There are four good reasons why KOBELCