and 22-mm distances from the weld toe. Then, by sectioning the main plates around the strain gauges into small cubes, released strains were measured and converted into residual stresses using the following relationship.

$$\sigma_{x,res} = \frac{E}{1-\nu^2}\left(\Delta\varepsilon_x + \nu\Delta\varepsilon_y\right) \quad (1)$$

where, $\sigma_{x,res}$ is the residual stress in the longitudinal direction of the specimen, $\Delta\varepsilon_x$ is the released strain in the longitudinal direction of the specimen, $\Delta\varepsilon_y$ is the released strain in the transverse direction of the specimen, ν is Poisson's ratio (= 0.3), and E is Young's modulus ($= 2.06 \times 10^5$ MPa).

The results of the FE analysis and the measurement for initial welding residual stress distribution and redistributed residual stresses by preloads are shown in Fig. 4. According to the results of FE analysis, the initial welding residual stresses near the weld toe of the main plate almost reach the yield stress of the material or more. The initial welding residual stress decreases from a tensile preload. The bigger the preload becomes, the more the residual stress decreases. Magnitudes of shaken-down residual stresses obtained by





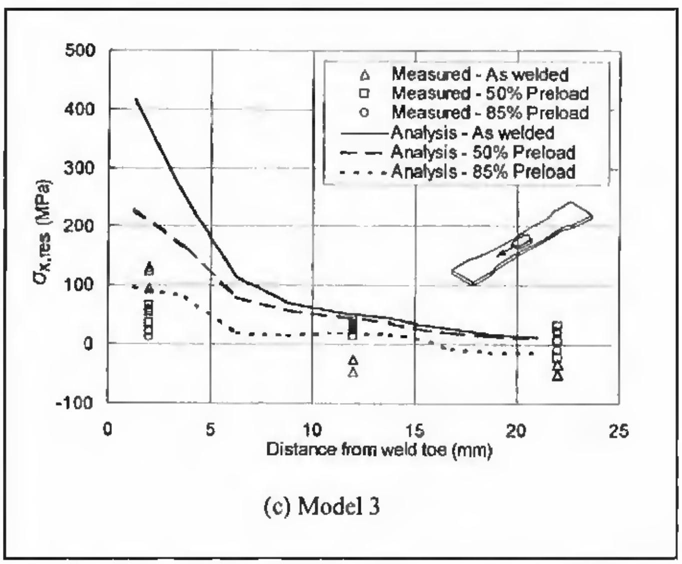


Fig. 4 — Residual stress distribution along centerline surface of main plate: Models 1, 2, 3.

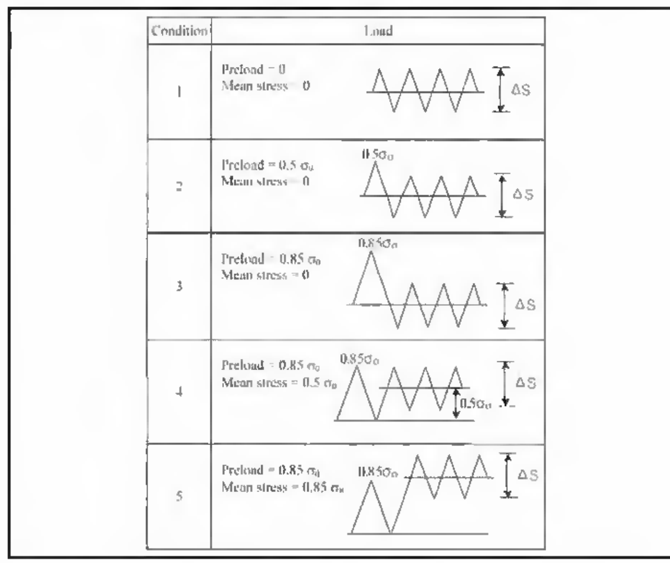


Fig. 5 — Fatigue test conditions of preload and mean stress.

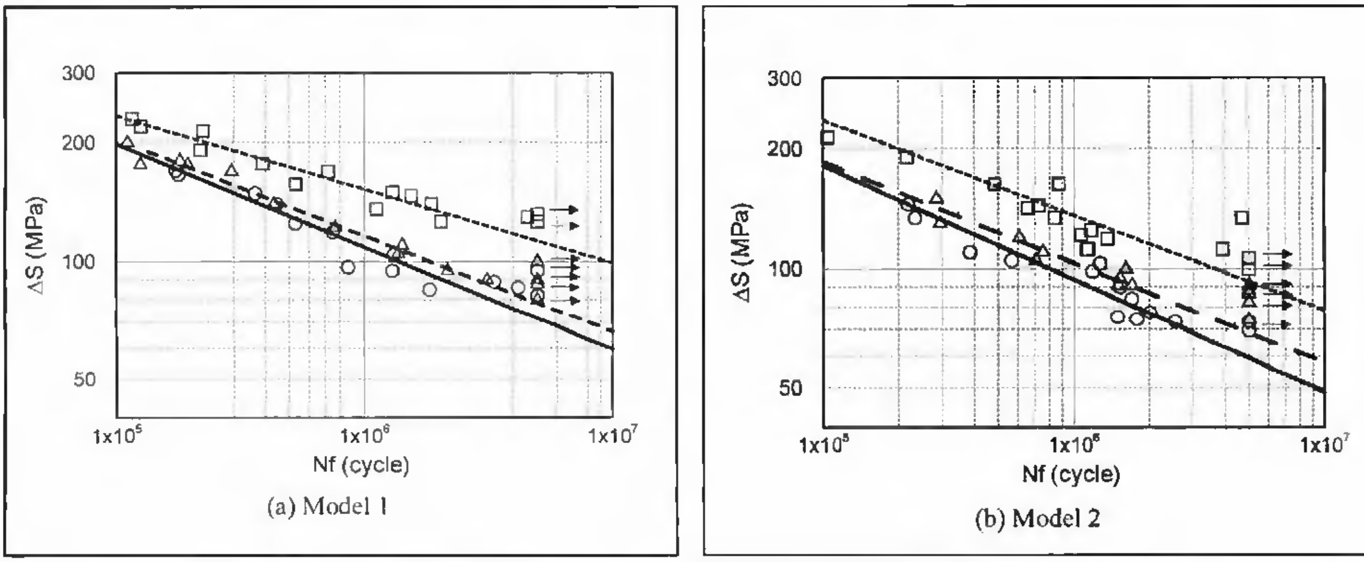
measurement were smaller than those obtained by FE analysis, but the decrement of the initial residual stress from the preload was clearly observed at the weld toe of the main plate.

Fatigue Tests

Fatigue tests were carried out under load-controlled axial loading with fully reversed constant amplitude at room temperature in air. Conditions for fatigue tests to evaluate the effects of both the redistributed residual stresses by tensile preload and the tensile mean stresses by static load are illustrated in Fig. 5. Test frequency was in the range of 6 to 20 Hz. Fifteen fatigue tests were performed per each test condition in accordance with the International Institute of Welding's (IIW) recommendation (Ref. 7). Fatigue tests

Table 3 — Hot-Spot Stress Value of Preload and Mean Stress

Model	SCF	Preload (MPa)	Mean Stress (MPa)	Case
		0	0	1
		175.0	0	3
1	1.49	297.4	0	6, 11
		297.4	175.0	12
		297.4	297.4	13
		0	0	1
		229.0	0	4
2	1.95	389.3	0	7, 14
		389.3	229.0	15
		389.3	389.3	16
		0	0	1
		155.0	0	2
3	1.32	263.5	0	5, 8
		263.5	155.0	9
		263.5	263.5	10



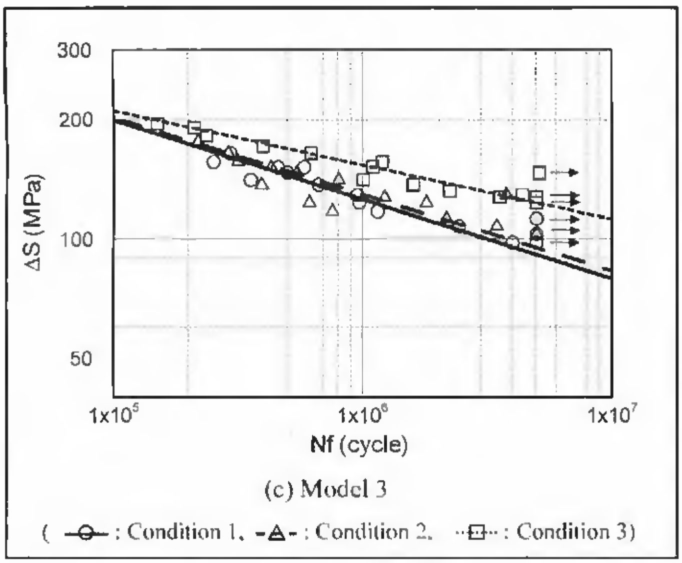


Fig. 6 — Test results and ΔS-N_f curves with redistributed residual stress by preload.

were carried out until approximately 5 × 10^6 cycles of loading and stopped, unless a fatigue crack was visually detected.

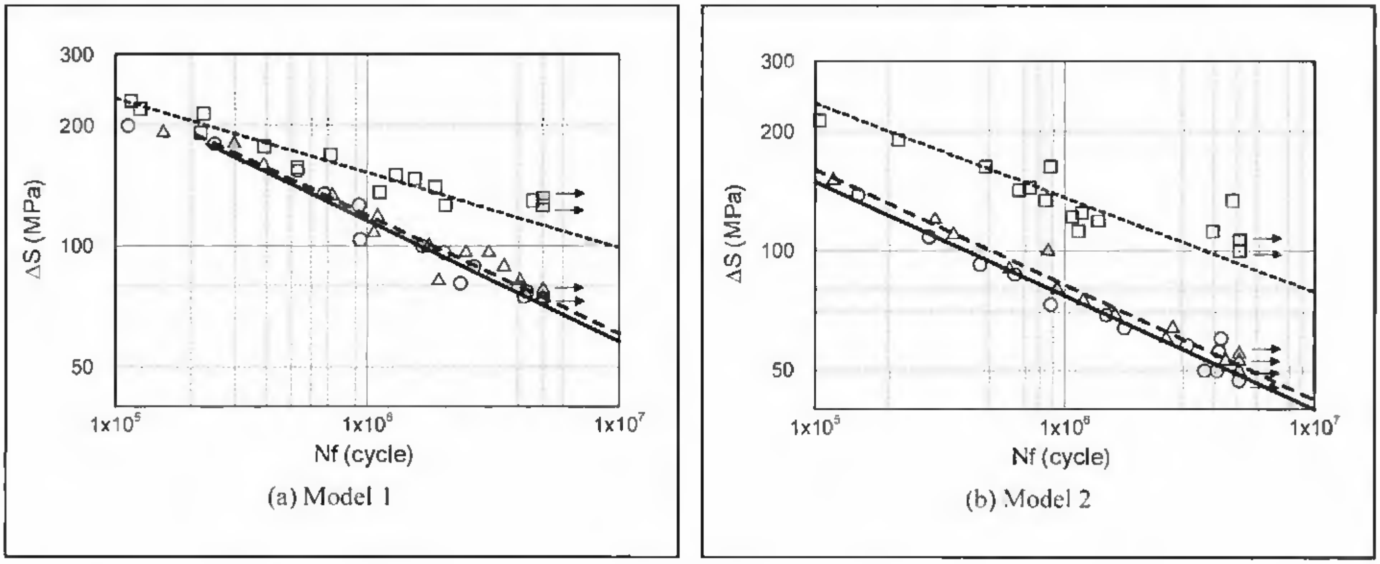
In this paper, the fatigue life of specimen N_f is defined as the number of load cycles until the specimen is totally failed because of fatigue damage in the ship structure being subject to fairly developed cracks, but not reaching catastrophic structural failure. The equation of the S-N curve for each test condition was determined with the results of N_f by least squares regression analysis. The test data stating that a crack was not detected until 5×10^6 of load cycles were not considered to derive the equation of an S-N curve.

Fatigue test results under conditions 1, 2, and 3 are plotted in Fig. 6, which represents the relation between nominal stress range (ΔS) and the failure life (N_f). The fatigue strength was clearly affected by preloads. The greater the preload, the more the fatigue strength of the weldment increased. This increment of fatigue strength was predominant at the lower cyclic stress range. Fatigue test results under conditions 3, 4, and 5 are plotted in Fig. 7. There were big differences of fatigue strength by tensile mean stresses when initial welding residual stresses had been shaken-down by the preload.

Applicability of Hot-Spot Stress

To evaluate fatigue strength properly, there should be consistency between the stress with which the S-N curve is defined and the one with which fatigue strength is calculated. Most S-N curves proposed by international institutes, such as IIW (Ref. 7) and BS5400 (Ref. 8), are defined with the nominal stress range and the related weld-joint type. The nominal stress excludes the stress concentration due to geometric shape such as structural discontinuities and presence of attachments. At most of the critical points in ship structure where fatigue strength is concerned, there are stress concentrations that depend not only on structural detail shapes but also on applied loading pattern. Furthermore, it is often hard to define the nominal stress due to the complexity of structure and loading. Accordingly, there is a high possibility of misevaluating the fatigue strength when it is evaluated with the nominal stress basis. Hot-spot stress is the recommended means of evaluating the fatigue strength in ship structures because it includes the stress concentration due to geometric shape. However, few S-N curves defined with hot-spot stress are proposed, except those for tubular joints. Therefore, it has been very hard to match the calculated hot-spot stress to the relevant S-N curve.

There are three different stress extrapolation techniques as commonly recommended procedures for the calculation of hot-spot stresses in welded structures, i.e. 1) linear extrapolation of stresses over reference points at 0.5 and 1.5 of plate thickness away from the hot spot; 2) linear extrapolation of stresses over reference points at 0.4 and 1.0 of plate thickness away from the hot spot; and 3) no extrapolation, but the stress value at 0.5 of plate thickness from the hot spot as the relevant hot spot stress. Finite element analyses using different types/sizes of elements and computing programs had been performed on various welded joints to calculate and to compare hot-spot stress values by these three techniques (Ref. 9). According to the results, the linear extrapolation of stresses at 0.5 and 1.5 of plate thickness had shown the least scatters of the values at the reference point in association with different types/sizes of elements and computing programs. In this regard, linear extrapolation of stresses over reference points at 0.5 and 1.5 of plate thickness away from the hot spot was adopted in this paper for the calculation of hot-spot stress values. Calculated stress concentration factors (SCFs) at the hot spot, using models constituted with 4-node plane stress elements (of which size at the concerned



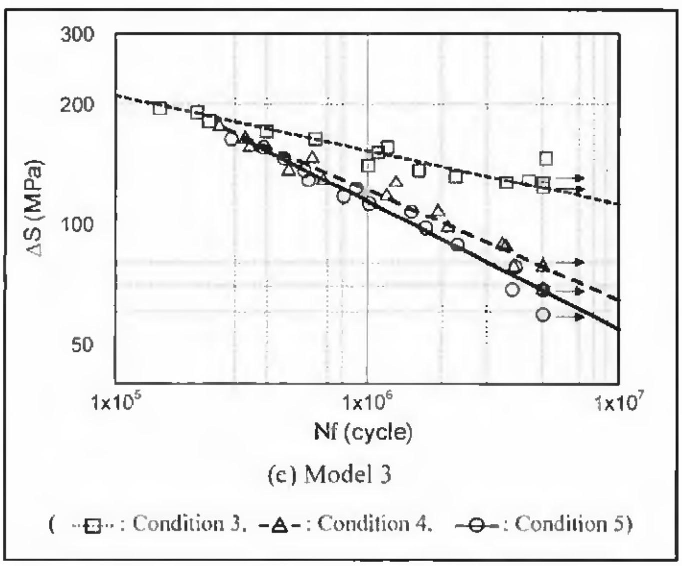


Fig. 7 — Test results and ΔS-N_f curves with mean stress: Models 1, 2, 3.

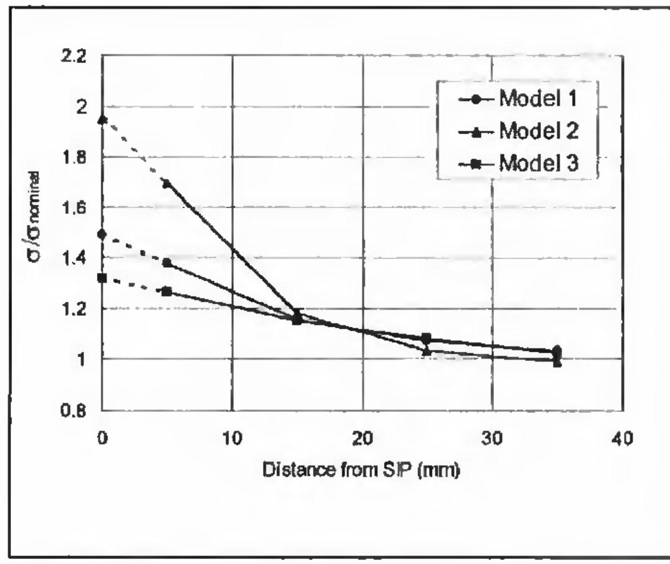


Fig. 8 — Longitudinal stress distribution from the structural intersection point (SIP) on main plate.

area was about the thickness order of the main plate), were obtained as 1.49 for Model 1, as 1.95 for Model 2, and as 1.32 for Model 3, as illustrated in Fig. 8. Table 3 lists the magnitude of preloads and mean stresses on each model, which are substituted into hot-spot stress values, and the number of cases in relation to Equations 2–8 and 12–20. To examine the applicability of a unified S-N curve based on the hot-spot stress for the evaluation of the fatigue strength of various weld joints, the fatigue test results of N_f for three models under the as-welded condition are plotted on Fig. 9 in relation to the nominal stress range of ΔS and to the hot-spot stress range of $\Delta\sigma_{spot}$. The hot-spot stress ranges were calculated by multiplying the stress concentration factors by the nominal stress ranges. The test results of Model 1, Model 2, and Model 3 coincided well with an S-N curve under the basis of hot-spot stresses, irrespective of their weld-joint type.

Proposed HD S-N Curve

To estimate the fatigue strength with an arbitrary preload and static load, it is necessary to derive an equation of S-N curves that reflects effects of redistributed residual stress and mean stress. From fatigue test results, the equation of S-N curves using the hot-spot stress range $\Delta\sigma$ was derived.

Pre-Load Effect

S-N curves under various preload cases, which were derived from the fatigue test results of Model 1, Model 2, and Model 3, are represented by the following equations:

Case 1 (σ_{load} = 0.0 MPa)

$$: \log N = 14.415 - 3.776 \log \Delta\sigma \qquad (2)$$

Case 2 (σ_{load} = 155.0 MPa)

$$: \log N = 17.579 - 5.184 \log \Delta\sigma \qquad (3)$$

Case 3 (σ_{load} = 175.0 MPa)

$$: \log N = 15.167 - 4.095 \log \Delta\sigma \qquad (4)$$

Case 4 (σ_{load} = 229.0 MPa)

$$: \log N = 15.103 - 3.950 \log \Delta\sigma \qquad (5)$$

Case 5 (σ_{load} = 263.5 MPa)

$$: \log N = 22.871 - 7.311 \log \Delta\sigma \qquad (6)$$

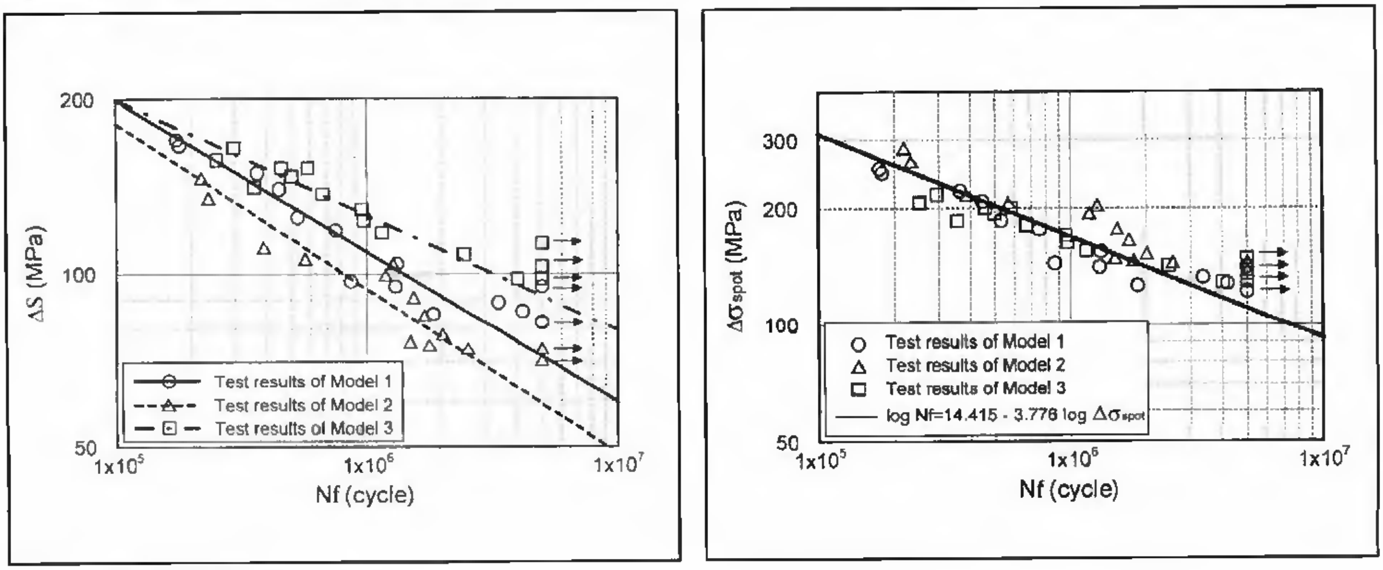


Fig. 9 — Fatigue test results under as-welded condition.

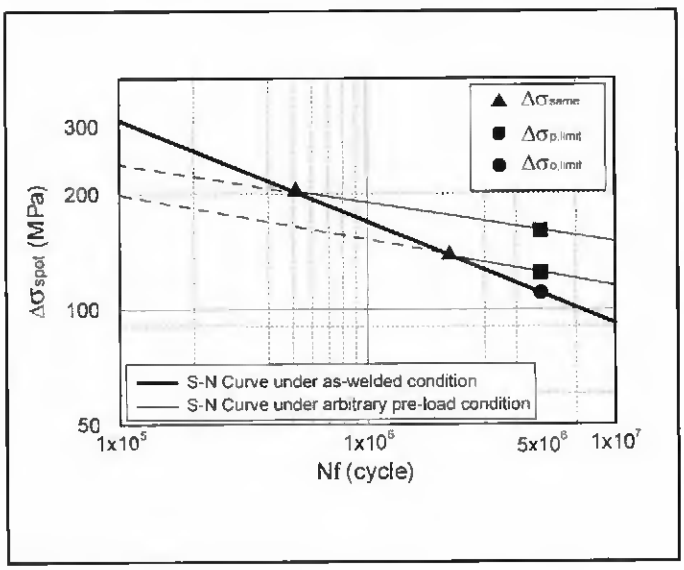


Fig. 10 — Definition of $\Delta\sigma_{same}$ and $\Delta\sigma_{p,limit}$.

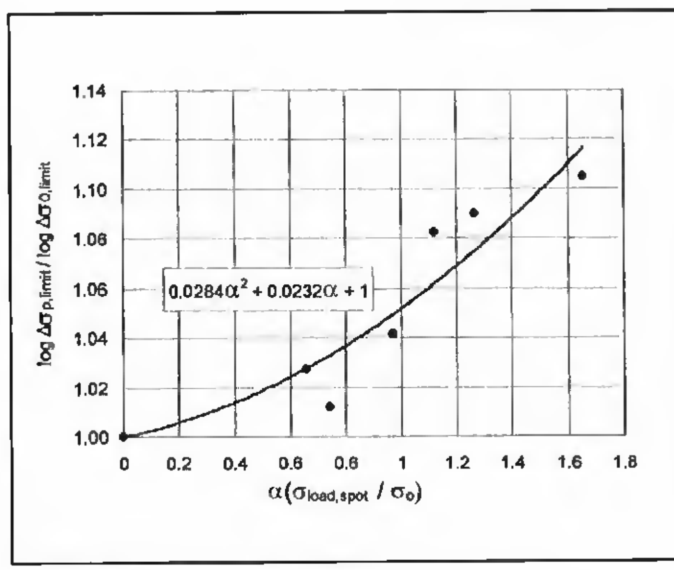


Fig. 11 — Relation between $\Delta\sigma_{p,limit}$ and magnitude of preload (α).

Case 6 (σ_{load} = 297.4 MPa)
: $\log N = 18.683 - 5.383 \log \Delta\sigma$ (7)

Case 7 (σ_{load} = 389.3 MPa)
: $\log N = 16.204 - 4.209 \log \Delta\sigma$ (8)

where σ_{load} is the magnitude of hot-spot stress by preload.

In this paper, the fatigue strength of hot-spot stress range at 5 × 10⁶ cycles under an arbitrary preload with zero mean stress is defined as fatigue limit $\Delta\sigma_{p,limit}$, as illustrated in Fig. 10. Then the fatigue limit under the as-welded condition $\Delta\sigma_{0,limit}$ is 110.44 MPa. Figure 11 shows the relation between the fatigue limit $\Delta\sigma_{p,limit}$ and the magnitude of preload, α. Provided the relation between log $\Delta\sigma_{p,limit}$ and α is approximated to the second order equation, the relation can be represented as follows by the least squares regression analysis.

$$\log \Delta\sigma_{p,limit} = (0.0284\alpha^2 + 0.0232\alpha + 1) \log \Delta\sigma_{0,limit} \quad (9)$$

where α is magnitude of tensile preload (σ_{load}/σ_o; σ_o = 235 MPa) and $\Delta\sigma_{0,limit}$ is the fatigue limit under the as-welded condition (= 110.44 MPa).

Intersected points between the S-N curve under the as-welded condition and the ones under various preload cases are defined as $\Delta\sigma_{same}$, as illustrated in Fig. 10. The value of $\Delta\sigma_{same}$ means the stress range at which the effect of redistributed residual stress on fatigue strength is diminished under each preloaded case. At the stress range beyond $\Delta\sigma_{same}$, it is expected there would be no change of fatigue strength between the as-welded condition and the preloaded case. Figure 12 shows the relation between $\Delta\sigma_{same}$ and α. The data of $\Delta\sigma_{same}$ for Cases 4 and 7 were discarded because they were far from a reasonable range. Provided the relation between $\Delta\sigma_{same}$ and α is approximated to be linear, the relation can be represented as follows by the least squares regression analysis.

$$\log \Delta\sigma_{same} = (0.196\alpha + 1)\log \Delta\sigma_{0,limit} \quad (10)$$

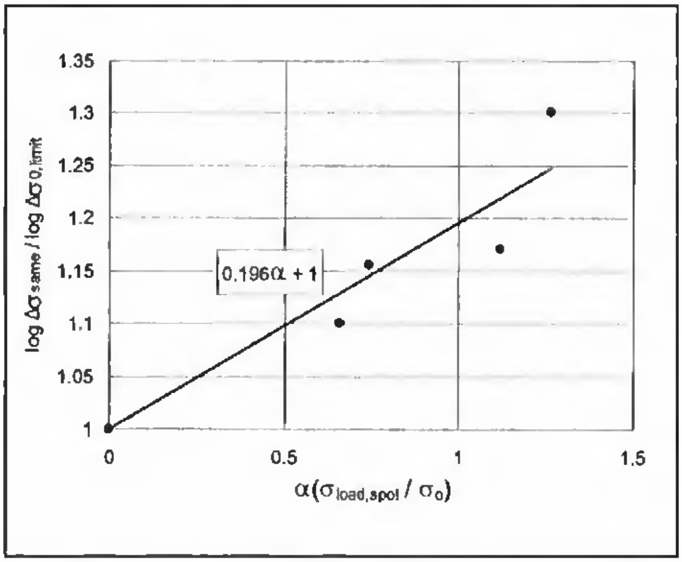


Fig. 12 — Relation between $\Delta\sigma_{same}$ and magnitude of preload (α).

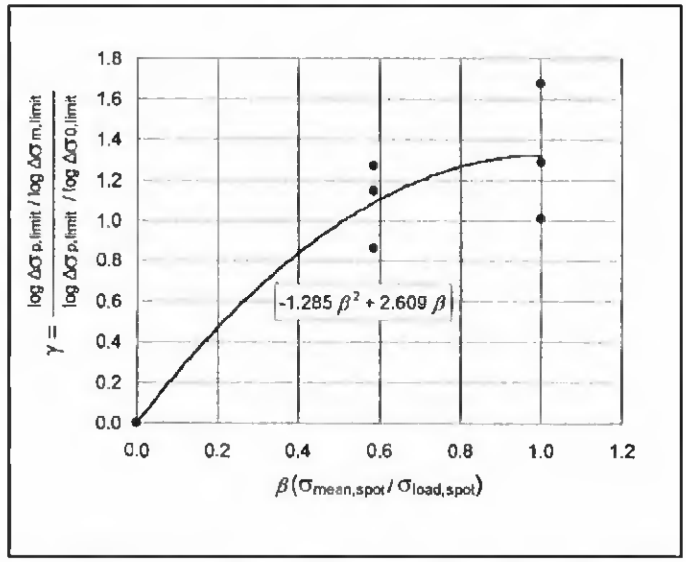


Fig. 13 — Relation between $\Delta\sigma_{p,limit}$ and magnitude of mean stress (β).

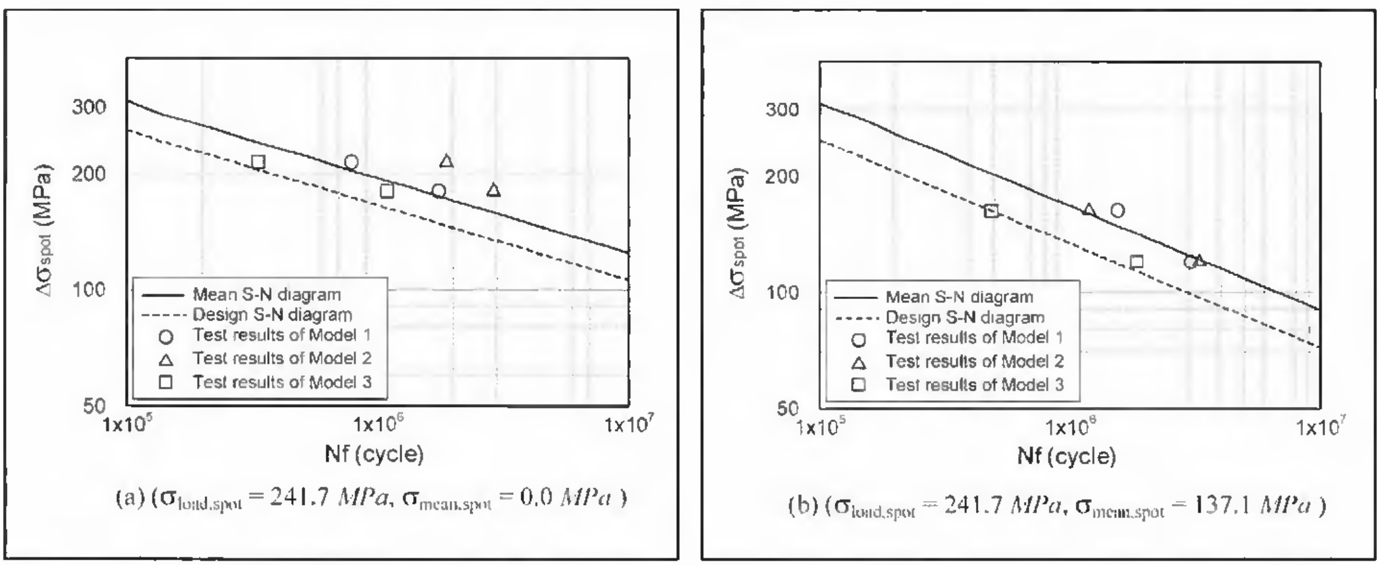


Fig. 14 — Comparison of HD S-N diagram and additional fatigue test results.

From Equations 9 and 10, the equation of S-N curves that reflects the effects of redistributed residual stress with an arbitrary tensile preload but without tensile mean stress can be derived as follows.

$$\log N = C_1 + m_1 \log \Delta\sigma \qquad (11)$$

where

$$C_1 = [(14.415 - 3.776 \log \Delta\sigma_{same}) \cdot \log \Delta\sigma_{p,limit} - 6.699 \cdot \log \Delta\sigma_{same}] / \log \Delta\sigma_{p,limit} - \log \Delta\sigma_{same}$$

$$m = \frac{6.699 - (14.415 - 3.776 \log \Delta\sigma_{same})}{\log \Delta\sigma_{m,limit} - \log \Delta\sigma_{same}} \qquad (\alpha > 0)$$

In the case of $\Delta\sigma \geq \Delta\sigma_{same}$ or $\alpha = 0$, Equation 2 is to be applied.

In the case of compressive preload, the S-N curve under the as-welded condition is recommended for the design purpose because there would be no large redistribution of residual stress from an engineering judgment.

Mean Stress Effect

It was determined that the effect of cyclic stress ratio (minimum stress/maximum stress) was minor on the fatigue strength of a structure under the initial residual stress condition by welding that almost reached yield stress of the material at the weld toe (Ref. 6). Therefore, the mean stress effect on the fatigue strength of structures is minor as far as they are exposed to cyclic loading under the as-welded condition. At the stress range beyond $\Delta\sigma_{same}$, where the effect of preload is diminished, the effect of the mean stress is also ignored, and Equation 2 of the as-welded condition may be applicable to arbitrary preloaded cases with mean stresses.

From Equations 2 and 10, fatigue test results under tensile mean stresses are represented as follows:

Case 8

$$(\sigma_{load} = 263.5 \text{ MPa}, \sigma_{mean} = 0.0 \text{ MPa}) \qquad (12)$$

$$: \log N = 14.415 - 3.776 \log\Delta\sigma \qquad (\Delta\sigma \geq \Delta\sigma_{same})$$

$$: \log N = 18.083 - 5.248 \log\Delta\sigma \qquad (\Delta\sigma < \Delta\sigma_{same})$$

Case 9

$$(\sigma_{load} = 263.5 \text{ MPa}, \sigma_{mean} = 155.0 \text{ MPa}) \qquad (13)$$

$$: \log N = 14.415 - 3.776 \log\Delta\sigma \qquad (\Delta\sigma \geq \Delta\sigma_{same})$$

$$: \log N = 13.756 - 3.512 \log\Delta\sigma \qquad (\Delta\sigma < \Delta\sigma_{same})$$

Case 10

$(\sigma_{load} = 263.5 \text{ MPa}, \sigma_{mean} = 263.5 \text{ MPa})$ (14)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 12.910 - 3.172 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 11

$(\sigma_{load} = 297.4 \text{ MPa}, \sigma_{mean} = 0.0 \text{ MPa})$ (15)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 18.570 - 5.405 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 12

$(\sigma_{load} = 297.4 \text{ MPa}, \sigma_{mean} = 175.0 \text{ MPa})$ (16)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 14.838 - 3.942 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 13

$(\sigma_{load} = 297.4 \text{ MPa}, \sigma_{mean} = 297.4 \text{ MPa})$ (17)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 14.385 - 3.765 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 14

$(\sigma_{load} = 389.3 \text{ MPa}, \sigma_{mean} = 0.0 \text{ MPa})$ (18)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 20.120 - 5.884 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 15

$(\sigma_{load} = 389.3 \text{ MPa}, \sigma_{mean} = 229.0 \text{ MPa})$ (19)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 13.917 - 3.593 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

Case 16

$(\sigma_{load} = 389.3 \text{ MPa}, \sigma_{mean} = 389.3 \text{ MPa})$ (20)

$: \log N = 14.415 - 3.776 \log\Delta\sigma \quad (\Delta\sigma \geq \Delta\sigma_{same})$

$: \log N = 13.466 - 3.426 \log\Delta\sigma \quad (\Delta\sigma < \Delta\sigma_{same})$

where σ_{mean} is the magnitude of hot-spot mean stress.

Figure 13 shows the relation between the fatigue limit with an arbitrary mean stress $\Delta\sigma_{m,limit}$ and the magnitude of the mean stress, β. Provided the relation between $\Delta\sigma_{m,limit}$ and β is approximated to a second order equation, the relation can be represented as follows:

$$\log \Delta\sigma_{m,limit} = \log \Delta\sigma_{p,limit} - \gamma(\Delta\sigma_{p,limit} - \log \Delta\sigma_{0,limit}) \quad (21)$$

where β is magnitude of tensile mean stress $(\sigma_{mean}/\sigma_{load})$ and

$$\gamma = \frac{\log\Delta\sigma_{p,limit} - \log\Delta\sigma_{m,limit}}{\log\Delta\sigma_{p,limit} - \log\Delta\sigma_{0,limit}}$$

$$= -1.285\beta^2 + 2.609\beta$$

From Equations 9 and 21, the fatigue limit with an arbitrary tensile mean stress under an arbitrary tensile preload can be derived as follows.

$$\log \Delta\sigma_{m,limit} = [(0.0284\alpha^2+0.0232\alpha+1) + (1.285\beta^2 - 2.609\beta)(0.0284\alpha^2+0.0232\alpha)] \cdot \log\Delta\sigma_{0,limit} \quad (22)$$

In the case of compressive mean stresses, the S-N curve under zero mean stress is recommended for the design purpose.

HD S-N Curve

From fatigue test results, Equation 10, the equation of the intersected point between the S-N curve under the as-welded condition and the ones under the preloaded case, and Equation 22, the equation of fatigue limit, have been established taking account of effects of the preload and the mean stress. The equations are based on the hot-spot stress and expected to be applicable for the fatigue assessment of various fillet welded structural joints. To propose "Hot spot stress-based Design S-N Curve (so called HD S-N Curve)," the standard deviation between equations and test results was calculated as 0.181 using the following equation.

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x}_i)^2 \quad (23)$$

where, s is standard deviation of logN, x_i is the logarithm of the number of cycles obtained from fatigue test results, and $\bar{x}_i$ is the logarithm of number of cycles calculated from the equation.

With 2.35% of probability of failure, the HD S-N Curve with mean minus two standard deviations, Equation 24, may be proposed in general for the assessment of the fatigue strength of fillet weld joints at the design stage.

$$\log N = C + m \log\Delta\sigma - 2s \quad (24)$$

where

$$C = [(14.415 - 3.776 \log\Delta\sigma_{same}) \cdot \log\Delta\sigma_{m,limit} - 6.699 \cdot \log\Delta\sigma_{same}] / (\log\Delta\sigma_{m,limit} - \log\Delta\sigma_{same})$$

when $(\Delta\sigma_{spot} < \Delta\sigma_{same})$, or $C = 14.415$ when $(\alpha = 0 \text{ or } \Delta\sigma_{spot} \geq \Delta\sigma_{same})$;

$$m = \frac{6.699 - (14.415 - 3.776 \log\Delta\sigma_{same})}{\log\Delta\sigma_{m,limit} - \log\Delta\sigma_{same}}$$

when $(\Delta\sigma_{spot} < \Delta\sigma_{same})$, or $m = -3.776$ when $(\alpha = 0 \text{ or } \Delta\sigma_{spot} \geq \Delta\sigma_{same})$;

s = the standard deviation of log N (= 0.181);

$\log \Delta\sigma_{same} = (0.196\alpha + 1)\log\Delta\sigma_{0,limit}$;

$\log \Delta\sigma_{m,limit} = [(0.0284\alpha^2+0.0232\alpha+1) + (1.285\beta^2-2.609\beta)(0.0284\alpha^2+0.0232\alpha)] \cdot \log \Delta\sigma_{0,limit}$;

α = the magnitude of tensile preload when $(\sigma_{load}/\sigma_0 \geq 0)$, or, in the case of compressive preload only, α = 0;

β = magnitude of tensile mean stress when $(1.0 \geq \sigma_{mean}/\sigma_{load} \geq 0)$, or, in the case of compressive mean stress, β = 0;

$\Delta\sigma_{0,limit}$ = fatigue limit under as-welded condition (= 110.44 MPa);

σ_0 = design yield stress (= 235 MPa);

σ_{load} = magnitude of hot-spot stress by preload (design load in general);

σ_{mean} = magnitude of hot-spot stress by actual static load related to concerned load condition.

Verification of HD S-D Curve

Additional fatigue tests were carried out under an arbitrary preload and two mean stress conditions to verify the HD S-N Curve. Fatigue test results and the HD S-N Curve under related test conditions are shown in Fig. 14. The additional fatigue test results show reasonable agreement with the HD S-N Curve.

Conclusion

Contemporary assessment proposals for the fatigue strength of ship structures have been derived from the research results for other industries such as steel bridges and offshore structures. It should be noted that, in ship structures, not only structural details in geometry and material but also loading patterns of the dynamic and the static types are different from those of other structures.

To examine the effect of static load history on ship structure, simulation by FE analysis and measurement by a sectioning method for the distribution of the residual stress were both carried out. Initial welding residual stresses at the weld toe, which almost reached tensile yield point of the material, were shaken down by the tensile preload. The bigger the preload became, the more the residual stress decreased, according to results of both the simulation and the measurement. Due to the effect of the tensile preload, the fatigue strength was changed. The bigger the tensile preload was, the more the fatigue strength increased, and this fatigue strength increment was predominant at the lower cyclic stress range.

Fatigue tests were also carried out applying the tensile mean stresses under preloaded conditions to examine the effect of the mean stress on fatigue strength. There were big differences of fatigue strength from tensile mean stresses when the preload had shaken-down initial welding residual stresses. The fatigue strength decreased drastically from the tensile mean stress, and this decrement was predominant at the lower cyclic stress range.

It is noteworthy that the main purpose of this research work emphasizes its practical application to ship structural design. From the results of fatigue tests, an empirical formula of S-N curves, taking account of the effect of the arbitrary preload and mean stress in consideration of loading conditions in ship structures, which was based on the hot-spot stress range, was derived in the closed form. The standard deviation between the formula and the fatigue test results was calculated. With 2.35% of probability of failure, "HD S-N Curve (Hot spot stress-based Design S-N Curve)" was proposed. However, to generalize and to utilize the HD S-N Curve in the shipbuilding industry, further research work on the following areas is recommended.

Fatigue tests on lower cyclic stress range. The fatigue tests were carried out until around 5×10^6 cycles of loading and stopped in this research work. In ship structure, the fatigue strength is assessed on the basis of design S-N curves and Miner's accumulative damage rule, with the stress spectrum in consideration of variable amplitude loads. Most fatigue damage is contributed by dynamic stress at the level of $2 \times 10^6 \sim 1 \times 10^8$ load cycles. In this regard, when a new Design S-N Curve is established, fatigue test results at the high cycle load region (around 1×10^7 cycles) are important to enhance the reliability of the S-N curve, even though it is very time-consuming to carry out tests at low stress ranges.

Definition of hot-spot stress. The resulting value of hot-spot stress may differ depending on the FE program or on the element type, although the procedure for the calculation is just the same (Ref. 9). It is necessary to establish a more appropriate procedure for the calculation of the hot-spot stress that may represent the state of stress in relation to the fatigue behavior of welded joints.

Different workmanship of welding. Fatigue strength of the welded structure is highly dependent on the quality of the fabrication. All specimens in this research work were fabricated by only one shipyard, with its normal workmanship. Comparison of test results with specimens fabricated by a variety of shipyards will be required.

Verification of shaken-down residual stresses in actual ship structures. The redistributions of initial welding residual stresses by preloads in small-scale specimens may not necessarily represent those in actual ship structures due to complexity of the structural geometry. In addition to welding residual stresses, other mechanical residual stresses, induced by forced restraints during block assembly and so on, are imposed simultaneously. It is necessary to measure shaken-down residual stresses at the hot spot of the ship structure by the cargo loading history and to calibrate the effect of preloads on the fatigue strength.

Accumulation of further experimental data. In this research work, fatigue tests were performed with only three fillet-welded joint types of specimens, which were fabricated with ship structural mild steel of grade A. Accumulation of experimental results with other joint types, such as lap joints, and other materials, such as higher tensile steel, is necessary. In addition, further fatigue tests under lower mean stress levels are recommended.

Fatigue tests under other types of loading. Fatigue tests were performed under uniaxial loads only. Fatigue strength under other types of loading such as out-of-plane bending loads and bi-axial loads should be verified.

Acknowledgment

A joint industry project to assess the fatigue capacity of floating production, storage, and off-loading (FPSO) units was established by Det Norske Veritas (DNV) under the title "FPSO JIP — Fatigue Capacity" (Ref. 10). The objective of this project was to provide data to obtain a reliable design basis that can be used to ensure sufficient fatigue capacity of FPSO units. This was to avoid costly maintenance during in-service life. Eighteen companies, including oil companies, classification societies, engineering companies, a governmental organization, and shipbuilders, joined the JIP. The fatigue test with small specimens of typical fillet weld joints in ship structures was one of the main tasks for investigation of the effect of mean and residual stress. The authors express appreciation to all participants of the JIP for their permission for the publication of fatigue test results. The conclusions expressed in this paper are those of authors and do not necessarily reflect the views of all participants.

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A Probabilistic Diffusion Weld Modeling Framework

A probabilistic modeling framework realistically accounts for manufacturing variability and successfully models bond impact strength in Ti-6Al-4V

BY V. R. DAVÉ, I. J. BEYERLEIN, D. A. HARTMAN, AND J. M. BARBIERI

ABSTRACT. Physics-based modeling of critical diffusion welds is problematic at best and, in practice, semi-empirical approaches are employed. This work reviews existing pore closure models identifying their shortcomings vis-à-vis actual manufacturing environments. A framework is developed that incorporates realistic manufacturing process attributes such as surface topography into pore closure models. Relevant quantities are represented as distribution functions instead of deterministic values, and manufacturing attributes are then correlated to parameters in these distribution functions. Using a Monte Carlo approach, the distribution of residual joint porosity as a function of both manufacturing attributes and bond process conditions (time, pressure, and temperature) can be derived. Existing models do not capture joint strength, so an additional objective of this work is to model the relationship between residual joint porosity and joint impact strength by applying probabilistic failure models. Finally, this overall approach is applied to model impact strength data of diffusion welds in Ti-6Al-4V.

Introduction

Diffusion welding has been successfully applied to critical components for the past 30-plus years. For demanding applications such as gas turbine engines, there are extreme quality requirements and significant process control challenges (Refs. 1–4). As a practical matter, manufacturers have resorted to empirical process development, occasionally augmented by process modeling. Physically motivated analytical approaches have seldom met with success in accelerating development efforts. The reasons for this are numerous but include:

1) No clear methodology for incorporating realistic manufacturing process attributes into physically motivated models

2) The lack of a linkage between pore closure models and mechanical properties

3) Insufficient or inaccurate materials data to evaluate all the material constants in pore closure models

Although infrequently used in the past, analytical models are useful. Diffusion weld quality assurance for critical applications is presently based on exhaustive and expensive nondestructive and destructive examination. Due to the extreme consequences of an in-service failure, this conservative strategy is adopted. From a manufacturing perspective, in-process quality assurance is desired, capturing all relevant manufacturing process attributes. From a design engineering perspective, assessment of component reliability as a function of manufacturing attributes is needed while minimizing specimen testing. For example, the fracture and fatigue properties of diffusion welded articles exhibit a strong dependence on residual porosity level, pointing to the need for probabilistic approaches to characterize the dependence of mechanical properties on porosity. Achieving these objectives would significantly reduce manufacturing cost and reduce the engineering effort needed to qualify new designs or processes. Improved modeling can therefore benefit manufacturing quality assurance as well as design reliability, and this work represents an initial effort along these lines. This is done by first relating machining process parameters to an initial porosity distribution, then allowing pore closure models to operate on the initial pore distribution to give a final pore distribution, and, finally, making the link between porosity and weld impact strength. Weld impact strength is chosen because it conservatively assesses weld quality.

KEY WORDS

Diffusion Welding
Titanium
Porosity
Probabilistic Model
Monte Carlo
Topography

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Review of Existing Pore Closure Models for Diffusion Welding and Their Shortcomings

The first conceptual process model by King and Owczarski (Ref. 5) had four stages — Fig. 1: 1) initial contact, 2) attainment of intimate interfacial contact, 3) grain boundary diffusion/migration, and, finally, 4) volume diffusion. Initial contact is limited to a few asperities, followed by Stage 1, in which the asperities are crushed. Stage 2 involves grain boundary diffusion and migration, whereas Stage 3 consists of volume diffusion to isolated voids. King and Owczarski offered a conceptual framework but did not quantitatively model pore closure. Kellerer and Milacek (Ref. 6) also identified creep and bulk diffusion as mechanisms through which intimate surface contact is developed. Another early work by Hamilton (Ref. 7) proposed that the diffusion welding process consists of four steps: 1) development of intimate interfacial contact, 2) formation of the metallic bond, 3) interdiffusion, and 4) recrystallization/grain growth. Hamilton modeled pore closure dominated by plastic flow with asperity crushing and successfully identified the pressure required to achieve joint tensile strengths approaching base material properties. Ironically, this early work offered predictive capability with respect to joint strength, whereas in subsequent works, this link to mechanical properties is absent.

The first quantitative pore closure

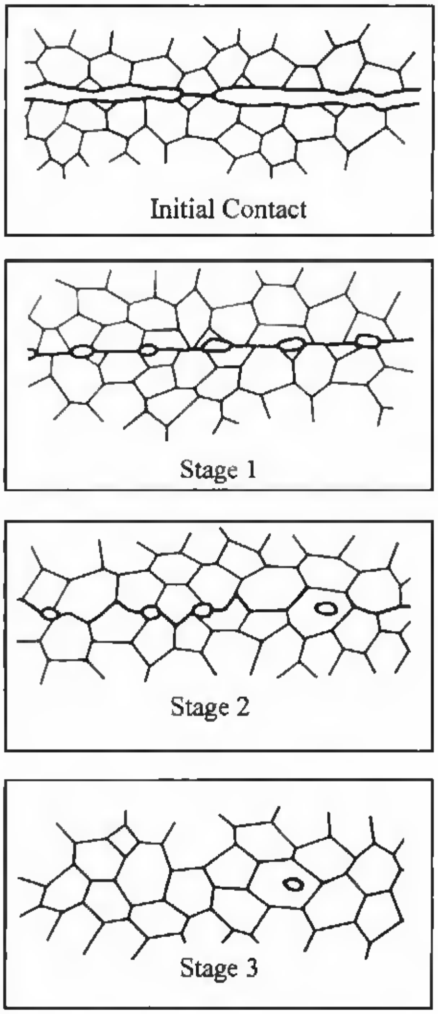

Fig. 1 — Schematic illustrating stages of diffusion welding.

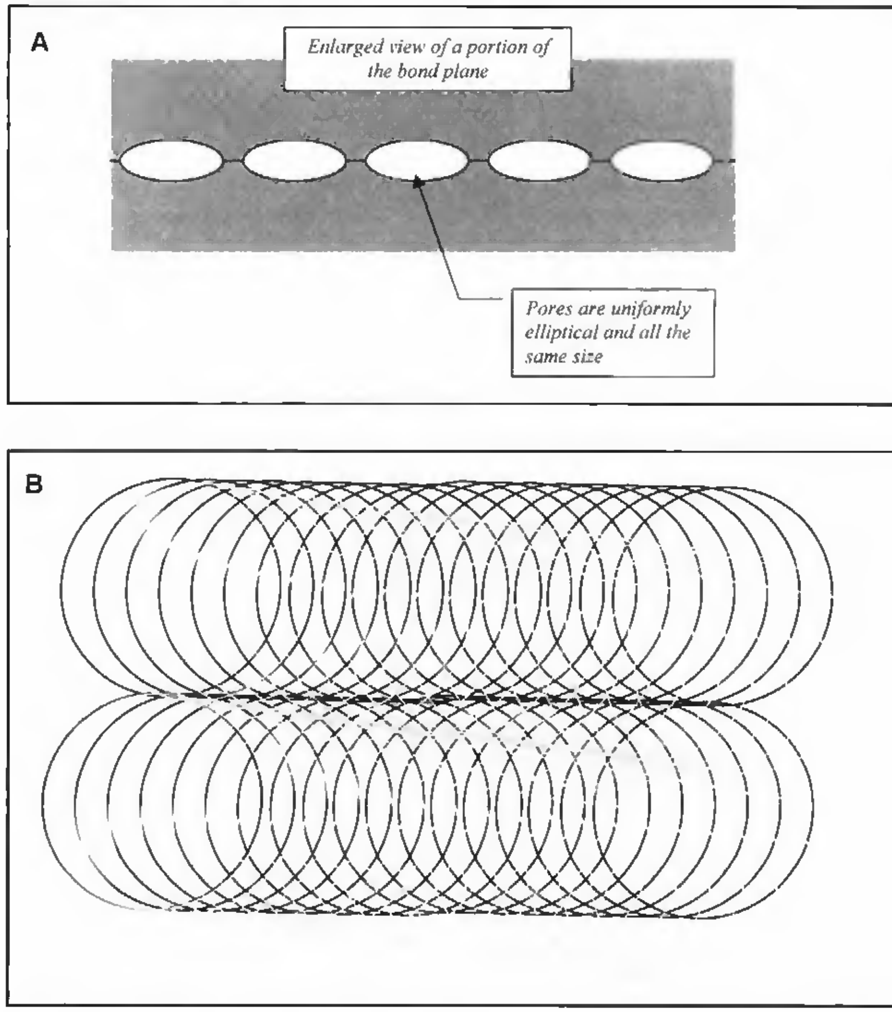

Fig. 2 — Weld surface topography. A — Idealized but inaccurate representation of pore distribution; B — schematic representation of the intersection of cutter marks of two machined surfaces.

model including multiple mechanisms was by Garmong, Paton, and Argon in 1975 (Ref. 8). Garmong et al. included the effects of surface topography by characterizing long and short wavelength surface features and proposed multiple local pore closure mechanisms, namely creep and vacancy diffusion. They were also the first to realize surface waviness (long wavelength features) could dominate the time required to attain interfacial contact but that local pore closure determines the rate of final densification and the residual porosity distribution. The physics of pore sintering based on surface energy and power law creep mechanisms is traceable to Coble (Ref. 9) and Wilkinson and Ashby (Ref. 10). Coble (Ref. 9) examined both surface energy and creep as driving forces, whereas Wilkinson and Ashby (Ref. 10) examined in greater detail the influence of creep.

The next significant extensions to pore closure models are found in a series of works first by Derby and Wallach (Refs. 11–14) and later by Hill and Wallach (Ref. 15). These models incorporate multiple pore closure mechanisms dominant at various stages in the welding process. Table 1 outlines these mechanisms and their underlying physical driving forces (Ref. 15). Although this series of models culminating in Ref. 15 significantly advanced understanding of pore closure mechanisms, the claim of the authors in Ref. 15, namely that modeling can "...virtually eliminate the need to experimentally optimize bonding conditions," is unfortunately not realized in industrial practice.

Additional models include Pilling et al. (Ref. 16) and Guo and Ridley (Ref. 17), who examined the diffusion welding of Ti-6Al-4V. Pilling et al. (Ref. 16) considered creep as influenced by effect of grain size. Guo and Ridley expanded upon this work to incorporate diffusion effects and the role of void shape and phase proportions (e.g., α and β phases). Takahaski and Inoue (Ref. 18) examined the method in which creep and diffusion terms are combined under various loading conditions. They found that void shrinkage depends on macroscopic mechanical constraint, i.e., boundary conditions imposed by tooling.

There is significant former Soviet Union work on diffusion welding mechanisms relevant to modeling. References 19 and 20 identified the importance of the local strain at the interface. One work examined relaxation of machining-induced residual stresses and found these strain rates to be twice as large as bulk creep rates (Ref. 21). Additionally the effects of rolling texture on joining kinetics have been examined for Alloy VT6 (aerospace grade Ti-6Al-4V) in Ref. 22. Several works examined the effect of residual gas at the weld interface, the dissolution kinetics of surface oxides, and the dependence of weld strength on the amount of surface oxide initially present (Refs. 23–25, respectively).

Now the shortcomings of current pore closure models are critically examined. Although this work does not address all of

Table 1 — Pore Closure Mechanisms and Their Underlying Physical Driving Forces

	Pore Closure Mechanism	Physical Driving Force(s)
1	Plastic yielding of asperities during initial contact	Mostly determined by stress state at bond
2	Creep	
3	Surface diffusion from a surface source to a neck (intersection region separating two pores)	Differences in surface curvature, so these mechanisms cease when pores no longer have varying radii of curvature
4	Volume diffusion from a surface source to a neck	
5	Vapor-phase transport from a surface source to a neck	
6	Diffusion along the bond interface or a grain boundary from interfacial sources to a neck	Chemical potential gradient, which will be influenced by local stress state
7	Volume diffusion from interfacial sources to a neck	

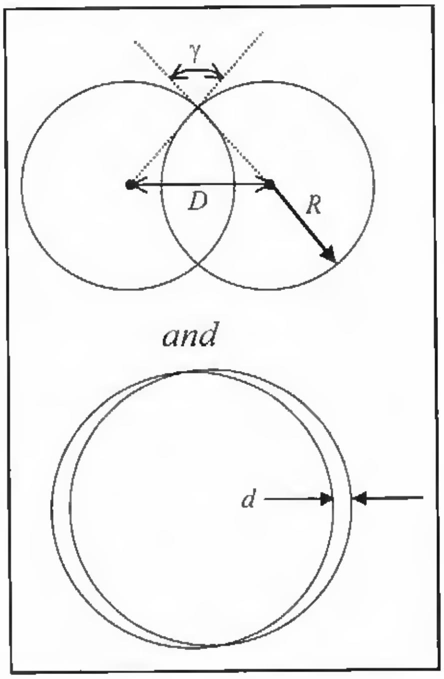

Fig. 3 — Important geometrical parameters that determine the intersection problem.

these, the modeling framework presented here is a useful starting point in making pore closure models more realistic. The most limiting shortcoming is that current models do not address the issue of joint strength. In solid-state diffusion welds the weld impact strength is the most sensitive measure of weld imperfections such as residual porosity or contamination (Ref. 26). The impact strength can drop significantly due to small fractions of residual porosity. Other than the early work by Hamilton (Ref. 7), the authors are not aware of a single work that attempts to model any aspect of diffusion weld mechanical properties. The probabilistic failure model in this present work is, therefore, the first of its kind as applied to diffusion welding.

Another shortcoming addressed in this work is the fact that current pore closure models portray weld surface topography too simplistically: actual engineering surfaces are not ideal arrays of pores. Although recognized by some workers (e.g., Ref. 14), to date there has not been a method proposed to account for this topographic variability. This work addresses surface topography in two ways. Firstly, the statistical problem of randomly intersecting circular machining marks is solved. Secondly the surface roughness on a microscopic scale is specified by distribution functions, and the nonlinear ordinary differential equations (ODE) in pore closure models then operate on such distributions. This is accomplished by a Monte Carlo method (see Appendix). It should be noted the proposed framework can be used to model any manufacturing uncertainty/variability including material properties, boundary conditions, etc. The physical phenomena not addressed in this work include weld contamination, material texture, residual stresses, and the effect of microstructural evolution on creep.

Probabilistic Approach to Pore Closure Models — Problem Formulation

The problem of weld surface topography will now be addressed. The idealized but incorrect representation of the weld plane is shown in Fig. 2A. Real surfaces are typically prepared using circular motion and a cutting tool with some specified cutting speed (surface velocity of tool relative to workpiece) and feed rate (distance between adjacent engagements of tool and workpiece). The part is generally larger than the cutting tool path and therefore the intersection of cutting tool marks from adjacent cuts is better represented by Fig. 2B. The black lines are cutter marks on one faying surface intersecting at some angle the gray machining marks on the opposite surface. It is assumed in this work that these circular marks randomly intersect. In addition to the intersection of cutter lines, other manufacturing attributes determining initial porosity distribution include the feed and the surface roughness. To a first approximation these three local surface quantities, feed, roughness,

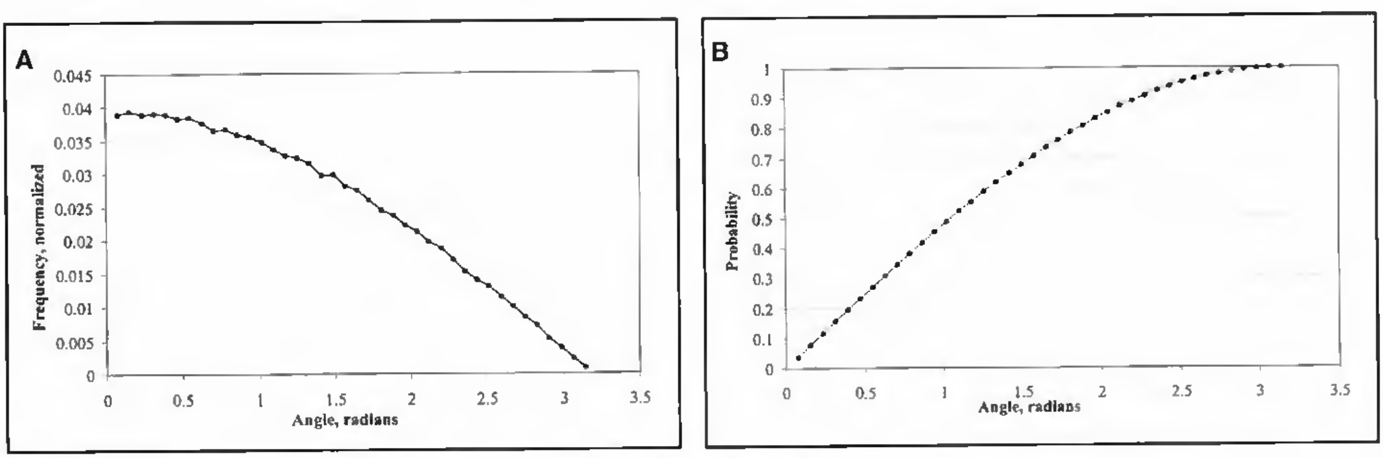

Fig. 4 — Intersection of cutter marks. A — Normalized PDF for angle of intersection γ; B — CDF corresponding to PDF shown in Fig. 4A.

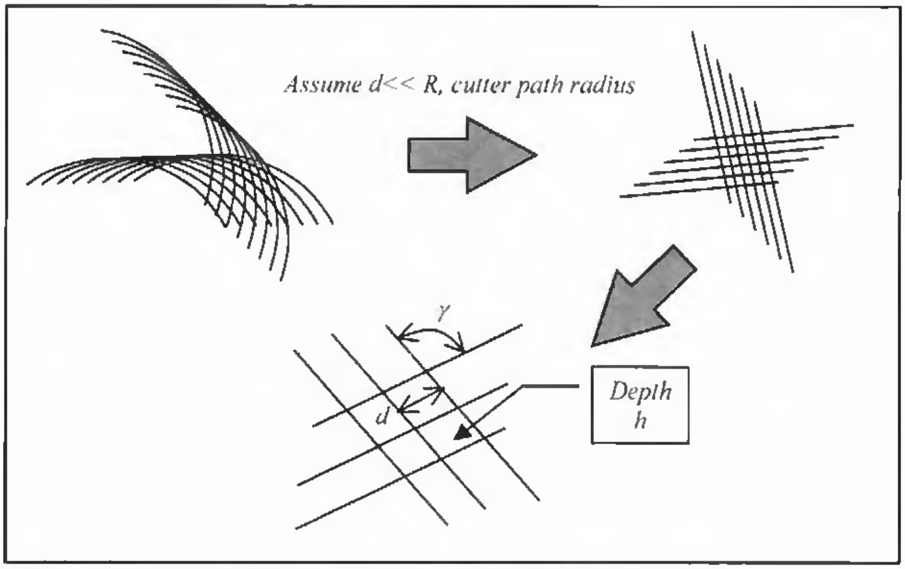

Fig. 5 — Initial porosity distribution locally described as arrays of ellipsoidal pores.

and the intersection angle, determine the distribution of initial voids.

The prototypical intersection event occurs when two circular marks cross, as shown in Fig. 3. The important variables are the center-to-center spacing D, the cutter radius R, intersection angle γ, and the feed spacing d when considering the marks immediately adjacent to the two intersecting circles. From elementary geometry, we see that

$$\gamma = 2\cdot\tan^{-1}\left\{\left[\left(\frac{1}{\phi}\right)^2-1\right]^{-\frac{1}{2}}\right\}$$

where R is the cutter path radius, and

$$\phi \equiv \frac{D}{2R}, 0<\phi<1 \quad (1)$$

Since the circles are assumed to intersect

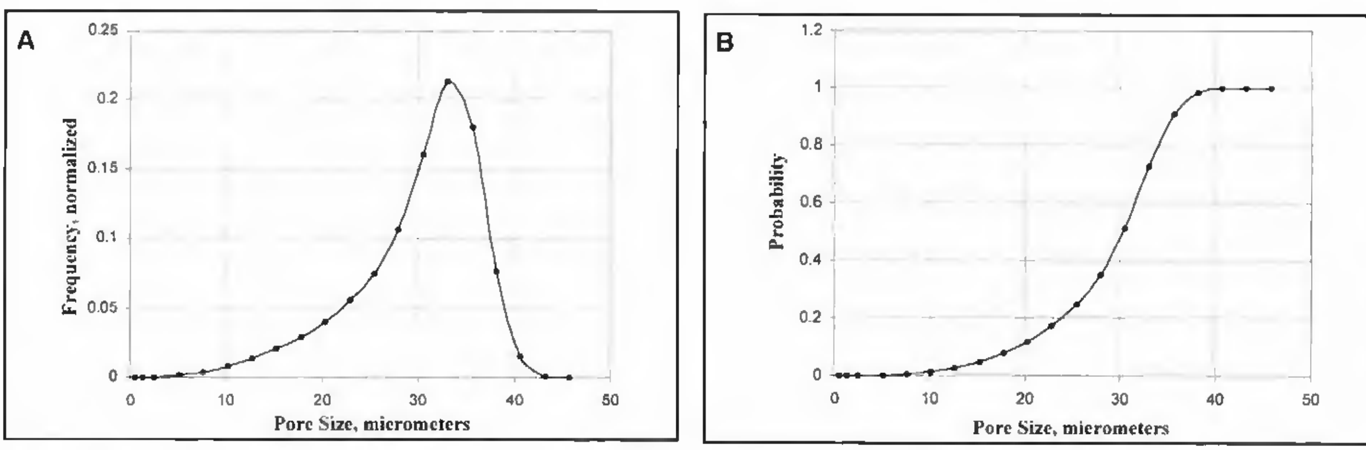

Fig. 6 — Initial pore distribution. A — Example of a normalized PDF for initial pore size; B — CDF corresponding to PDF shown in Fig. 6A.

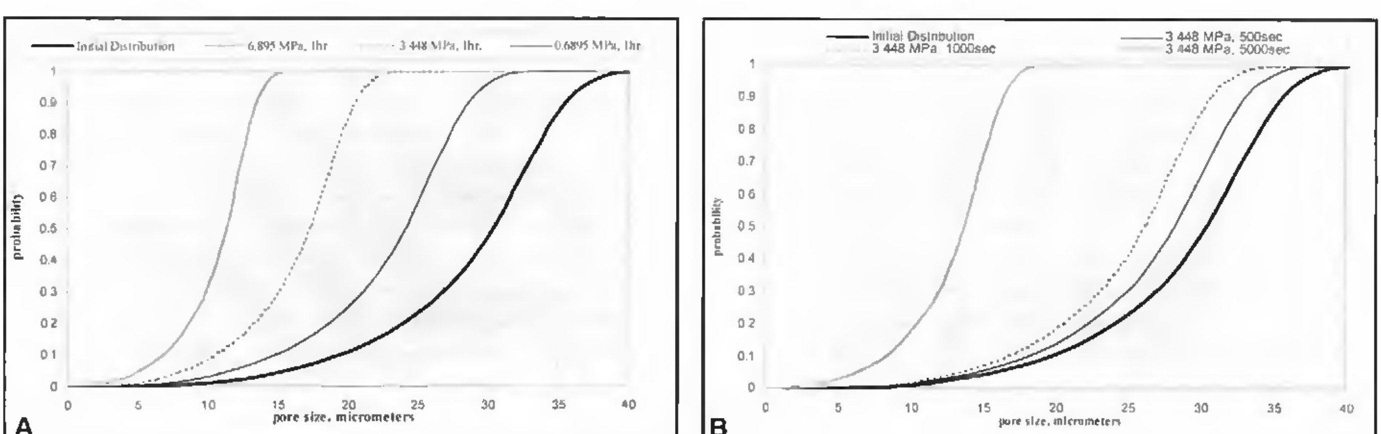

Fig. 7 — Evolution of pore size distribution. A — As a function of externally applied weld pressure; B — as a function of weld time at a given applied pressure.

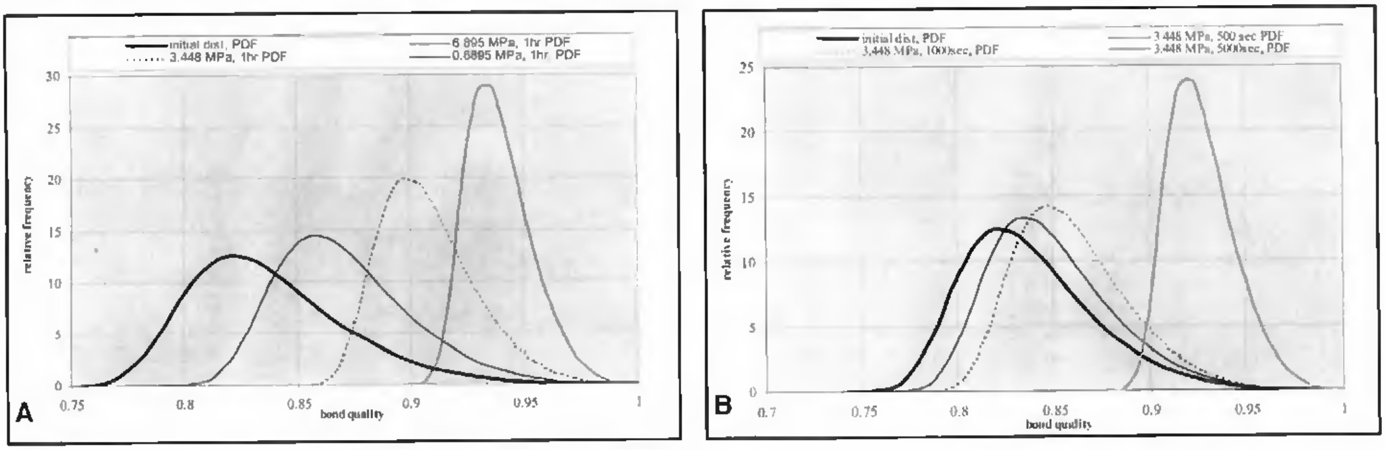

Fig. 8 — PDFs showing evolution of weld quality. A — As a function of applied pressure; B — as a function of weld time at a given pressure.

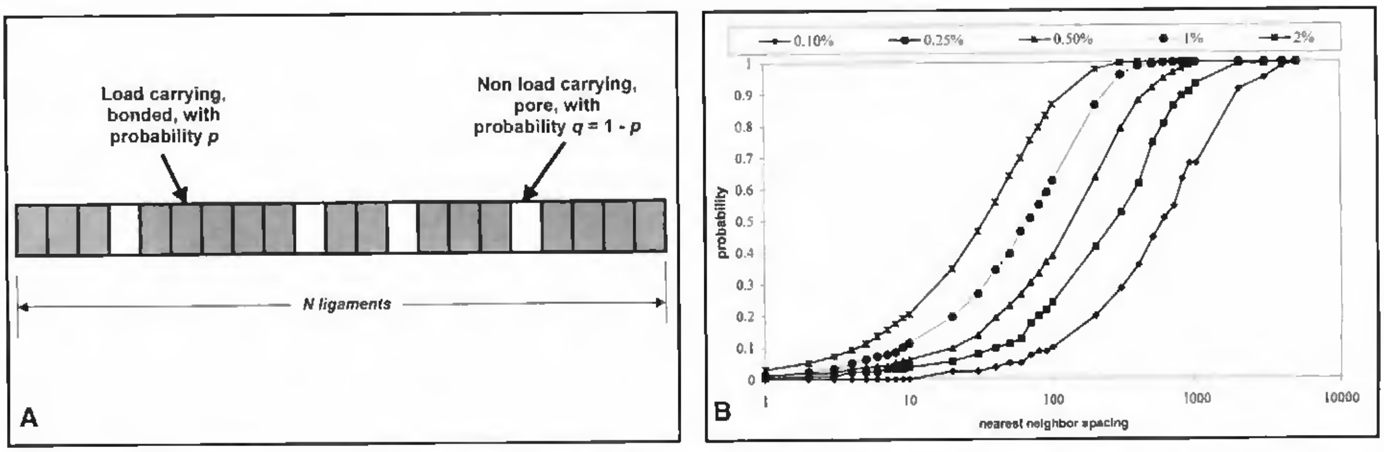

Fig. 9 — Schematic of 1-D lattice model of a diffusion weld. A — Welded vs. unwelded elements; B — CDFs for pore nearest neighbor spacing as a function of porosity level.

Table 2 — Material Constants Used in Modeling Pore Closure

Material Constant	Numerical Value (cgs units)
γ, pore surface energy	1000 erg/cm^2
D, diffusivity	10^{-9} cm^2/s
K_1, material parameter in constitutive equation for material creep	4.235×10^{-12} (dynes/cm^2)$^{-1}$ · (s)$^{-1}$
σ_0, material parameter in constitutive equation for material creep	3.275×10^{-6} (dynes/cm^2)
Ω, vacancy volume	2.7×10^{-23} cm^3
B, vacancy sink radius (assumed to be identical to average value of the feed spacing d)	0.01778 cm

at random on the weld plane, ϕ may be thought of as a uniform random variable on the interval [0,1]. Equation 1 then generates the probability density function (*PDF*) and the cumulative distribution function (*CDF*) for the angle of intersection γ. The *PDF* is the frequency of occurrence of a particular quantity, whereas the *CDF* is the probability that the given quantity will assume a value less than or equal to a specified value. A Monte Carlo method as described in the Appendix is used to perform the evaluation. The histogram bin size for the angle γ is 0.025π over the range $[0,\pi]$. The resulting normalized *PDF* and *CDF* for the angle of intersection γ are shown in Fig. 4A and 4B, respectively. These calculated distribution functions are continuous but "serrated" on account of the finite bin size. These distributions are independent of cutter size and are valid as long as the assumption of random intersection is met.

The feed d is assumed to obey a distribution function as well. Typical feed rates for the finish machining of titanium are on the order of 178 micrometers/rev (0.007 in./rev) (Ref. 27). The feed rate varies due to vibration in the tool or fixture, tool wear, and material hardening during cutting and residual stress-induced surface deformation. In practice the distribution function for the feed spacing can be experimentally determined from surface profile traces measuring the distribution of peak-to-peak spacing. Similarly, the initial void depth h is correlated to the surface roughness of the as-machined surface as well as subsequent steps such as chemical cleaning. In this work it will be assumed that both d and h are normally distributed.

Using the relationship in Equation 1 and assuming d and h follow normal distribution laws, the initial distribution of porosity is calculated, i.e., initial conditions for pore closure models. Figure 5 illustrates that if the feed is much smaller than the cutter path radius R, then the local surface intersection problem is reduced to the problem of an array of ellipsoidal pores specified by d, h, and γ. In this work a further simplifying assumption will be made: "equivalent" spherical pores are assumed because the model by Garmong et al. (Ref. 8) used in subsequent calculations is only valid for spherical pores. The models of Derby and Wallach (Refs. 11–14) and Hill and Wallach (Ref. 15) are capable of handling elliptical pores. More complex models would be a numerical extension of this work without significant qualitative differences. The equivalent spherical pore radius will be taken as the radius of a spherical pore with the same volume as an ellipsoid.

$$r_{equiv} = \sqrt[3]{hd^2 \cos\left(\frac{\gamma}{2}\right) \cdot \sin\left(\frac{\gamma}{2}\right)} \quad (2)$$

Figure 6A shows the normalized *PDF* for the initial pore size assuming the following: d_{mean} = 178 micrometers (0.007 in.) with an assumed standard deviation of 17.8 micrometers (0.0007 in.), h_{mean} corresponds roughly to R_{max} and $R_{max'} \approx 2.54$ micrometer (100 microinch), and the standard deviation for h is assumed to be 0.254 micrometer (10 microinch). Figure 6B shows the corresponding *CDF*. Note the skew-type asymmetry of this distribution.

Next, the initial pore size distribution is incorporated into mechanistic models for pore closure. The initial pore size is assumed to be a continuous random variable with distributions as described by Fig. 6A and 6B. The final pore size will therefore be a function of this random variable, also depending on parameters such as pressure and temperature. To find the distribution function for the final pore size given the distribution for the initial pore size, the following identity is invoked (Ref. 28):

$$\begin{aligned} &\text{Given random variable } X \text{ and} \\ &\text{a function } Y \equiv g(X) \\ &\text{where } g(X) \text{ is a monotonic} \\ &\text{function of } X \text{, then} \\ &CDF_Y(t) \equiv P(Y \le t) \\ &\qquad = P\left(X \le g^{-1}(t)\right) \\ &\qquad \equiv CDF_x\left(g^{-1}(t)\right) \end{aligned} \quad (3)$$

For the simple case in which the final pore size depends only on the initial pore size with pressure, temperature, etc., appearing as fixed parameters, equating probabilities for equivalent events as formally described in Equation 3 is valid. In this case the function g is the solution to the ODEs for pore closure. If, however, pressure and temperature also obey distributions, or if more complex models are used involving more than one random variable, Equation 5 cannot be used because there will be multiple ways to create equivalent outcomes. In such cases, a Monte Carlo approach is used — Fig. A1.

As previously mentioned, the model used in this work is due to Garmong et al. (Ref. 8). This model is described by the ODEs below

$$\left(\frac{da}{dt}\right)_{TOTAL} = \left(\frac{da}{dt}\right)_{CREEP} + \left(\frac{da}{dt}\right)_{DIFFUSION} \quad (4)$$

where a is the pore size and t is the elapsed time.

The creep and diffusion contributions are specified by

$$\left(\frac{da}{dt}\right)_{DIFFUSION} = -\left(\frac{D\Omega}{kT}\right) \cdot \frac{d}{a(d-a)} \cdot \left[\frac{2\gamma}{a} + P_{ext}\right] \quad (5a)$$

where D is the diffusion constant (self-diffusion for vacancies); Ω is the vacancy volume; k is Boltzmann's constant; T is the absolute temperature; d is the spacing between pores, i.e., the feed rate; γ is the pore surface energy; and P_{ext} is the externally applied stress.

$$\left(\frac{da}{dt}\right)_{CREEP} = -\frac{3K_1 a}{4} \left\{2\sigma_0 \ln\left(\frac{d}{a}\right) + \left(\frac{2\gamma}{a} + P_{ext} - P_{int}\right)\right\} \cdot \left(1 - \frac{a^3}{d^3}\right)^{-1} \quad (5b)$$

where K_1 is a material constant in a constitutive creep model described in Ref. 8; σ_0 is also a material constant in a constitutive creep model described in Ref. 8; d is the spacing between pores, i.e. the feed rate; and P_{int} is the pressure inside the pore due to trapped residual gas.

These equations were solved using a fourth-order Runge-Kutta method (Ref. 29) with fixed step size. The material constants used from Ref. 8 are reproduced in Table 2. Equations 5a and 5b were numerically integrated using the initial pore size distribution shown in Fig. 6A. For a given initial pore size, the final pore size was calculated. The probability associated with the given initial pore size as in Fig. 6B was also assigned to the corresponding final pore size to create the *CDF* for final pore size in accordance with Equation 3.

Probabilistic Approach to Pore Closure Models — Model Results

The resulting *CDF*s for final pore size are shown in Fig. 7A for various levels of applied external load, namely 0.6895 MPa (100 lb/in.^{2}), 3.448 MPa (500 lb/in.^{2}), and 6.895 MPa (1000 lb/in.^{2}) at a weld time of one hour. Alternatively at a stress of 3.448 MPa, the effect of varying weld time is shown in Fig. 7B. These *CDF*s were then fitted to the following functional form using a nonlinear least squares algorithm:

$$G(z) = erf\left[A \cdot z^B\right] \quad (6)$$

where A and B are parameters and *erf* is the error function.

The resulting fitted *CDF*s were differentiated to get the corresponding *PDF*s, as shown in Fig. 8A and B. Figures 8A and B show *PDF*s with equivalent weld quality shown on the abscissa. This quality was calculated as follows:

$$\begin{aligned} &\text{for any given pore size,} \\ &\text{porosity fraction} = \frac{a}{d} \\ &\text{equivalent weld quality} = 1 \\ &- \text{porosity fraction} = 1 - \frac{a}{d} \end{aligned} \quad (7)$$

As weld quality improves, the *PDF*s become more sharply peaked — a phenomenon observed in actual production situations (Ref. 30). It is, therefore, seen that even a simple mechanistic pore closure model, when combined with the probabilistic framework proposed herein, produces results representative of production situations. The link to impact strength is equally important and will now be established.

Statistical Models for Composite Strength and Their Applicability to Modeling Impact Strength for Diffusion Welded Components

The strength model used is due to Phoenix and Beyerlein (Refs. 31, 32), who developed a series of probabilistic models for the failure of composites by considering load-sharing effects, random strength flaws, and clustering of failure sites. One model in particular (Ref. 31) predicts the *CDF* for strength of a 1-D "weld line" consisting of an initial distribution of intact welded ligaments and broken ligaments or pores. This model may also be used to model impact tests performed on diffusion welded Ti-6Al-4V because (Ref. 33) of the following:

■ High strain rate or high rate of load-

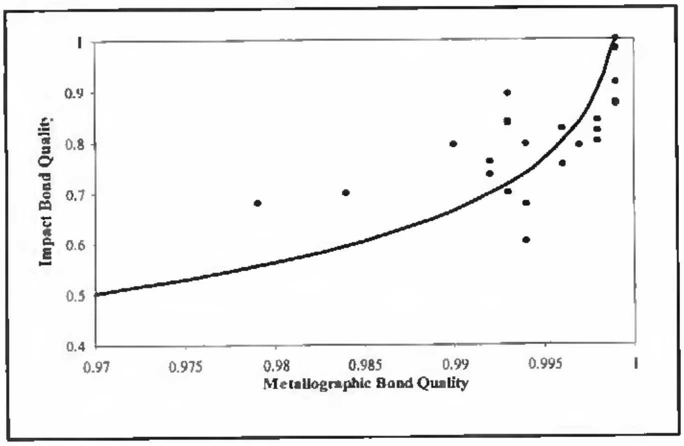

Fig. 10 — Comparison between Equation 9 (solid line) and data for diffusion welds in Ti-6Al-4V.

ing is conducive to brittle fracture.

■ Brittle fracture can more readily occur in materials with low notch toughness such as high-strength Ti-alloys.

■ The presence of flaws such as residual weld-interface porosity exacerbates the tendency towards brittle fracture and leads to variations in strength from one weld to another.

It is, therefore, a reasonable approximation to apply a probabilistic failure model developed for composites to the case of interest here.

The strength model used in this work is based on the clustering of defects (pores) and the effect of such clusters on component strength. The model, therefore, emphasizes the local interaction among defects as eventually resulting in global failure. To understand just how quickly pore clustering develops, consider a simple numerical experiment on a 1-D lattice. Suppose each point is a welded ligament or a pore as schematically shown in Fig. 9A. Now consider what happens when porosity is introduced at random sites with a probability of occurrence ranging from 0.001 to 0.02. The resulting *CDF*s showing the nearest neighbor spacing are shown in Fig. 9B. It is seen the pore spacing decays very rapidly as the porosity level increases and the number of clustered pores goes up significantly.

The detailed derivation for the strength model is beyond the scope of this article but is found in Refs. 31 and 32. The essential concepts are as follows:

■ The diffusion weld is a lattice of intact and broken ligaments; the broken ligaments are pores.

■ A 1-D row of weld ligaments is considered with probability p that a weld ligament will be intact (full strength) and probability $1-p = q$ that it will be a pore (nil strength).

■ Tapered load sharing is assumed: a pore distributes ⅔ of the load it would have carried to the nearest neighbor and ⅓ to the next-nearest neighbor.

■ Local failure configurations are considered in detail for a 1-D lattice, and their probabilities of occurrence are determined.

■ The distribution function for strength is estimated with special attention to the asymptotic behavior for large numbers of ligaments.

The principal result used in this work is given by Equation 78b from Ref. 31, which gives the strength of a 1-D lattice in the asymptotic limit for large lattice sizes.

$$\text{failure load} \propto \frac{-ln\left(q^2\delta\right)}{ln\left(n\right)},$$

$$\delta \approx \sqrt{q} + q/2 \tag{8}$$

where n is the lattice size of weld ligaments, q is the probability of occurrence of a pore, and δ is the solution of a characteristic equation describing certain key local failure configurations (clustering of defects).

At some residual porosity level the weld impact properties approach that of base metal. For the Ti-6Al-4V diffusion welds herein, this is experimentally found to be approximately 0.1%, or $q = 0.001$. The quantity of interest is therefore the failure load in comparison to that of base material, namely the ratio

$$Q \equiv ln\left(q^2\delta\right) / \left[ln\left(q^2\delta\right)\right]_{q=0.001} \tag{9}$$

This ratio Q is the weld quality as determined by impact testing and is related through Equations 10 and 11 to the metallographic weld quality, namely 1-q. Also note this equation is independent of the size of the welded area. The result of plotting Equation 9 against actual data from diffusion welds made in Ti-6Al-4V is shown in Fig. 10. The material used was AMS 4928 with welding conditions as follows: weld pressures of 1.379–13.79 MPa (200–2000 lb/in.^{2}), time of 1–3 hours, and temperatures of 871°C–982°C (1600°F–1800°F). It is seen that Equation 9 models the relationship between metallographic quality and impact quality reasonably well. The most significant limitation of the current strength model is it is 1-D.

Conclusions

This work has extended current modeling approaches for diffusion welding by implementing the following:

1) A probabilistic framework tracking the evolution of porosity distributions and incorporating the effects of weld process parameters and manufacturing process attributes

2) This modeling framework allows mechanistically-based pore closure models to be effectively applied to real manufacturing situations

3) The probabilistic pore closure modeling approach realistically describes the evolution of metallographic weld quality as observed in manufacturing practice, namely that as the weld quality improves the *PDF*, representing metallographic weld quality, becomes more narrowly distributed about its mean

4) A probabilistic failure model is used to successfully model the relationship between metallographic weld quality and impact weld quality as measured by fraction of base metal impact strength

The modeling framework presented here therefore accomplishes the said objective of linking weld impact strength and weld process attributes through a probabilistic treatment of the evolution of porosity distributions. The approach is general and may be used with any pore closure model. Future work required to further validate this modeling approach includes additional experimental verification and utilization of other pore closure models such as those by Derby and Wallach (Refs. 11–14) and Hill and Wallach (Ref. 15). Additionally, a method of extracting 2-D and 3-D surface topography parameters directly from measurements is desirable, going beyond simple notions of R_a and capturing higher dimensional features of real surfaces. Other uses for the model include performing various tradeoff studies. For example, for a certain required level of weld quality, a constrained optimization problem examines tradeoffs between pressure, temperature, time, and surface finish.

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Appendix

A Concise Overview of the Monte Carlo Method

The Monte Carlo method of statistical trials was invented at Los Alamos National Laboratory (Refs. 34, 35) to solve complex physical problems in an era before powerful computers. The method assumes the existence of a set of random numbers and a set of probabilities describing the occurrence of given events. Suppose there are j such discrete events, each with probability of occurrence p_j. If we assume at least one of these events must occur, then

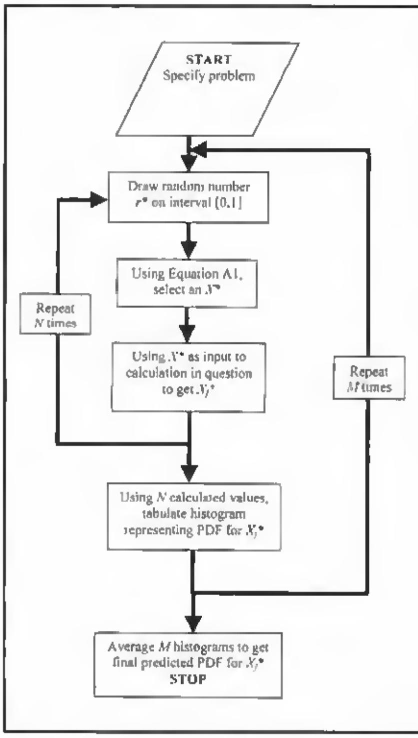

Fig. A1 — Flowchart of Monte Carlo computational approach.

$$\sum_{j=1}^{J} p_j = 1 \qquad \text{(A1)}$$

If the probabilities are arranged on the interval [0,1], and if we choose a random number r on the same interval, then the

Monte Carlo method assumes event j is "selected" if

$$\sum_{n=1}^{j-1} p_n \leq r \leq \sum_{n=1}^{j} p_n \qquad \text{(A2)}$$

This is also known as a "roulette wheel" method of selection.

In this work, we take the limit as the bin size or the width of the slots on the roulette wheel get very small and the distribution of probabilities on the interval [0,1] becomes continuous. Then, for a given random variable X, we assume the value X^* is selected for the calculation if for a given random number r^*

$$X^* \text{ is chosen if } r^* = CDF_X(X^*) \qquad \text{(A3)}$$

The flowchart in Fig. A1 schematically shows what happens after the selection process. The value of X^* is taken as an input to the problem, e.g., the *ODE* describing pore closure. In that case, the final pore diameter X_f^* is the output. The selection process is then repeated and a new final pore size is calculated and so on.

This is repeated for N trials, and M runs of N trials are done to get adequate averaging statistics. The *PDF* for the final pore size X_f^* is assembled by tabulating the M histograms from each run and averaging them. This can be repeated for various initial pore size distributions and values of the process variables to completely characterize the way in which the final pore size distribution evolves as a function of manufacturing process attributes. Although the case shown here is for only one random variable, the more general case of multiple random variables can also be handled by the Monte Carlo method. For example, pressure, temperature, and even material properties could all be represented by distribution functions in the same manner as initial pore size.

Preparation of Manuscripts for Submission to the *Welding Journal* Research Supplement

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

- Why was the work done?
- What was done?
- What was found?
- What is the significance of your results?
- What are your most important conclusions?

With those questions in mind, most authors can logically organize their material along the following lines, using suitable headings and subheadings to divide the paper.

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

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

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

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

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

6) **Acknowledgment, References and Appendix.**

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

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Selection of Schedules Based on Heat Balance in Resistance Spot Welding

A theory that takes into account heat input in the fusion zone, HAZ, and electrode indention was used to develop schedules for welding combinations of uneven sheet thicknesses

BY S. AGASHE AND H. ZHANG

ABSTRACT. It is impossible to make a complete list of welding schedules in resistance spot welding because of the large number of possibilities of sheet combinations. Therefore, the welding parameters chosen for a particular welding operation are largely dependent on the experience of the operator, although some guidelines are available. The difficulty in schedule selection arises from the number of interdependent parameters involved, such as different sheet thickness combinations, different material properties of the sheets, welding current and welding time, electrode face diameter, electrode force, etc. There are a number of efforts attempting to develop systematic procedures for welding schedule selection, such as the law of thermal similarity, yet none of them has been widely accepted, primarily due to the fact that the schedules produced by these procedures are often proven inadequate.

In this study, a new method is proposed for selecting welding schedules based on the heat balance in welding. A theoretical derivation of welding parameters is conducted using a "characteristic" thickness, instead of the physical thickness of sheets. This thickness consists of the effects and contributions of electrode indentation, heat-affected zone, and fusion zone. The theory has been verified by welding low-carbon steel sheets of uneven thickness.

Introduction

Resistance spot welding (RSW) is a major sheet metal joining process in many industries, such as the automotive, appliance, and aerospace industies. Resistance welding was invented by Elihu Thomson in 1877 (Ref. 1) and has grown enormously since the first steel welded automobile was introduced in 1933 (Ref. 1). Resistance spot welding has become the predominant means for auto body assembly, with an average of two to five thousand spots on each passenger car produced (Ref. 1).

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In resistance spot welding, a primary concern for a practitioner is to select correct welding schedules. A welding schedule is a set of welding parameters, such as welding current, weld time, electrode force, and electrode face diameter, which would produce a weld with desired features, such as certain geometric dimensions, weld strength, etc. The Resistance Welder Manufacturers' Association (RWMA) (Ref. 2) offers weld schedules and many other recommended practices are available for this purpose. Most of the weld schedules are empirically developed. Although they are very useful in finding good weld schedules for even-thickness welding, schedules for welding uneven-thickness sheets are generally developed by and practiced within individual manufacturers. Because even-thickness combinations are rarely used in practice, there is clearly a practical need of welding schedules for uneven-thickness combinations. Both theoretical and combined theoretical-empirical methods have been employed for systematically determining welding schedules. The common techniques used in this respect are summarized below.

The Law of Thermal Similarity

The law of thermal similarity (LOTS) has been commonly used in the automotive industry in Japan to develop resistance welding schedules (Ref. 3). It is based on a heat flow analysis, which attempts to make the temperature distributions in various weld thicknesses similar. The LOTS has been used to develop schedules to obtain desirable temperature profiles based on the known data, i.e., to extrapolate the results obtained from known standard specimens for predicting the temperature profile for a different combination of sheet stack up (Ref. 4). It gives a relationship between the distance and time that makes the temperature distributions similar for different thickness stack ups. It has been mostly used as a guideline for choosing welding schedules for thick sheets based on those verified for thin sheets.

KEY WORDS

Resistance Welding
Weld Schedule
Heat Balance
Spot Welding
Uneven Thickness
Sheet Metal

The law of thermal similarity states that similar temperature profiles will be produced if the weld time is proportional to the square of the sheet thickness (Ref. 4), or

$$t \propto h^2 \quad (1)$$

i.e., if the welding time is t_1 for a sheet of thickness h_1, then $n^2 t_1$ is the time needed to weld a sheet of thickness $n \times h_1$. The total weld time is determined by the total thickness of the stack up and the thinnest outer sheet determines the maximum duration of any weld pulse. Other welding parameters can be derived similarly.

In general, when the plate thickness and diameter of the electrodes are magnified by n times, the welding time should be increased to n^2 times and the current density decreased to n times in order to have the new temperature distribution similar to the original one (Refs. 3, 5).

Let h_1 (h_2), de_1 (de_2), δ_1 (δ_2), and t_1 (t_2) be the thickness, electrode diameter, current density, and welding time, respectively, of the original sheet stack up (the new sheet stack up). Then, the temperature distributions for the two stack ups are similar if (Ref. 3)

$$h_2 = n \times h_1 \quad (2)$$

$$de_2 = n \times de_1 \quad (3)$$

$$\delta_2 = (1/n) \times \delta_1 \quad (4)$$

$$t_2 = n^2 \times t_1 \quad (5)$$

Table 1 — Welds Made with Different Schedules

Sheet Thickness (mm)	Source of Weld Schedule	LOTS Factor n	Electrode Diameter (mm)	Welding Current (A)	Welding Time (ms/cycles)	Electrode Force (kg/lb)	Weld Diameter (mm)	Expulsion Occurrence	Surface Condition
0.75	Handbook (Ref. 6)		6.35	10500	150/9	227/500	6.10	No	Good
	LOTS from 1.21	0.62	4.41	8367	77/4.6	136/299	3.2	No	Good
	LOTS from 1.89	0.40	3.15	6547	45/2.68	93/204	2.89	No	Good
1.21	Handbook (Ref. 6)		7.11	13500	200/12	354/80	7.07	No	Good
	LOTS from 0.75	1.61	10.24	16940	390/23.43	590/1301	7.76	Very Heavy	Damaged
	LOTS from 1.89	0.64	5.08	10563	116/6.97	242/532	3.4	No	Good
1.89	Handbook (Ref. 6)		7.94	16500	283/17	590/1300	8.01	No	Good
	LOTS from 0.75	2.52	16.00	26460	953/57.15	1440/3175	11.3	Very Heavy	Damaged
	LOTS from 1.21	1.56	11.11	21086	488/29.28	863/1903	10.8	Very Heavy	Damaged

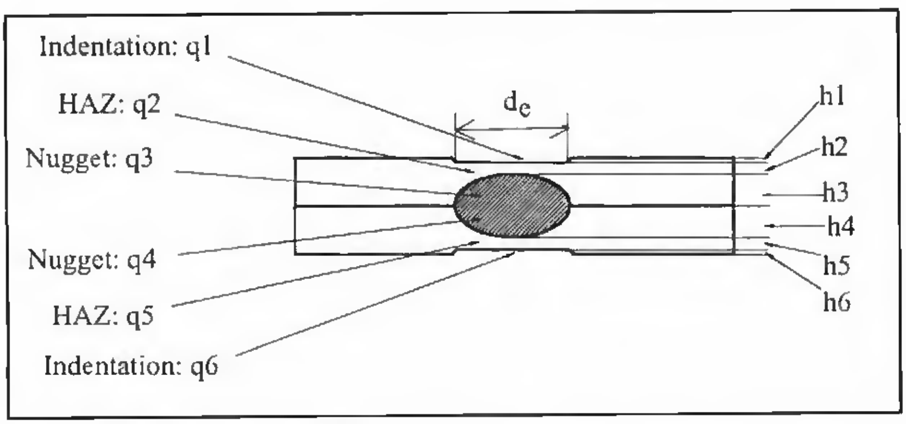

Fig. 1 — Partition of zones in a weldment for heat calculation. q = heat (Joules), h = thickness (mm).

Limitations of the Law of Thermal Similarity

Although the law of thermal similarity may theoretically yield similar temperature profiles for different stack ups, many of the welds obtained by the authors using the LOTS schedules were either undersized or with heavy expulsion. As the purpose of the LOTS is mainly for obtaining an understanding of the RSW process, its use for predicting schedules for actual welding practice is limited. The law does not hold well in welding sheets of dissimilar thicknesses as it only considers the total thickness of the stack up and does not account for the individual thicknesses of the sheets. The LOTS does not consider the effect of the actual heat input to make a weld. A welding experiment carried out by the authors on uncoated mild carbon steel highlights the differences between handbook-suggested schedules and those predicted by the LOTS, as seen in Table 1. In Table 1, three materials of different thickness were welded using schedules obtained from the *Welding Handbook* (Ref. 6) and from the LOTS. The schedules based on LOTS for welding a particular thickness are derived from the schedules for welding the other two materials (selected using the schedules from the *Welding Handbook* (Ref. 6). For instance, a schedule for welding 0.75-mm steel can be obtained directly from the *Welding Handbook* (Ref. 6) (first row of Table 1), or it can be derived using LOTS based on proven schedules (provided by the *Welding Handbook)* (Ref. 6) on 1.21-mm steel and 1.89-mm steel (second and third rows of Table 1). A good welding schedule is defined as the one that yields a large weld without expulsion. It can be clearly seen that there is a large difference between the weld schedules suggested by the *Welding Handbook* (Ref. 6) and those predicted by the LOTS; and the former are usually more realistic and yield significantly better welds than the latter. Due to the limitations mentioned above, the LOTS cannot be directly used for practical welding as it was not intended for such a purpose in the first place.

A new theory is proposed in this work to overcome some of these limitations. The weld schedules predicted as per the new theory are based on heat balance equations and are, therefore, closer than the LOTS to the actual physical welding conditions. Besides providing more accurate welding schedules, the theory can accommodate different sheet thicknesses in a single stack up, and is thus closer to the practical welding scenario.

Heat Balance

In RSW, heat balance can be defined as a condition in which the fusion zones on both pieces being joined undergo approximately the same degree of heating and pressure application (Ref. 7). It describes the ideal situation when a symmetric weld (with equal depth of nugget penetration) is made. Heat balance is influenced by the relative thermal and electrical conductivities of the materials to be joined, the geometry of the weldment, the thermal and electrical conductivities, and the geometry of the electrodes.

A heat balance can be achieved if two identical sheets are welded together with electrodes of equal mass and contour and heat is generated in both the pieces uniformly, with an oval-shaped weld cross section. However, if one of the pieces has higher electric resistivity than the other, heat will be generated more rapidly in this piece, resulting in a less-than-perfect weld depending upon the amount of heat imbalance. In the case of dissimilar metals, such as when welding plain carbon steel to stainless steel, this dissimilarity can be compensated for by increasing the electrode contact area on the high-resistivity stainless steel side, or by using an electrode material of higher resistance on the low-resistivity carbon steel side. In the case of similar metals of unequal thickness, proper heat balance can be achieved by using a smaller contacting electrode area on the thinner sheet, with short times and high current densities (Refs. 7, 8).

Proposed Theory

The basic idea of the theory proposed in this work is that the total heat needed to create a weldment can be partitioned into those needed for the fusion zone, the heat-affected zone (HAZ), and the indented area, where significant amount of heat is required. Instead of considering the thickness of the entire stack up (as by the LOTS), the heat input into each of the zones of the stack up is accounted for. Therefore, rather than treating it as an entity, the weldment is split into different zones for heat calculation. Such a division is necessary when the sheets have different thicknesses, material properties, etc. So, for a two-sheet stack up, there are two nugget zones at the center, surrounded on either side by a heat-affected zone and an outer indentation zone, as shown in Fig. 1.

The basic equation for heat calculation during heating a solid or a liquid is

$$Q = m \times C_p \times \Delta T \qquad (6)$$

where m is the mass, C_p is the specific heat of the material, and ΔT is the change in temperature due to heating. Each zone is idealized as a short cylinder for simplicity. For instance, assuming the HAZ has the same diameter as the electrode face, the mass of the HAZ can be expressed as

$$m = \frac{\pi}{4} \times d_e^2 \times h \times \rho \qquad (7)$$

where d_e is the electrode diameter, h is the height of the HAZ, and ρ is the density of the sheet. Then the heat in the HAZ can be calculated using Equation 6.

The heat components can be calculated once the mass, thermal properties, and the possible maximum temperature increases are known. The volumes of various zones in a weldment are generally different. However, an assumption that the zones are (short) cylinders of the same diameter but different heights is made in this study for simplicity. Actually, their diameters are not much different for a well-controlled grown weld. The electrode diameter d_e can be used as the diameter of all the zones (cylinders). A nominal value was used for d_e as their sizes usually vary during welding, and the size of a weld is desired to be close to that of the electrodes. For the indentation, heat is accounted for by assuming two (empty) cylinders of indentation experience a heating from room temperature up to (but below) melting temperature. It comprises the contribution from both sides of the weldment

$$q1 = \frac{\pi}{4} d_{e_1}^2 \rho_1 C_{p_1} h_1 \Delta T_1 \qquad (8)$$

$$q6 = \frac{\pi}{4} d_{e_2}^2 \rho_2 C_{p_2} h_6 \Delta T_6 \qquad (9)$$

where $\Delta T_1 = \Delta T_6 = T_{melt} - T_{amb}$, the difference between the melting temperature and room temperature, d_{e1} and d_{e2} are the face diameters of the electrodes on both sides, C_{p1} and C_{p6} are the specific heats of the respective materials, and h_1 and h_6 are the depths of indentations, respectively, for the upper and lower sheets.

Similarly for the heat-affected zone, the heat inputs on both sides are

$$q2 = \frac{\pi}{4} d_{e_1}^2 \rho_1 C_{p_1} h_2 \Delta T_2 \qquad (10)$$

$$q5 = \frac{\pi}{4} d_{e_2}^2 \rho_2 C_{p_2} h_5 \Delta T_5 \qquad (11)$$

where $\Delta T_2 = \Delta T_5 = T_{melt} - T_{amb}$ and d_e is the electrode diameter, which is used as an approximation for the diameter of the HAZ.

The solid-liquid phase transformation takes place in the nugget zone, and the heat input during melting needs to be calculated separately. The heat of the nugget includes that required for heating the metal from room temperature to the melting point, the latent heat required for melting, and the heat needed to raise the temperature beyond the melting point of the metal. The density and specific heat are different for each stage. However, the specific heat was found to be almost identical for all three stages, and hence can be assumed constant.

Let

$$q3 = \frac{\pi}{4} d_{e_1}^2 h_3 \begin{bmatrix} \rho_1 C_{p_1} \left(T_{melt} - T_{amb}\right) + \\ \rho_1' L_{f_1} + \rho_1'' C_{p_1}' \left(T_{max} - T_{melt}\right) \end{bmatrix} \qquad (12)$$

$$q^4 = \frac{\pi}{4} d_{e_2}^2 h_4 \begin{bmatrix} \rho_2 C_{p_2} \left(T_{melt} - T_{amb}\right) \\ + \rho_2' L_{f_2} + \rho_2'' C_{p_2}' \left(T_{max} - T_{melt}\right) \end{bmatrix} \qquad (13)$$

be the heat input to the two halves of the nugget, where h_3 and h_4 are the heights of the fusion zone in each sheet, ρ'_1 and ρ'_2 are the liquid densities at melting temperature, ρ''_1 and ρ''_2 are the average densities, C'_{p1} and C'_{p2} are the average specific heats of the liquid between T_{max} and T_{melt}, and L_{f1} and L_{f2} are the latent heats of fusion.

The total heat used to make the weldment = q = q1 + q2 + q3 + q4 + q5 + q6, or

$$\begin{aligned} q = {} & \frac{\pi}{4} d_{e_1}^2 \rho_1 C_{p_1} h_1 \Delta T_1 \\ & + \frac{\pi}{4} d_{e_1}^2 \rho_1 C_{p_1} h_2 \Delta T_2 + \frac{\pi}{4} d_{e_1}^2 h_3 \\ & \begin{bmatrix} \rho_1 C_{p_1} \left(T_{melt} - T_{amb}\right) \\ + \rho_1' L_{f_1} + \rho_1'' C_{p_1}' \left(T_{max} - T_{melt}\right) \end{bmatrix} \\ & + \frac{\pi}{4} d_{e_2}^2 h_4 \begin{bmatrix} \rho_2 C_{p_2} \left(T_{melt} - T_{amb}\right) + \\ \rho_2' L_{f_2} + \rho_2'' C_{p_2}' \left(T_{max} - T_{melt}\right) \end{bmatrix} \\ & + \frac{\pi}{4} d_{e_2}^2 \rho_2 C_{p_2} h_5 \Delta T_5 \\ & + \frac{\pi}{4} d_{e_2}^2 \rho_2 C_{p_2} h_6 \Delta T_6 \end{aligned} \qquad (14)$$

Based on the heat components calculated, a characteristic dimension H is defined as

$$\begin{aligned} H = {} & h_1 \frac{q1}{q} + h_2 \frac{q2}{q} + h_3 \frac{q3}{q} \\ & + h_4 \frac{q4}{q} + h_5 \frac{q5}{q} + h_6 \frac{q6}{q} \end{aligned} \qquad (15)$$

This characteristic dimension is used instead of the actual thickness of the entire stack up (as used in the LOTS) as it differentiates the contributions of various regions in an actual heating process. Although they are closely related in the physical process, h_is (i = 1...6) are independently defined, and they can be altered independently to obtain the desired features of a weldment.

This theory was verified in the case of developing welding schedules for uneven-thickness sheet stack ups. The first step is to develop good schedules for welding even-thickness sheet stack ups. One can use proven, good welding schedules for equal thickness sheets, such as those listed in the *Welding Handbook* (Ref. 6). The schedules for welding uneven-thicknesses can then be developed using those for welding even-thickness sheets and this theory.

For even thickness stack up, the weld time, welding current, electrode force, and electrode diameters were chosen from the *Welding Handbooks* (Refs. 6, 7), as shown in Table 2.

For a sheet stack up, the heat input needed for making a weldment is propor-

Table 2 — Welding Handbook Schedules for Uncoated Low-Carbon Steel Sheets (Refs. 6, 7)

Sheet Thickness (mm)	Welding Current (A)	Weld Time (ms/cyc)	Electrode Force (kg/lb)	Electrode Diameter (mm)
0.508	8500	117/7	181/400	4.78
0.635	9500	133/8	204/450	4.78
0.762	10500	150/9	227/500	6.35
0.889	11500	150/9	272/600	6.35
1.016	12500	167/10	317/700	6.35
1.143	13000	183/11	340/750	6.35
1.270	13500	200/12	363/800	7.92
1.397	14000	217/13	408/900	7.92
1.524	15000	233/14	454/1000	7.92
1.778	16000	267/16	544/1200	7.92
2.032	17000	300/18	635/1400	7.92
2.286	18000	333/20	726/1600	9.53
2.667	19500	383/23	816/1800	9.53
3.048	21000	467/28	952/2100	9.53

tional to the square of welding current, weld time, and the resistance offered by the sheet material (Ref. 8)

$$q \propto I^2 \times R \times \tau \qquad (16)$$

The resistance in turn can be assumed proportional to the characteristic dimension of the stack up and inversely proportional to the square of the nugget diameter, as assumed by other researchers (Ref. 9)

$$R \propto \frac{H}{d_e^2} \qquad (17)$$

Therefore,

$$q \propto I^2 \times \frac{H}{d_e^2} \times \tau \qquad (18)$$

The derivation of these equations does not consider the heat loss through the electrodes and sheets (a variable during welding), which is obviously an approximation, as this heat takes a large portion of the total heat generated during welding. Only the total heat needed to create various dimensions of a weldment is taken into consideration in this study.

Consider a case of two-sheet welding. Let I_1, H_1, τ_1, de_1, and F_1 be the current, characteristic dimension, time, nugget diameter, and electrode force, respectively, for one stack up, and I_2, H_2, τ_2, de_2, and F_2 be the current, characteristic dimension, time, nugget diameter, and electrode force, respectively, for another stack up. Based on the assumption the amount of heat needed to make the uneven-thickness welding is the sum of one-half of that for thin even-thickness welding and one-half of that for thick even-thickness welding, the parameters for uneven-thickness welding can be approximated as

$$H_3 = \frac{\dfrac{I_1^2 \times H_1 \times \tau_1}{d_{e_1}^2} + \dfrac{I_2^2 \times H_2 \times \tau_2}{d_{e_2}^2}}{\dfrac{I_1^2 \times \tau_1}{d_{e_1}^2} + \dfrac{I_2^2 \times \tau_2}{d_{e_2}^2}} \qquad (19)$$

$$\tau_3 = \frac{\dfrac{I_1^2 \times H_1 \times \tau_1}{d_{e_1}^2} + \dfrac{I_2^2 \times H_2 \times \tau_2}{d_{e_2}^2}}{H_3 \times \left(\dfrac{I_1^2}{d_{e_1}^2} + \dfrac{I_2^2}{d_{e_2}^2}\right)} \qquad (20)$$

$$I_3^2 = \frac{\dfrac{I_1^2 \times H_1 \times \tau_1}{d_{e_1}^2} + \dfrac{I_2^2 \times H_2 \times \tau_2}{d_{e_2}^2}}{H_3 \times \tau_3 \times \left(\dfrac{1}{d_{e_1}^2} + \dfrac{1}{d_{e_2}^2}\right)} \qquad (21)$$

As the electrode force is proportional to the square of the electrode diameter to keep a constant pressure (Ref. 8),

$$F \propto d_e^2 \qquad (22)$$

Therefore,

$$F_3 = \frac{\dfrac{F_1}{d_{e_1}^2} + \dfrac{F_2}{d_{e_2}^2}}{\dfrac{1}{d_{e_1}^2} + \dfrac{1}{d_{e_2}^2}} \qquad (23)$$

The temperature in the weldment is assumed proportional to the heat generated, and inversely proportional to the characteristic thickness and the square of the electrode diameter (Ref. 9) when the welds formed are similar

$$T \propto \frac{q}{H \times d_e^2} \qquad (24)$$

As the zones in a weldment are assumed similar to their counterparts in the individual welds, Equation 24 can be used to approximate the temperature of a weldment. Let q_1 and q_2 be the total heat content of the two stacks, then, for the combination stack up, the heat content q_3 is given by

$$q_3 = \frac{\dfrac{q_1}{H_1 \times d_{e_1}^2} + \dfrac{q_2}{H_2 \times d_{e_2}^2}}{\dfrac{1}{H_3} \times \left(\dfrac{1}{d_{e_1}^2} + \dfrac{1}{d_{e_2}^2}\right)} \qquad (25)$$

Experiment

Experiments were carried out to verify the theory and prove it suitable for use as a guideline for selecting welding schedules not listed in the *Welding Handbook*. The experiments were conducted on a resistance spot welding machine equipped with a programmable weld control unit. A 35-KVA transformer was used along with a "C" type gun. The raw material used was bare mild carbon steel sheets of 14- (0.75-mm), 18- (1.21-mm), and 22- (1.89-mm) gauge of ASTM A569 and ASTM A366 grade.

Ambient temperature = 27°C, melting point for mild steel = 1535°C, maximum temperature reached was assumed to be 1735°C (with 200°C overheating), specific heat of mild steel = 252914.79 J/kg°C, latent heat of fusion = 241585.5 J/kg, the average density of mild steel between room temperature (27°C) and melting temperature (1535°C) is 7470 kg/m^3, (liquid) density at 1535°C = 7190 kg/m^3, density at 1735°C = 6991 kg/m^3 (Refs. 10–12). Several sets of welds were made with the calculated schedules based on the schedules for even-thickness sheet welding listed in the *Welding Handbook* (Ref. 6). The welds were peel tested and the weld diameter was measured. Samples were prepared for metallographic examination and measuring various dimensions. With the help of these measured dimensions, the welding parameters for other sheets were predicted using the equations of the proposed theory. Then using these predicted weld parameters, new sets of welds were made,

Table 3 — Experiment Results

Expt No.	Thickness (mm)	Electrode Diameter (mm)	Welding Current (A)	Weld Time (ms/cyc)	Electrode Force (kg/lb)	Heat (Joules)	Charac. Thickness (mm)	Minimum Weld Diameter (mm)(a)	Average Weld Diameter (mm)
1	0.75 + 0.75	6.35	9750	150/9	227/500	840095	0.468	3.43	5.302
2	1.21 + 1.21	7.14	13500	200/12	354/780	1416971	0.749	4.58	7
Prediction	0.75 + 1.21	6.35/7.14	11557	180/10.81	283/624	1205616	0.656	3.43	—
3	0.75 + 1.21	6.35/7.14	10500	183/11	286/630	1135177	0.665	3.43	5.9

(a) The minimum weld size required as listed in the Welding Handbook (Ref. 6)

and the procedure was repeated. Finally, the weld parameters obtained from welding schedules predicted by the proposed theory were compared with those obtained in actual welding.

Results and Discussion

First, even-thickness sheets of 0.75 and 1.21 mm thicknesses were welded, with schedules very close to the ones given in the *Welding Handbook* (Ref. 6). The weld diameter was measured, and microscopic observations revealed the thicknesses of various zones for calculating the characteristic dimensions. From this data, weld schedules for a stack of 0.75- + 1.21- mm sheets were predicted using the equations of the proposed theory. Welding using these schedules yielded the expected weld sizes without expulsion. The results are tabulated in Table 3.

In Table 3, the current in the experiment (No. 3) was searched, based on the predicted value, to obtain a similar characteristic height as the predicted. This practice was to show that a characteristic height (and, therefore, a weldment) can be created in welding using schedules derived by the theory. The table reveals the experimental results obtained for the uneven-thickness combination are in good agreement with those predicted by the theory. The welding schedules predicted by the proposed theory yielded a good weld in terms of size and surface quality. Several additional tests were carried out to further verify the results of the proposed theory and build a confidence interval on its ability to predict correct weld schedules.

Using the same welding schedule, several welds were made and the weld size was measured to establish a variance on the weld diameter. The variance on the mean diameter of the welds was found to be very small ($\mu_d = 4.93$, $\sigma^2 = 0.0514$).

With all other weld parameters kept constant, the weld time was varied over a range. It was confirmed the weld by the selected schedule had the largest size without expulsion. Weld times below the selected one resulted in undersize welds, while weld times above the chosen one led to expulsion.

With all other weld parameters kept constant, the weld current was varied over a range. It also proved that the weld current at the schedule selected gave the largest nugget size without expulsion. Again, lower than selected currents gave a smaller weld button while expulsion occurred for higher currents.

Experiments have shown the predicted welding parameters used are optimized to have the largest weld diameter without expulsion. The parameters can be predicted with 98% confidence. Thus the theory helps to predict welding schedules for uneven-thickness sheets with good accuracy and ease for practical use.

Summary

A new theory based on heat balance was proposed for developing schedules in welding uneven-thickness sheet combinations. It takes into account the heat input into the fusion zone, the HAZ, and the electrode indentation and uses basic proportionality equations to reflect their contributions in welding to predict the welding parameters. The proposed theory was verified experimentally, and it provides a simple guideline for selecting weld schedules for uneven-thickness, two-sheet metal welding, based on those of even-thickness schedules. The theory and the procedure can be implemented in a production environment and can serve as a ready reference for choosing welding parameters on the shop floor.

Acknowledgment

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Liquation Cracking in Partial-Penetration Aluminum Welds: Effect of Penetration Oscillation and Backfilling

Surprisingly, the papillary- (nipple-) type penetration common in aluminum welds can oscillate along the weld and promote cracking that can be difficult to eliminate with filler metals

BY C. HUANG AND S. KOU

ABSTRACT. Aluminum alloys are susceptible to liquation cracking in the partially melted zone (PMZ), where grain boundary (GB) liquation occurs during welding. Liquation cracking near the weld root in partial-penetration aluminum welds was investigated. Gas metal arc welding (GMAW) with Ar shielding was conducted on binary Al-Cu Alloy 2219. Filler metals of various Cu and Si contents were used, including 1100, 2319, 4145, 4047, and 2319 plus extra Cu. The results were as follows. First, the papillary type penetration common in aluminum GMAW was observed and it oscillated up and down, resulting in a wavy weld root along the weld. Second, liquation cracking was observed in welds with penetration oscillation but not in welds without. Third, liquation cracking most often occurred in between waves of the wavy weld root. Fourth, changing the filler metal did not eliminate liquation cracking. Fifth, the PMZ grains near the weld root were deformed, suggesting that weld metal solidification induced localized tensile stress/strain in the liquated PMZ near the weld root. Sixth, a mechanism was proposed to explain the effect of penetration oscillation: the PMZ GBs near the weld root immediately behind the oscillating penetration front of the weld pool are both in tension and liquated, and cracking can occur if liquation is significant. Seventh, highly alloyed filler metals that delay weld metal solidification (4145, 4047, and 2319 plus extra Cu) resulted in large liquation cracks backfilled with much eutectic-rich material. Eighth, a mechanism was proposed to explain the large cracks: backfilling of cracks by an abundant solute-rich interdendritic liquid from the nearby weld metal can cause melting around the cracks and worsen GB liquation and, hence, liquation cracking, which in turn increases backfilling.

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Introduction

The partially melted zone (PMZ) is the region immediately outside the fusion zone, where liquation occurs during welding because of heating above the eutectic temperature (or the solidus temperature if the workpiece is completely solutionized before welding) (Ref. 1). Liquation can occur along the grain boundary (GB) as well as in the grain interior. Grain boundary liquation can cause cracking in the PMZ. PMZ cracking has also been called edge-of-weld cracking (Ref. 2), base-metal cracking (Ref. 3), hot cracking (Ref. 4), heat-affected zone cracking (Ref. 5), and liquation cracking (Ref. 6). The name liquation cracking is used in the present study.

Aluminum alloys are known to be susceptible to liquation cracking in the PMZ during welding. Liquation cracking in aluminum welds has been a subject of great interest in welding (Refs. 1–16).

Huang and Kou (Refs. 16–20) recently studied PMZ liquation in the welds of Alloys 2219, 2024, 6061, and 7075, including the liquation mechanisms, GB solidification, GB segregation, and PMZ weakening caused by GB segregation. Alloy 2219 is used to investigate liquation cracking in the present study.

Metzger (Ref. 3) reported the effect of the weld metal composition on liquation cracking in aluminum welds. Liquation cracking occurred in full-penetration gas tungsten arc (GTA) welds of Alloy 6061 made with Al-Mg fillers at high dilution ratios but not with Al-Si fillers at any dilution ratios. Metzger's study has been confirmed by subsequent studies on 6061 and similar alloys such as 6063 and 6082 (Refs. 5, 7–12).

KEY WORDS

Aluminum Alloys
Gas Metal Arc Welding (GMAW)
Liquation Cracking
Papillary Penetration
Penetration Oscillation

Gittos and Scott (Ref. 5) conducted the circular-patch test (Ref. 21) on an aluminum alloy close to Alloy 6082 in composition. Full-penetration GTA welds were made with filler metals of Al-5Mg and Al-5Si. As in the study of Metzger (Ref. 3), liquation cracking occurred in the welds made with the Al-5Mg filler at high dilution ratios (about 80%) but not in the welds made with the Al-5Si filler at any dilution ratios.

Katoh et al. (Ref. 7), Kerr et al. (Ref. 8), and Miyazaki et al. (Ref. 9) conducted the Varestraint test (Refs. 22, 23) on 6000-series alloys including Alloy 6061. Partial-penetration GTA and gas metal arc (GMA) welds were made. Longitudinal liquation cracking occurred with a 5356 filler but not with a 4043 filler.

The present study deals with liquation cracking near the weld root in partial-penetration aluminum welds, focusing on the effect of penetration oscillation and backfilling on liquation cracking. The simple binary Al-Cu Alloy 2219 was selected to help understand liquation cracking more easily. However, similar cracking has also been observed in multicomponent aluminum alloys and the results will be reported elsewhere. Liquation cracking in full-penetration aluminum welds will also be reported elsewhere (Ref. 24).

Experimental Procedure

The workpiece was Alloy 2219-T851. "T8" stands for solution heat treating and cold working, followed by artificial aging, and "Tx51" stands for stress relieving by stretching (Ref. 25). The actual compositions of the alloys are listed in Table 1 along with those of the filler metals. The workpiece was 20 cm long (8 in.), 10 cm wide (4-in.), and 9.5 mm thick (⅜ in.). It was welded in the as-received condition.

Bead-on-plate GMAW was carried out perpendicular to the rolling direction of the workpiece. Figure 1 shows that the workpiece was neither clamped down to any fixture nor subjected to any augmented strains such as bending. It simply rested on the top of two aluminum supports mounted on a carriage. A semiautomatic welding gun was mounted on a stationary support and the workpiece moved at a constant speed under the gun.

The welding parameters were 7.41-mm/s (17.5-in./min) travel speed, 30-V arc voltage, 250-A average current, and Ar shielding. The wire diameter was 1.2 mm (¾4 in.) and the feed rate was 18.6 cm/s (440 in./min). The contact tube to workpiece distance was about 12.7 mm (0.5 in.), and the torch was held perpendicular to the workpiece.

The filler metals were 1100, 2319, 4145, 4047, and 2319 plus extra Cu. Filler metal 1100 has essentially no Cu, and the matching filler 2319 has as much Cu as Alloy 2219. Filler metal 4145 has about 4 wt-% Cu and 10 wt-% Si, and filler metal 4047

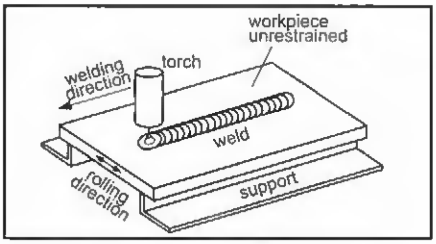

Fig. 1 — Welding with workpiece unrestrained to avoid interfering with interaction between the weld metal and partially melted zone during welding.

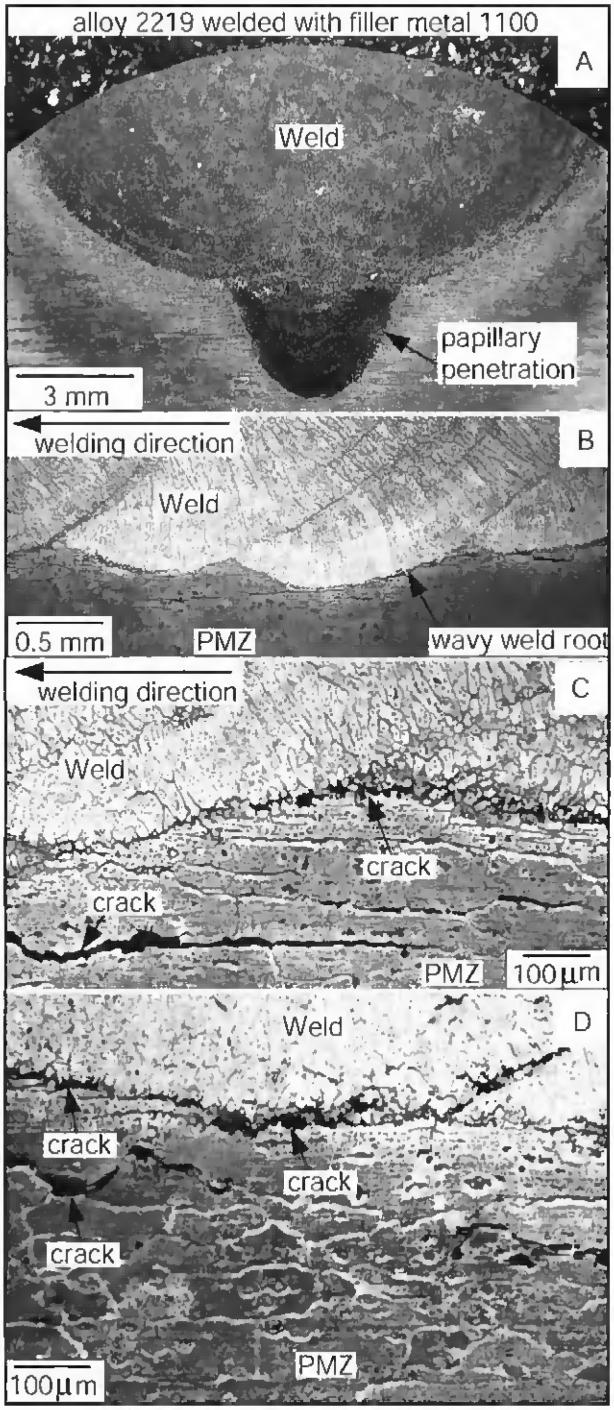

Fig. 2 — Weld made with filler metal 1100: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

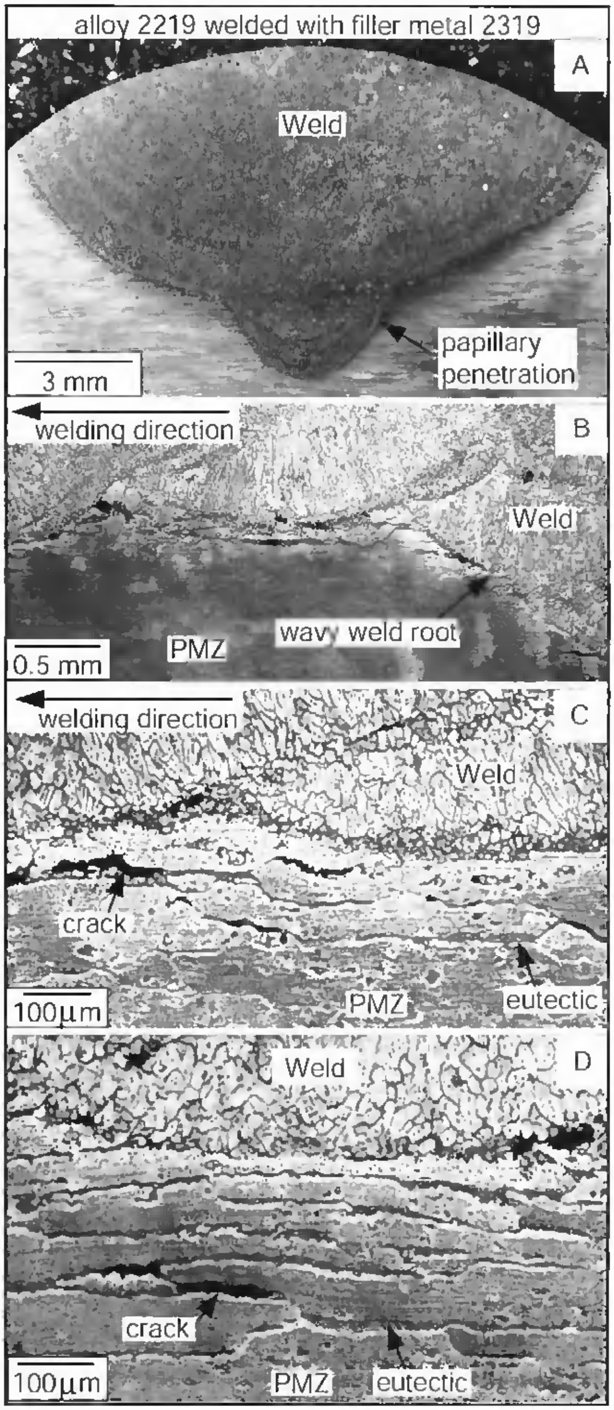

Fig. 3 — Weld made with filler metal 2319: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

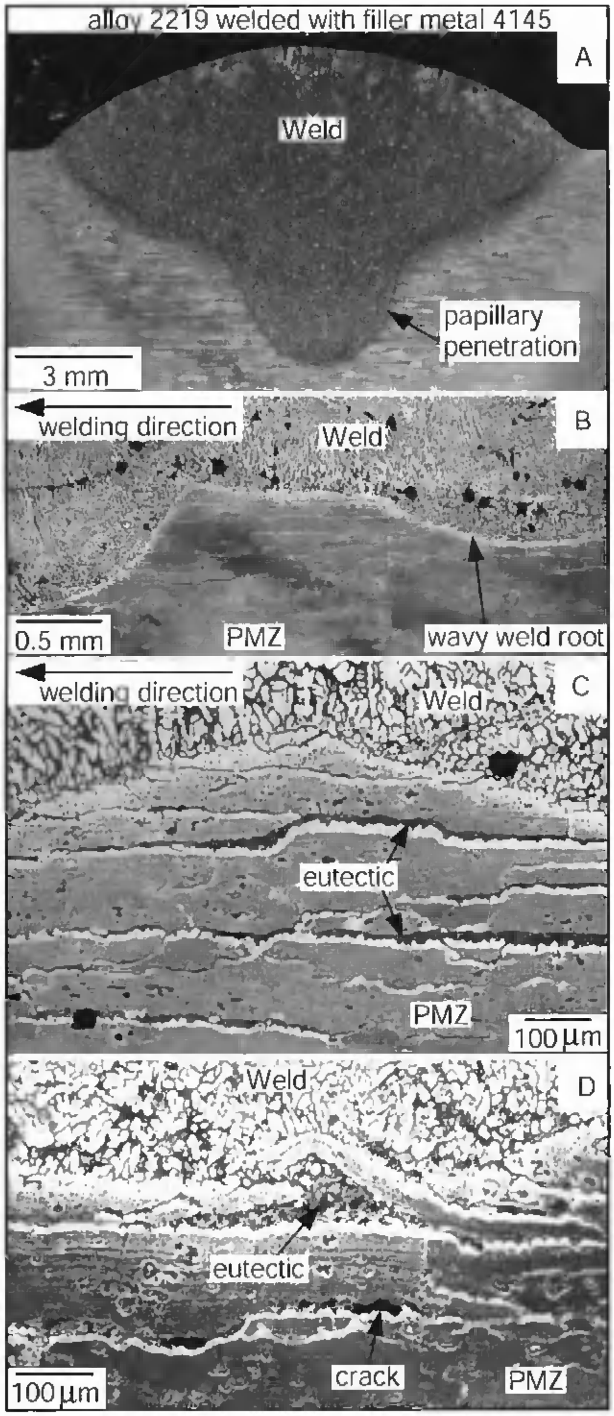

Fig. 4 — Weld made with filler metal 4145: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

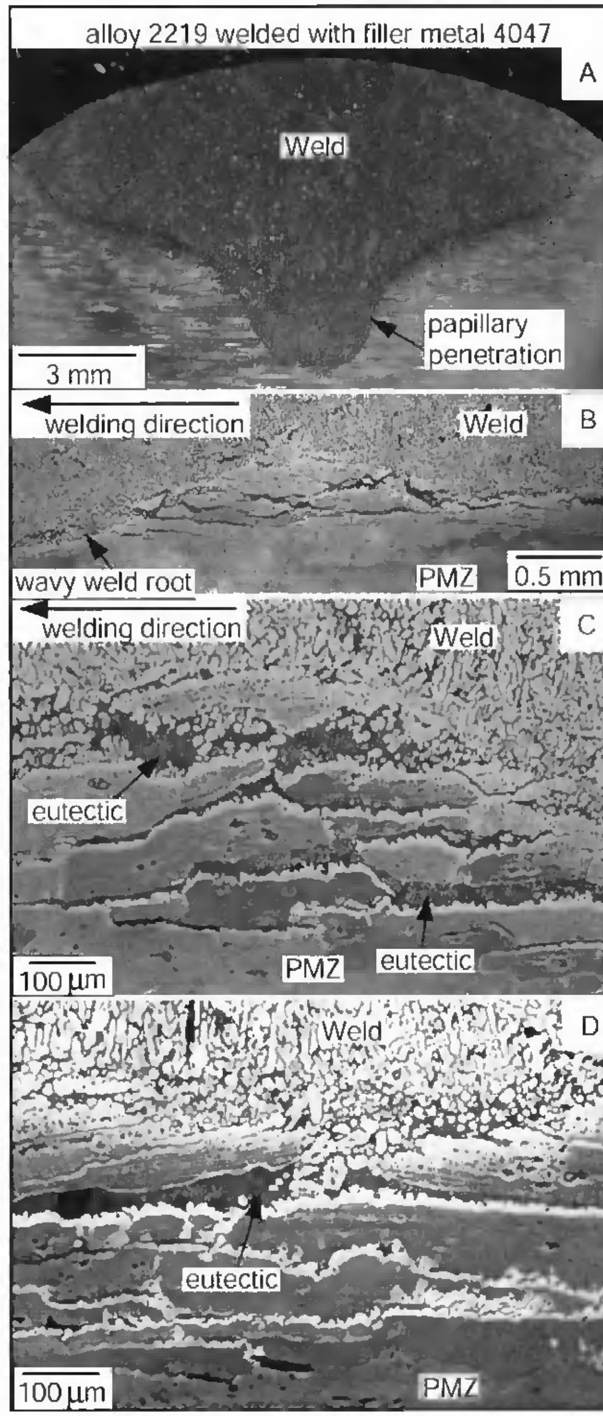

Fig. 5 — Weld made with filler metal 4047: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

Table 1 — Chemical Compositions of the Workpiece and Welding Wire in Wt-%

	Si	Cu	Mn	Mg	Cr	Zn	Ti	Fe	Zr
Workpiece									
2219	0.09	6.49	0.32	0.01	–	0.03	0.06	0.14	0.13
Filler Metals									
1100	0.08	0.08	0.01	–	–	0.02	–	0.52	–
2319	0.10	6.30	0.30	–	–	–	0.15	0.15	0.18
4145	9.9	3.9	0.01	0.05	0.01	0.04	–	0.2	–
4047	11.6	0.03	–	0.02	–	–	–	0.2	–

has about 12 wt-% Si. The extra Cu was a pair of Cu wires of 99.999 wt-% purity and 1 mm diameter that were positioned in a 2-mm-wide by 1-mm-deep rectangular groove along the centerline of the workpiece surface. The Cu wires were gas tungsten arc welded (GTAW) three times to melt and mix with the surrounding base metal. The condition for GTAW was 14 V, 160 A, DC electrode negative, and 4.2-mm/s (10-in./min) travel speed with Ar

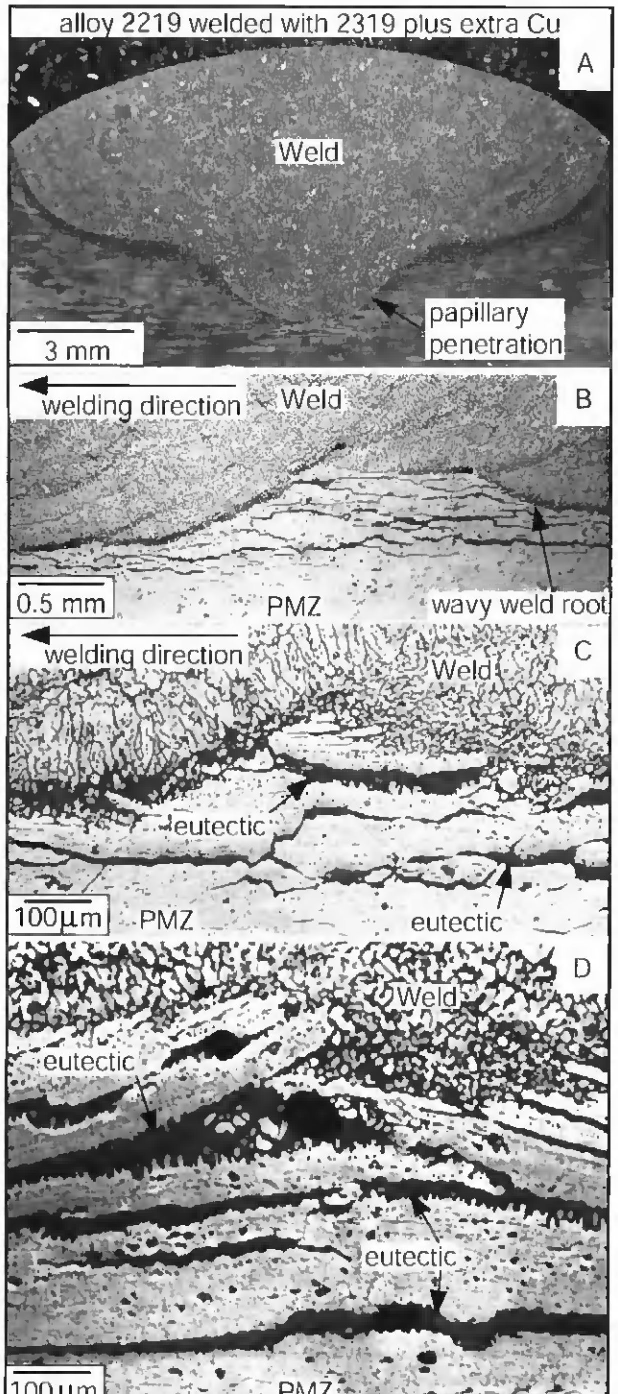

Fig. 6 — Weld made with filler metal 2219 plus extra Cu: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

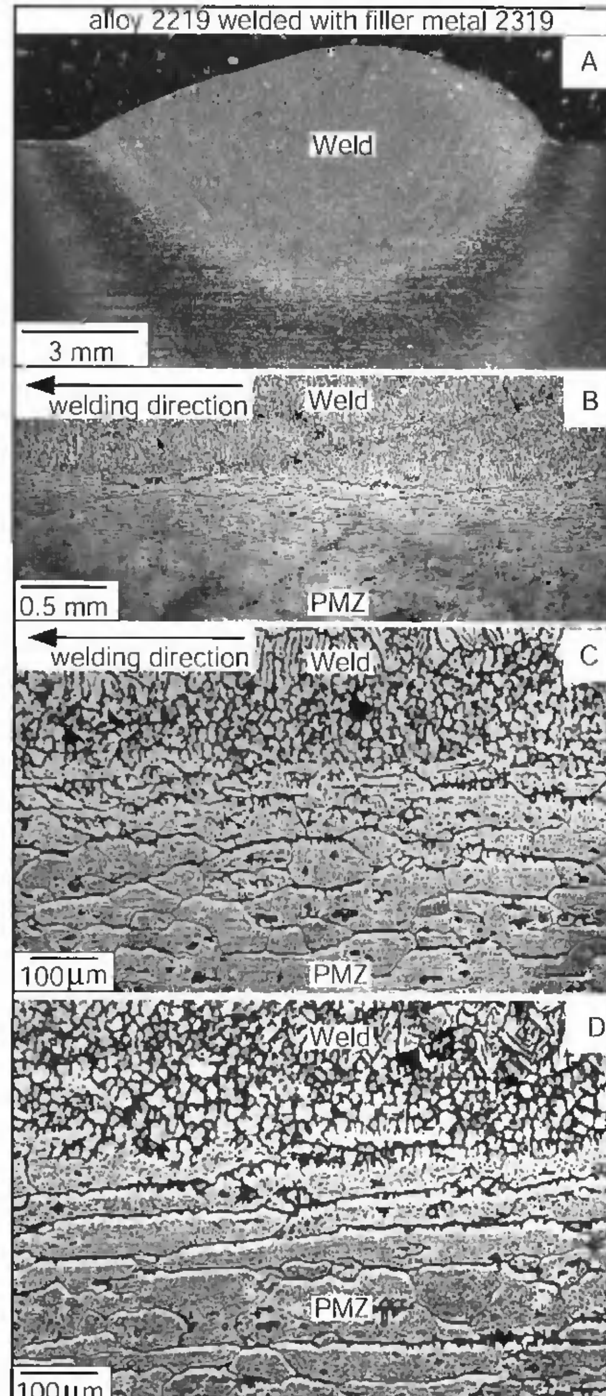

Fig. 7 — Smooth weld made with filler metal 2319 without papillary penetration and liquation cracking: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

shielding. The resultant weld bead was about 6 mm wide at the top and 4 mm deep, which was well within the GMA weld made subsequently with filler metal 2319 in order to include all the extra Cu into the GMA weld.

A workpiece 20 cm long (8 in.), 10 cm wide (4 in.), and 7.9 mm thick ($\frac{5}{16}$ in.) was also welded. The welding parameters were 7.20-mm/s (17-in./min) travel speed, 26.5-V arc voltage, 195-A average current, and Ar shielding. The welding wire was a 1.2-mm-diameter wire of Alloy 2319, and the wire feed rate was 13.5 cm/s (320 in./min). The contact tube to workpiece distance was 25.4 mm (1 in.), and the torch pointed forward at a 15-deg angle from the vertical line instead of vertically down.

The resultant welds were cut, polished, and etched with a solution of 0.5 vol-% HF in water for microstructural examination by optical microscopy. Transverse cross sections of the welds were taken with a digital camera.

The concentration of any element, E, in the weld metal was calculated as follows:

$$\%E \text{ in weld metal} = (\%E \text{ in base metal}) \times [A_b / (A_b + A_f)] + (\%E \text{ in filler metal}) \times [A_f / (A_b + A_f)] \quad (1)$$

where A_b and A_f are the areas in the weld

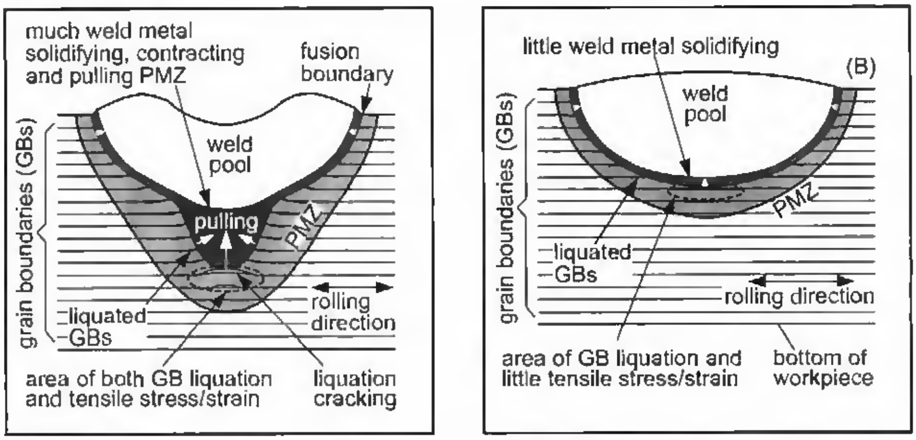

Fig. 8 — Localized stress/strain in the partially melted zone (PMZ) in the transverse cross section of a solidifying weld pool traveling perpendicular to the rolling direction. A — Papillary penetration; B — smooth weld bottom.

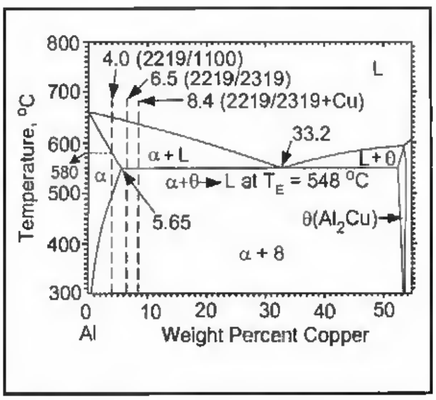

Fig. 9 — Aluminum-rich side of Al-Cu phase diagram (Ref. 38).

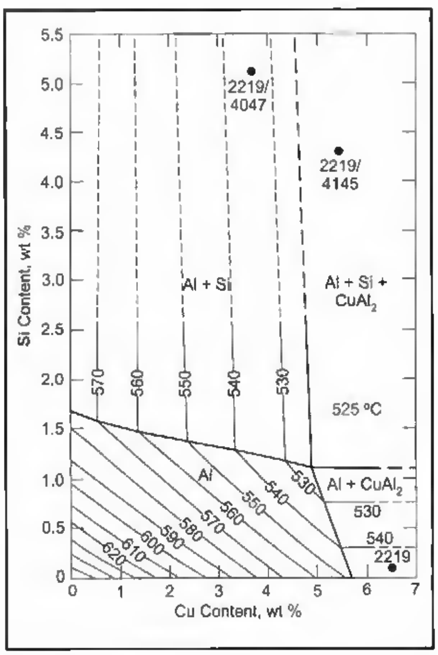

Fig. 10 — Al-Cu-Si solidus temperature map (Ref. 39). 2219/4145 and 2219/4047 denote welds of Alloy 2219 made with filler metals 4145 and 4047, respectively.

transverse cross section that represent contributions from the base metal and filler metal, respectively. The ratio $A_b/(A_b + A_f)$ is the dilution ratio. Areas A_b and A_f were determined from the transverse macrograph by using commercial computer software.

Results and Discussion

Characteristics of Weld Penetration

Figures 2 through 6 show the results of the bead-on-plate welds made in the 9.5-mm (⅜-in.) workpiece with various filler metals. The transverse macrographs of the welds in Figs. 2A through 6A show a papillary- (nipple-) type penetration. Some of the papillary penetrations were shallower than others. The depth appeared to vary to some extent with the filler metal, but no apparent patterns of variations were found.

The longitudinal macrographs of the same welds in Figs. 2B through 6B show that the weld root was wavy along the weld instead of smooth. This surprising result indicates that papillary penetration was not steady but oscillated up and down along the weld.

In GMAW, spray transfer is the most commonly used mode of metal transfer from the welding wire to the weld pool. In GMAW of aluminum alloys with Ar shielding, which is the most widely used process for welding aluminum alloys, the arc energy is concentrated along the core of the arc because of the relatively low thermal conductivity of Ar. Consequently, the Ar arc plasma has a very high-energy core and an outer mantle of lesser thermal energy. This helps to produce a stable, axial transfer of metal droplets through an Ar arc plasma. The resultant weld transverse cross section is often characterized by a papillary-type penetration pattern (Ref. 26).

While the papillary-type penetration pattern in GMAW of aluminum alloys is well-known, the oscillation of a papillary penetration along the weld is not (at least not to the best knowledge of the authors).

As shown in Figs. 2B through 6B, the penetration depth of the GMA welds made with Ar shielding oscillated rather than remaining constant. The causes for penetration oscillation can be fluctuations in, for instance, the welding current, welding wire melt rate, or droplet transfer. With the superheat and momentum of the filler metal droplets in spray transfer, these fluctuations can cause thermal and, hence, melting fluctuations at the pool bottom when the droplets penetrate the weld pool and impinge on the pool bottom. Fluctuations in the arc pressure can cause pool surface oscillation (Refs. 27–32), which may also affect heat transfer to the pool bottom.

Penetration Oscillation and Liquation Cracking

The longitudinal micrographs of the welds in Figs. 2C through 6C show liquation cracking in the PMZ near the weld root. The cracks were intergranular, ranging from open (Fig. 2C) to backfilled (Figs. 4C–6C). The transverse micrographs of the welds in Figs. 2D through 6D show similar characteristics of liquation cracking. It is evident from Fig. 2B and C through Fig. 6B and C that liquation cracking occurred most often in the area between waves of the wavy weld root.

Of all the filler metals used for welding Alloy 2219 in the present study, 2319 resulted in the least liquation cracking. It is known that many welds of Alloy 2219 fabricated with filler metal 2319 have been found crack-free. In the aerospace industry, such welds have been made by GTAW, which does not cause penetration oscillation. The authors have made such welds by full-penetration GMAW in circular-patch testing, and, of course, no penetration oscillation can occur in full-penetration welds. They have also made such welds by partial-penetration GMAW in which penetration oscillation was absent. What Fig. 3 shows clearly is that small liquation cracks can appear in partial-penetration GMAW of 2219 with 2319 and Ar if PMZ liquation is significant and penetration oscillation is clear (that is, the weld root shows clear waves along the welding direction).

The presence of liquation cracking in the full-penetration GTA welds of Metzger (Ref. 3) and Gittos and Scott

(Ref. 5), where neither the papillary penetration nor penetration oscillation exists, does not necessarily imply that the weld penetration type is not a dominant factor in liquation cracking. The present study by no means suggests liquation cracking cannot occur in aluminum welds unless the papillary penetration or penetration oscillation exists. As mentioned previously, liquation cracking has been observed in full-penetration aluminum welds by the authors and it will be reported elsewhere (Ref. 24).

Steady Penetration and Absence of Liquation Cracking

Figure 7 shows a bead-on-plate weld made in the 7.9-mm (5/16-in.) workpiece with filler metal 2319. As shown in the transverse macrograph in Fig. 7A, the bottom of the weld was smooth and without any papillary penetration. The use of the lower welding current (wire feed rate), the longer distance between the contact tube and the workpiece, and the 15-deg torch angle made the weld bottom smooth but reduced the penetration depth by about 40%.

As shown in the longitudinal macrograph in Fig. 7B, the weld root was smooth and without clear penetration oscillation along the weld. Neither the longitudinal micrograph of the weld in Fig. 7C nor the transverse micrograph in Fig. 7D shows any evidence of liquation cracking in the PMZ.

Another 2219 weld was made in the 9.5-mm-thick (3/8-in.) workpiece by gas-tungsten arc welding with Ar and filler metal 1100. The weld had a penetration depth about the same as that in the 2219 weld shown in Fig. 2. However, the weld was smooth — without a papillary penetration or a wavy weld root. No liquation cracking was observed. This will be discussed further elsewhere because of space limitations.

In summary, liquation cracking occurred in welds with a wavy weld root but did not occur in welds with a smooth weld root, and the effect of weld penetration oscillation on liquation cracking was thus demonstrated.

Deformation, Cracking, and Localized Stress/Strain in PMZ

According to Borland (Ref. 33), there are essentially three hot cracking theories — the shrinkage-brittleness theory, the strain theory, and the generalized theory that includes the relevant ideas from the first two theories. According to the generalized theory, cracking can take place in a material in which continuous liquid films separate grains or in which some solid-solid bridges exist between grains (Ref. 33). When the localized tensile stress/strain in the material exceeds its resistance to cracking, hot cracking occurs.

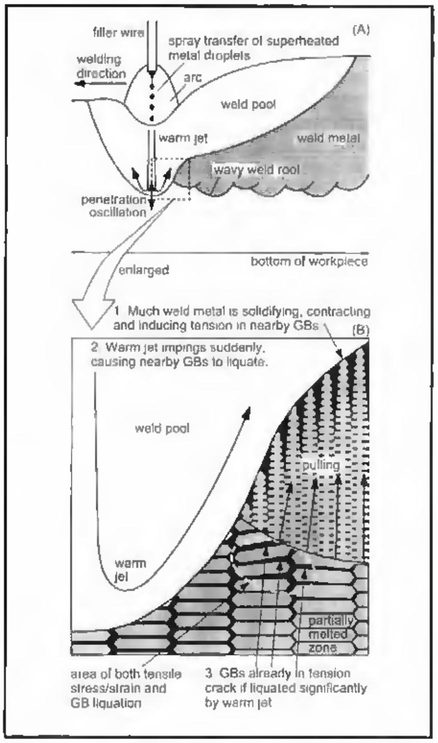

Fig. 11 — Mechanism of liquation cracking near weld root induced by penetration oscillation and grain-boundary liquation. A — Overview; B — enlarged view (with cracks backfilled).

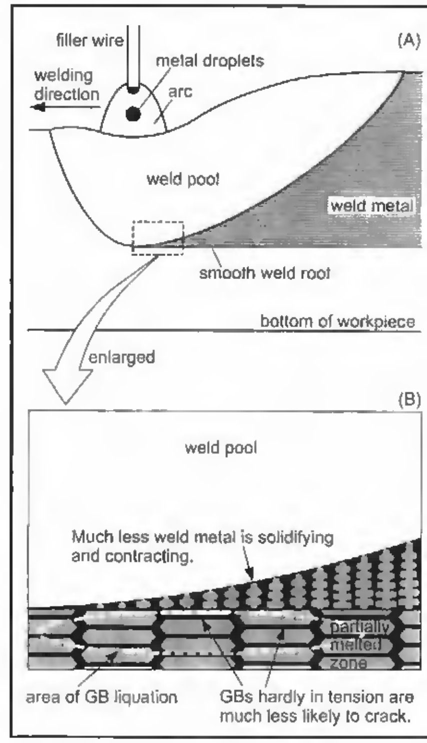

Fig. 12 — Liquation cracking is much less likely to occur without penetration oscillation. A — Overview; B — enlarged view.

Since the workpiece was not bent during welding to cause cracking as in Varestaint testing, the PMZ microstructure and cracks were not changed by any external forces and thus can provide qualitative information about the localized stress/strain in the PMZ that caused liquation cracking. The use of a freestanding workpiece does not eliminate the self-induced stress/strain during welding. However, liquation cracking occurs in an area in the PMZ near to the weld root, about 500 μm based on Figs. 2 through 6. It is likely that in the PMZ *near to the weld root*, the contraction of the solidifying weld metal dominates the tensile stress/strain during welding. This is because the solidification shrinkage and thermal contraction of aluminum alloys are both high and because no external stress/strain was applied during welding. The solidification shrinkage of aluminum is as high as 6.6% (Ref. 34). The thermal expansion coefficient of aluminum is roughly twice that of iron base alloys.

Before preceding any further, it should be pointed out that analysis of the localized stress/strain in the PMZ of a weld with penetration oscillation is beyond the scope of the present study. As already shown, liquation cracking occurred in welds with clear penetration oscillation but did not occur in smooth welds. The authors are unaware of any liquation cracking theories that consider the localized stress/strain in welds with penetration oscillation. They are also unaware of any methods for calculating or measuring the localized stress/strain in welds with penetration oscillation. The thermomechanical properties of semisolids such as the liquated PMZ and the solidifying weld metal are unavailable in the first place. Figures 2 through 6 show that liquation cracking occurred most often in the tiny area between waves along the wavy weld root, which can be far too small, too hot, and inaccessible for stress/strain measurements. Therefore, liquation cracking will be discussed based on the localized stress/strain in the PMZ near the weld root that was deduced from the deformed grains and cracks. In the study of Gittos and Scott (Ref. 5), the phrase "tensile strains arising from weld metal solidification" was used to qualitatively describe the localized stress/strain in the PMZ.

Figures 3D through 6D showed that the PMZ grains near the weld root were deformed; that is, pulled upward toward the tip of the papillary penetration. The deformed grains and the liquation cracks together suggest that weld metal solidification in the papillary penetration induced an upward tensile stress/strain in the PMZ near the tip of weld-pool penetration during welding and caused liquation cracking.

The localized tensile stress/strain in-

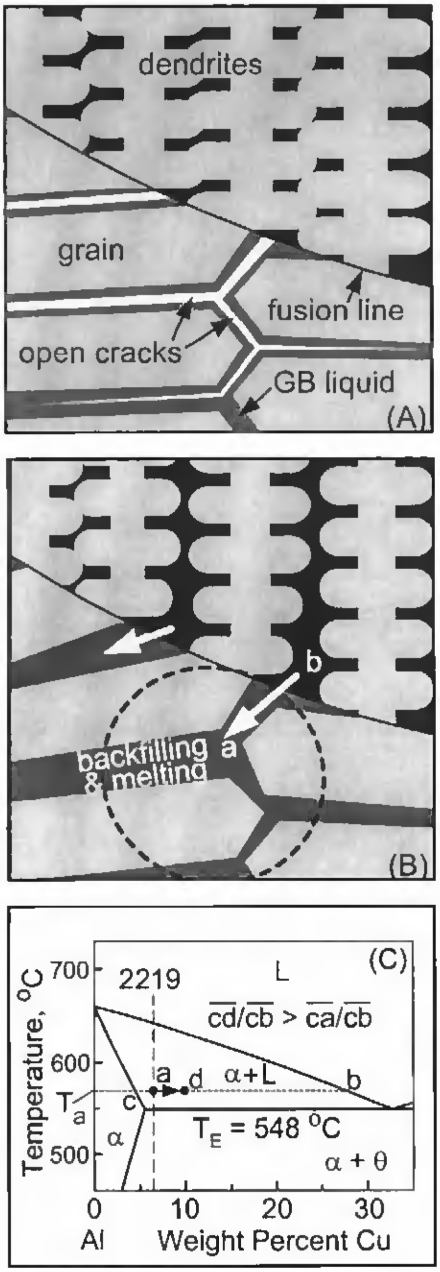

Fig. 13 — Backfilling of liquation cracks. A — No backfilling; B — backfilling and backfilling-induced melting; C — backfilling-induced increase in local average composition and increase in liquid fraction (melting) around cracks.

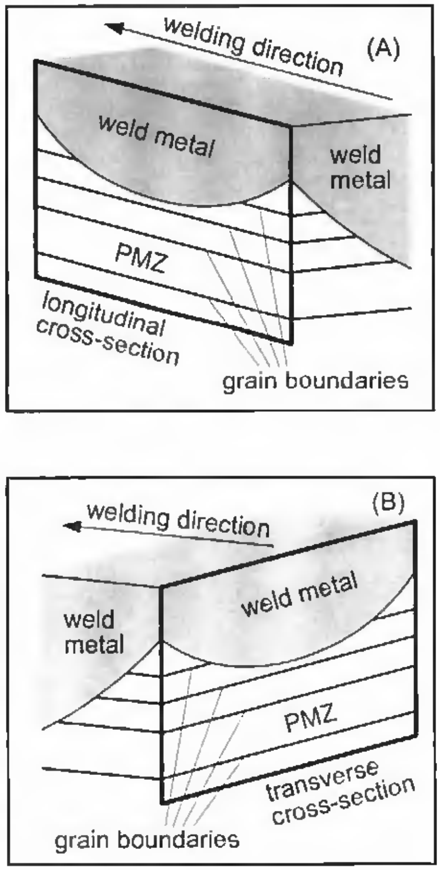

Fig. 14 — Access of grain boundaries in partially melted zone (PMZ) to weld metal. A — Longitudinal cross section; B — transverse cross section.

duced in the PMZ near the weld root increases with increasing extent of weld metal solidification. That is, the more solid that forms in the weld metal, the greater the localized tensile stress/strain is induced in the PMZ near the weld root by weld metal contraction. Meanwhile, the material resistance of the PMZ to cracking decreases with increasing extent of GB liquation. Thus, in the PMZ near the weld root the localized tensile stress/strain competes with the material resistance to cracking. If, near the weld root, much weld metal is already solidifying while the PMZ is still liquated significantly, it is likely that the localized tensile stress/strain exceeds the material resistance to cracking and liquation cracking occurs. On the other hand, if little weld metal is solidifying while the PMZ is still liquated significantly, liquation cracking is unlikely to occur.

Figure 8 shows the transverse cross section of a solidifying weld pool traveling perpendicular to the rolling direction and the localized stress/strain in the PMZ near the weld root. As shown in Fig. 8A, the solidifying weld metal is significantly thicker inside the papillary penetration than elsewhere. (It is thicker because the weld metal in the papillary penetration, surrounded by a cooler PMZ on all sides as well as at the bottom, solidified rapidly. This is evident because the dendrite arm spacing was much finer inside the papillary penetration than near the bulk weld, but this will be shown elsewhere due to space limitations.) Because the solidifying weld metal is relatively thick inside the papillary penetration, it is already developing strength and contracting. The PMZ, however, does not contract as much as the weld metal does because solidification shrinkage is much less in the PMZ, in view of the much smaller volume of the GB liquid than the weld pool. Consequently, tensile stress/strain is induced in the PMZ near the weld root. This tensile stress/strain can be harmful because it is concentrated near the tip and normal to liquated GBs and thus can easily open them up.

On the other hand, as shown in Fig. 8B, the solidifying weld metal near the bottom of a smooth weld pool is much thinner, and thus it induces little tensile stress/strain in the PMZ nearby. This smooth weld without a papillary penetration is similar to that shown in Fig. 7. As shown in Figs. 7C and D, there was no liquation cracking in the weld. Very small waves and slightly deformed grains were observed occasionally along the weld, but no cracks were found.

As can be seen from Fig. 8A, liquation cracking is more likely to occur at the bottom of the fusion boundary than at the top. This was confirmed by the absence of liquation cracking at the top (micrographs not shown because of space limitations). Here, the direction of the tensile stress/strain is nearly parallel to the GBs, and the solidifying weld metal is thin. Furthermore, there is less liquation because of the steeper temperature gradients (that is, narrower PMZ) at the top (Refs. 1, 19).

Before leaving this section, it is worth discussing the weld made with filler metal 2319 plus extra Cu (Fig. 6) a little further. Making a solute-rich preweld before welding is an established technique for achieving the desired weld metal composition (Refs. 35–37). The severe liquation cracking (Fig. 6D) was not likely to be caused by the early formation of high-temperature, Cu-rich intermetallic compounds because the microstructure showed no evidence of such compounds in the weld metal. The liquation cracking was not likely to be caused by the residual stresses induced by the additional GTA passes, either. This is because the welds made with filler metals 4145 (Fig. 4D) and 4047 (Fig. 5D) also showed much liquation cracking — without making a solute-rich preweld before GMAW.

Solidus Temperatures and Liquation Cracking

According to Gittos and Scott (Ref. 5), the solidus temperature of the weld metal vs. that of the base metal has a strong effect on liquation cracking. Figure 9 shows the binary Al-Cu phase diagram (Ref. 38), which can be used to determine the solidus temperature of the weld metal in welds made with filler metals 1100, 2319, and 2319 with extra Cu. Likewise, Fig. 10 shows the solidus temperatures of Al-Cu-Si ternary alloys (Ref. 39), which can be used for the welds made with filler metals 4145 and 4047. The solid lines represent experimental data and the broken lines are extrapolated from the solid lines.

Consider first the welds made in Alloy 2219 (Al-6.49Cu) with filler metal 1100 (Al-0.08Cu), 2319 (Al-6.30Cu), or 2319 with extra Cu. With 1100, the weld metal composition was Al-4.0Cu (dilution ratio 60.6%). From Fig. 9, the solidus temperature of the weld metal is 580°C. Similarly, with 2319 the weld metal composition was Al-6.4Cu (dilution ratio 60.6%). Since the eutectic temperature 548°C is the lowest possible temperature for an equilibrium liquid phase to exist in this weld metal, it is taken as its solidus temperature for the purpose of discussion. With 2319 plus extra Cu, the weld metal composition was Al-8.4Cu (dilution ratio 56.8%). The solidus temperature of the weld metal is again taken as the eutectic temperature 548°C.

Consider now the welds made in Alloy 2219 (Al-6.49Cu-0.09Si) with filler metals 4145 (Al-3.9Cu-9.9Si) and 4047 (Al-11.6Si-0.03Cu). With filler metal 4145, the weld metal composition was Al-5.38Cu-4.31Si (dilution ratio 57.0%). As shown in Fig. 10, the solidus temperature of the weld metal was 525°C. Similarly, with filler metal 4047, the weld metal composition was Al-3.67Cu-5.11Si (dilution ratio 56.4%) and the solidus temperature was 534°C.

In order to double-check the accuracy of the extrapolated solidus temperatures in Fig. 10, the computer program *Pandat* (Ref. 40) was used. The program calculates phase diagrams and solidification paths based on thermodynamic models and data. The calculated solidus temperatures based on equilibrium solidification was 524°C for the weld made with filler metal 4145 and 534°C for the weld made with filler metal 4047, which confirmed the solidus temperatures in Fig. 10.

Gittos and Scott (Ref. 5) stated, "The proposed mechanism of HAZ cracking is that, during welding, grain boundary melting occurs in the HAZ and with certain base metal and weld metal compositions, it is possible for the base metal solidus to be below the weld metal solidus. Thus, when tensile strains arising from weld metal solidification are imposed on the HAZ, cracking occurs at such boundaries." In the weld made with filler metal 1100 in the present study, liquation cracking occurred and the weld metal did have a higher solidus temperature (580°C) than the base metal (548°C). In the welds made with filler metals 2319 and 2319 plus extra Cu, however, liquation cracking occurred but the weld metal did not have a higher solidus temperature than the base metal. In the welds made with filler metal 4145 and 4047, liquation cracking also occurred, but the weld metal did not have a higher solidus temperature than the base metal, either.

In fact, Miyazaki et al. (Ref. 9) have also stated: "When the A6061 alloy was actually GMA welded using 5356 filler metal, longitudinal cracking was observed, but, contrary to Gittos et al., it was not observed that the solidus temperature of the weld metal became higher than that of the base metal." It was suggested that constitutional liquation induced by low-temperature eutectic reactions in the base metal could have made the effective solidus temperatures of the base metals lower than those of the weld metal. While this is likely to be true for Alloy 6061, liquation occurs in Alloy 2219 at the eutectic temperature 548°C and is thus not lower than that of the weld metal.

It is worth pointing out that the solidus temperature is relevant for equilibrium solidification. However, equilibrium solidification is not likely to occur in welding in view of the high cooling rates during welding, and the terminal solidification occurs through eutectic reactions at temperatures well below the solidus temperature. The solidus temperatures of the weld metal and the base metal are discussed in this section only for the purpose of comparing the experimental results in the present study with the theory of Gittos and Scott (Ref. 5).

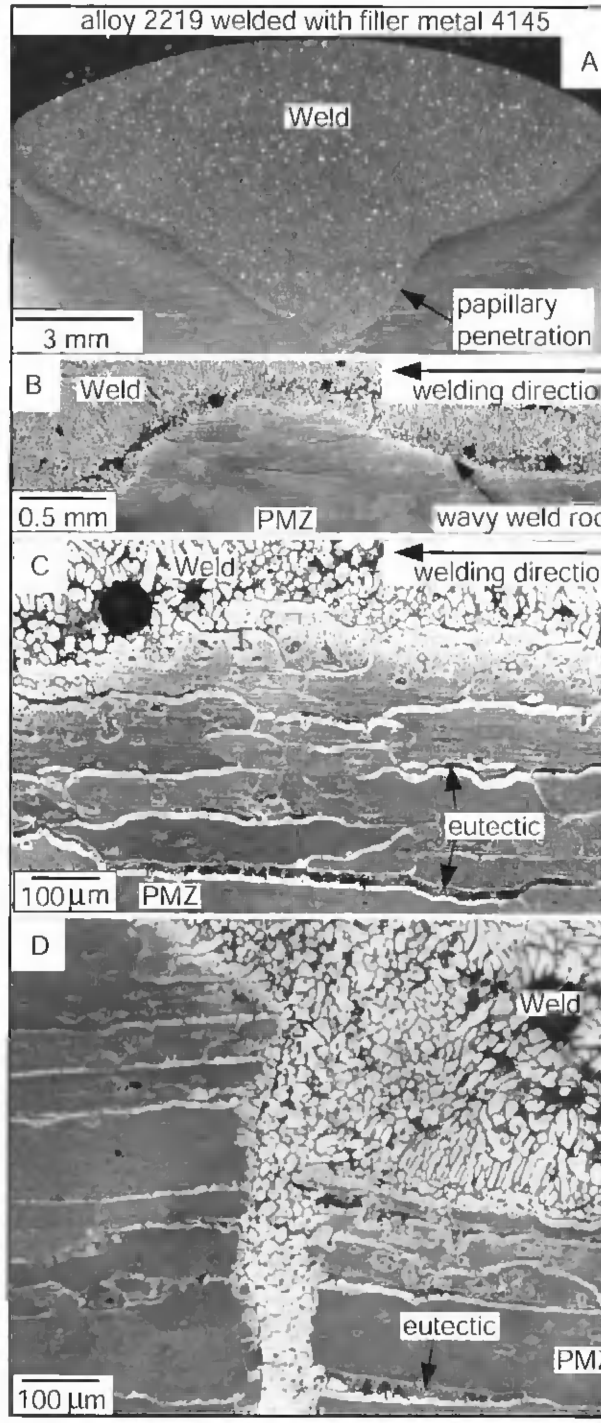

Fig. 15 — Weld in a butt joint made with filler metal 4145: A — transverse macrograph; B — longitudinal macrograph; C — longitudinal micrograph; D — transverse micrograph.

Effect of Penetration Oscillation on Liquation Cracking

A liquation-cracking mechanism is proposed in Fig. 11 to help explain the effect of penetration oscillation on liquation cracking. The emphasis is to explain the effect of penetration oscillation on liquation cracking observed in the present study — not to indicate that the conventional liquation cracking is generally incorrect.

As shown in Fig. 11A, in GMAW with spray transfer, weld-pool penetration can oscillate and result in a wavy weld root along the weld. A depression is formed at the pool bottom when the jet carrying the superheat of the liquid droplets impinges on the pool bottom. The area inside the rectangle is enlarged in Fig. 11B. As shown, much weld metal has already been solidifying, developing strength, contracting, and pulling the PMZ underneath. As such, significant tensile stress/strain is induced in the PMZ by weld metal solidification. When the warm jet impinges suddenly, the nearby GBs liquate upon heating by the jet. The PMZ GBs near the weld root immediately behind the oscillating weld-pool penetration front, as indicated in the figure, are subjected to both GB liquation and tensile stress/strain. If liquation is significant, the GBs can be severely weakened. Consequently, the localized tensile stress/strain can exceed the material resistance to cracking, and liquation cracking can occur. The incipient liquation cracks are likely to be small but they can gradually grow in size as weld metal solidification continues during welding. Figure 8A, in fact, is a transverse cross section showing the localized stress/strain in the PMZ near the weld root immediately behind the weld-pool penetration front.

Significant GB liquation is required for liquation cracking to occur even in the presence of clear penetration oscillation. For an aluminum alloy that can liquate significantly during welding, such as Alloy 2219, liquation cracking can occur easily in a weld with clear penetration oscillation. However, for an alloy that liquates much less significantly, liquation cracking may not occur even with clear penetration oscillation. This is because GBs are still well bridged together because of the relatively light GB liquation; that is, the PMZ resistance to cracking exceeds the localized tensile stress/strain. For instance, Alloy 6061 welded under the same condition as Alloy 2219 showed clear penetration oscillation. However, it neither liquated significantly nor exhibited liquation cracking. The results of Alloy 6061 will be reported elsewhere because of space limitations.

The absence of liquation cracking in a weld with a smooth weld root (Fig. 7) can be explained with the help of Fig. 12A, which shows a steady weld pool and the smooth weld root behind it. There is neither penetration oscillation nor a wavy weld root. The area inside the rectangle is enlarged in Fig. 12B. As compared to the case in Fig. 11B, there is much less weld metal solidification to induce tensile stress/strain in the PMZ and cause it to exceed the PMZ resistance to cracking. Farther down the weld, weld metal solidification increases but PMZ solidification also increases, and the PMZ tensile stress/strain still may not exceed the PMZ resistance to cracking.

As mentioned previously, liquation cracking most often occurred in the PMZ in the area between neighboring waves of the wavy weld root — Figs. 2B and C through Figs. 6B and C. During welding, this area corresponds to that near the weld root immediately behind the oscillating penetration front of the weld pool, which is essentially the area of both GB liquation and tensile stress/strain shown in Fig. 11B. Since the weld-pool penetration front subsequently solidifies as the next wave in the wavy weld root, this area ends up being between two neighboring waves. This explains why liquation cracking most often occurs in the area between neighboring waves of the wavy weld root.

In view of Fig. 11 and the rapid solidification of the weld metal near the weld root, it is likely there can still be enough weld metal solidifying before the warm jet impinges even when weld metal solidification is delayed by using a highly-alloyed filled metal. Thus, near the weld root the localized stress/strain induced in the PMZ by weld metal solidification, though reduced, can still exceed the PMZ resistance to cracking. This is consistent with the liquation cracking in the welds made with filler metal 4145, 4047, or 2319 plus Cu — Figs. 4–6. In fact, not only cracking occurred; the cracks were large and backfilled with much eutectic-rich material. This will be explained subsequently in the section below, headed "Backfilling-Induced Melting and Its Effect on Liquation Cracking."

Backfilling of Cracks

When liquation cracks are formed, a vacuum is created within them. A liquid connected to the cracks may or may not be sucked into them, depending on factors such as the quantity, viscosity, surface tension, and freezing temperature range of the liquid. Consequently, the cracks may remain open, as shown in Fig. 13A, or be backfilled as shown in Fig. 13B (and Fig. 11B as well).

If liquation cracks are backfilled, the liquid sucked into the cracks is most likely the solute-rich or even eutectic interdendritic liquid in the solidifying weld metal that is connected to the cracks rather than the liquid in the weld pool. This is because the material in the backfilled cracks was rich in eutectic — Figs. 3–6.

The higher the fraction of the solute-rich or eutectic interdendritic liquid in the solidifying weld metal at fusion boundary, the more backfilling can occur. Consider the welds made with filler metals 1100, 2319, and 2319 plus extra Cu. From the Al-Cu phase diagram shown in Fig. 9, the equilibrium partition ratio k = 5.65%/33.2% = 0.17 and the eutectic composition C_E = 33.2% Cu. For ease of discussion, the fraction of the liquid eutectic f_E will be used here as an indication of the amount of a solute-rich as well as a eutectic interdendritic liquid in the weld metal at the fusion line. The fraction of the liquid eutectic f_E can be calculated using the following form of the Scheil equation as an approximation (Ref. 1).

$$f_E = \left(\frac{C_o}{C_E}\right)^{\frac{1}{1-k}} \tag{2}$$

According to Equation 2, for the weld metal of the weld made with filler metal 1100, C_o = 4.0% Cu and f_E = 0.08. For that with filler metal 2319, C_o = 6.4% Cu and f_E = 0.14, and for that with 2319 plus Cu, C_o = 8.4% Cu and f_E = 0.19. This suggests that backfilling should increase as the filler metal is changed from 1100 to 2319, and 2319 plus Cu. Figures 2, 3, and 6 do show this trend. However, the cracks were much larger and were backfilled with much more eutectic-rich material in the case of 2319 plus Cu than in the case of 2319. These differences, which cannot be explained based on the fraction of eutectic alone, will be explained later in the next section.

Savage and Dickinson (Ref. 35) suggested that the viscosity of the weld metal may also affect backfilling. Si decreases the viscosity of aluminum (Ref. 41) and it has been used to improve the fluidity of molten aluminum in metal casting. Since filler metal 4047 contained about 12% Si, it may increase the Si content of the interdendritic eutectic in the solidifying weld metal and thus help backfilling. Cu, on the other hand, increases the viscosity of aluminum (Ref. 41). This implies that filler metal 1100 should help backfilling while 2319 plus Cu should discourage it. However, liquation cracks were open with filler metal 1100 but backfilled with 2319 plus Cu. Therefore, the effect of Cu on viscosity seemed minor. Neither Si nor Cu has a significant effect on the surface tension of aluminum (Ref. 41).

Although some GBs may appear to be separated from the weld metal, they can, in fact, be connected to the solidifying weld metal during welding to allow backfilling. Figure 14A shows how GBs in a longitudinal cross section (Figs. 3C–6C) can have access to the weld metal. This makes sense only if the longitudinal cross section is not along the weld central plane. However, it is unlikely that a weld was cut precisely along the weld central plane. Furthermore, even if this were true, the penetration tip of the weld pool still did not necessarily move along the weld central plane. Rather, it could oscillate left and right as well as up and down as it traveled along the welding direction, in view of the unsteady nature of filler metal transfer during welding.

Similarly, Fig. 14B shows how GBs in a transverse cross section (Figs. 3D–6D) can have access to the weld metal. It makes sense only if the transverse cross section is not cut precisely at the bottom of a wave of the wavy weld root, but it is not very likely that this actually happened.

Backfilling-Induced Melting and Its Effect on Liquation Cracking

As mentioned previously, liquation cracks were much larger and backfilled with much more eutectic-rich material when using highly alloyed filler metals 4145, 4047, and 2319 plus Cu — Figs. 4–6. This phenomenon will be explained with the help of the macrosegregation theory in metal casting. In metal casting, the flow of the solute-rich interdendritic liquid in the mushy zone (solid + liquid) can change the local average composition and liquid fraction in the mushy zone and cause eutectic-rich channels (freckles) to form in the ingots (Ref. 34).

Consider the backfilling illustrated in Fig. 13B. Point **a** is in the PMZ near the fusion boundary, where the temperature is T_a, and point **b** is in the solidifying weld metal nearby. Because of the high thermal conductivity of aluminum, the temperature at point **b** should be nearly identical to T_a. The white arrow from point **b** to point **a** indicates backfilling in the same direction. For simplicity, the composition fluctuation in the workpiece is neglected. Also, as in the derivation of the Scheil equation, the interdendritic liquid is assumed to be in equilibrium with the solid and to be locally homogeneous. In the Al-Cu phase diagram shown in Fig. 13C, point **a** indicates the local average composition of the area surrounding point **a** in Fig. 13B (indicated by the circle); that is, the workpiece composition (6.49% Cu). Likewise, point **b** in Fig. 13C indicates the composition of the interdendritic liquid at point **b** in Fig. 13B. As shown, the solute content at point **b** is much higher than the local average solute content at point **a**.

Consider first the hypothetical case in which the solute content of the interdendritic liquid at point **b** is identical to that of the local average solute content at point **a**. The local average liquid fraction at point **a** may increase momentarily when the interdendritic liquid at point **b** backfills the crack at point **a** but will quickly go back to its initial value before backfilling because there is only one local average liquid fraction at point **a** at a given temperature and composition. This can be seen from the following Scheil equation (Ref. 1):

$$f_L = \left(\frac{(-m_L)C_o}{T_m - T}\right)^{\frac{1}{1-k}} \tag{3}$$

where f_L is the liquid fraction, m_L (<0) the slope of the liquidus line in the phase diagram, C_o the solute content, T_m the melting point of pure aluminum, T temperature, and k the equilibrium partition ratio. According to Equation 3, at a given T and C_o, there is only one f_L.

However, as shown in Fig. 13C, the solute content of the interdendritic liquid at point **b** is much higher than the local average solute content at point **a**. Therefore, when the solute-rich interdendritic liquid flows from point **b** to point a, the local average solute content at point a can increase significantly, as represented by the arrow pointing from point a to point **d** in Fig. 13C. Using the simple lever-arm rule and the phase diagram as a rough indication, it can be seen that the fraction of liquid increases from **ca/cb** before backfilling to **cd/cb** after. Likewise, according to Equation 3, at a given temperature T, the local average liquid fraction f_L increases with increasing local average solute content C_o. As such, when the solute-rich interdendritic liquid flows from point **b** to point **a**, the local average liquid fraction at point a can increase significantly.

Therefore, when the solute-rich interdendritic liquid backfills a liquation crack, it can melt the material along the crack and cause more GB liquation. Since the GBs around the crack are in tension (Fig. 11B), further GB liquation causes further liquation cracking. Further liquation cracking, in turn, causes further backfilling — as long as there is sufficient solute-rich interdendritic liquid at the fusion boundary available for backfilling. This cycle can continue until the local fusion boundary cools down to the eutectic temperature and solidifies completely. This is especially true for welds made with a highly alloyed filler metal such as 2319 plus Cu (and 4145 and 4047), in which there is abundant solute-rich interdendritic liquid available at the fusion boundary for backfilling. This may explain the formation of large liquation cracks and their backfilling with much eutectic-rich material in Fig. 6 (and Figs. 4 and 5).

Weld in a Butt Joint with Papillary Penetration

In Fig. 8 the grains are continuous and pointing in the rolling direction, but in the case of a butt joint, the grains are discontinuous at the joint. It is thus interesting to see the effect of this discontinuity.

Figure 15 shows a weld in a butt joint made in the 9.5-mm (⅜-in.) workpiece with filler metal 4145. As shown by the transverse macrograph of the weld in Fig. 15A, the weld had a papillary penetration similar to those in Figs. 2A through 6A. As shown by the longitudinal macrograph in Fig. 15B, the weld had a wavy weld root similar to those in Figs. 2B through 6B.

The longitudinal micrograph in Fig. 15C shows that the weld had liquation cracks. The cracks were intergranular and mostly backfilled, similar to those in Fig. 4C. The transverse micrograph in Fig. 15D shows the weld bottom near the butt joint, the fusion boundary being higher on the left and lower on the right. Some weld metal leaked into the gap at the joint during welding. Liquation cracking was evident in the PMZ near the joint. The grains in the PMZ near the weld root were deformed, similar to those shown in Fig. 4D. Therefore, the characteristics of papillary penetration and liquation cracking in a weld in a butt joint are similar to those in a bead-on-plate weld. For a weld in a butt joint with a much larger joint gap, however, liquation cracking at the weld root may not occur.

The results in the present study also have practical implications for dual-pass welding in butt joints. In such welding the first pass is made from one side of the workpiece and the second pass from the opposite side. First, if the penetration tips from the two sides fail to overlap with each other, numerous liquation cracks can be present along the weld. Second, with sufficient overlapping between the two passes, the weld root of the second pass can still be wavy and thus can cause liquation cracking inside the first pass if GB liquation is significant near the weld root.

Conclusions

In view of the susceptibility of aluminum alloys to liquation cracking and the wide use of Ar-shielded GMAW for aluminum welding, liquation cracking was studied in partial-penetration aluminum welds made using GMAW with Ar shielding. Alloy 2219, which is a simple binary Al-Cu alloy easy to understand, was welded with filler metals of various Cu and Si contents, including 1100, 2319, 4145, 4047, and 2319 plus extra Cu. Liquation cracking near the weld root was examined in the transverse and longitudinal macrographs and micrographs of the resultant welds. The conclusions are as follows:

- The papillary-type penetration common in GMAW tends to oscillate up and down during welding. The penetration oscillation results in a wavy weld root along the weld.
- The combination of clear penetration oscillation and significant GB liquation promotes liquation cracking. Liquation cracking near the weld root has a much greater tendency to occur in welds with penetration oscillation than in welds without it.
- In welds with penetration oscillation, liquation cracking occurs most often in the PMZ between neighboring waves of the wavy weld root.
- In welds with penetration oscillation, adjusting the weld metal composition with the filler metal can be ineffective in eliminating liquation cracking, though it has been shown effective in full-penetration aluminum welds and perhaps in partial-penetration aluminum welds without penetration oscillation as well.
- In welds with papillary penetration, the deformation of the PMZ grains near

the weld root suggests that weld metal solidification induces tensile stress/strain in the PMZ near the weld root. The high solidification shrinkage and thermal contraction of aluminum alloys cause the solidifying weld metal to contract and pull the PMZ.

• Susceptibility to liquation cracking can vary significantly within the PMZ. Liquation cracking can be much more significant near the weld root than at the weld top, where there are less liquation and tensile stress/strain.

• In welds with penetration oscillation, liquation cracking can still occur even when the weld-metal solidus temperature is not higher than the base-metal solidus temperature, contrary to the full-penetration welds in the study of Gittos and Scott (Ref. 5).

• A liquation-cracking mechanism has been proposed to explain the effect of penetration oscillation on liquation cracking: the PMZ GBs near the weld root immediately behind the oscillating penetration front of the weld pool are subjected to both GB liquation and tensile stress/strain, and liquation cracking can occur if liquation is significant enough to weaken the GBs severely.

• When attempting to use highly alloyed filler metals to delay weld metal solidification and thus eliminate liquation cracking, large liquation cracks can form and be backfilled with much eutectic-rich material if penetration oscillation is present.

• A backfilling-induced melting mechanism has been proposed to explain the large backfilled cracks. Backfilling of liquation cracks by an abundant solute-rich interdendritic liquid from the nearby solidifying weld metal can cause melting along the cracks to worsen GB liquation and, hence, liquation cracking, which in turn increases backfilling.

Acknowledgments

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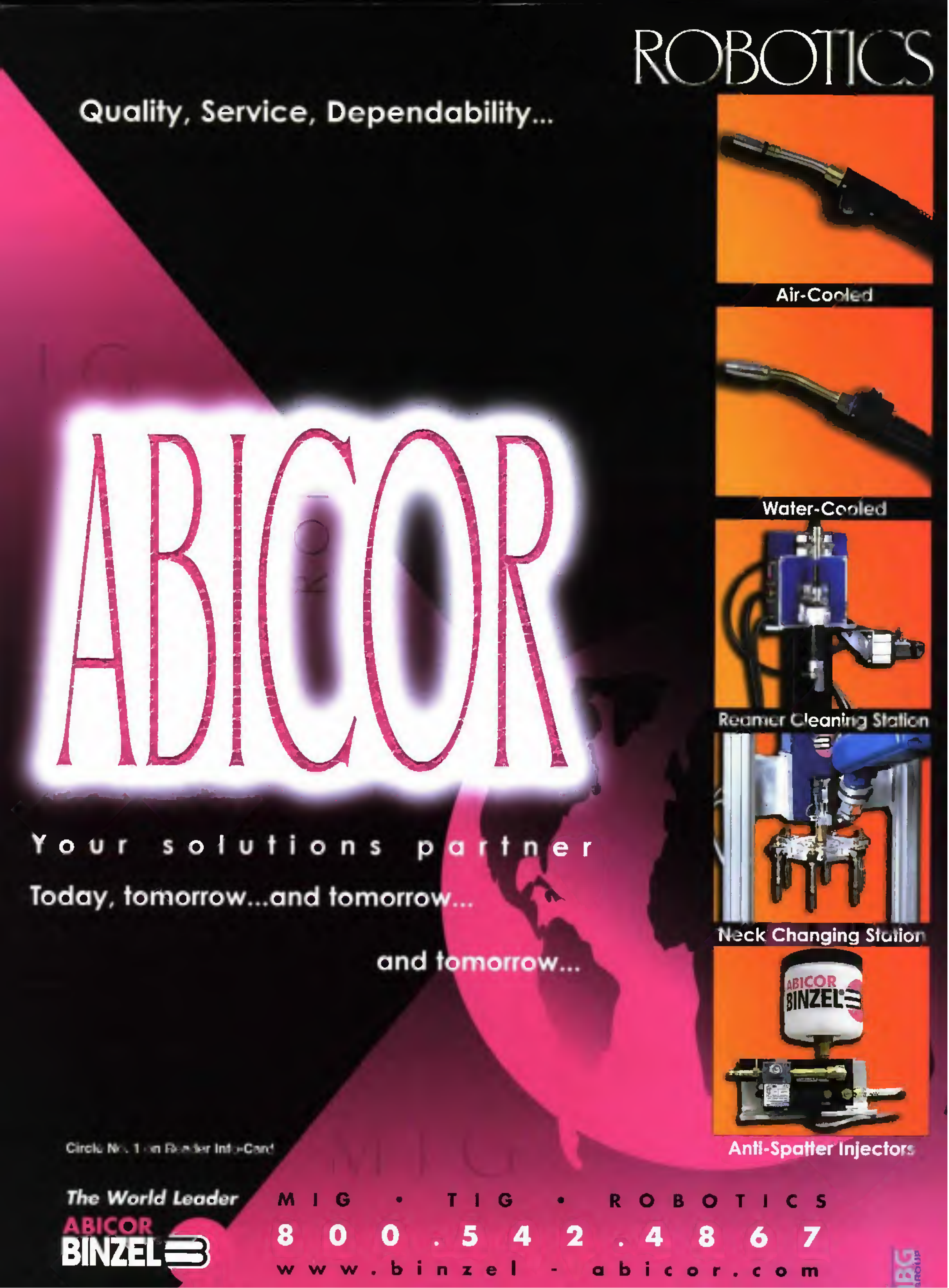
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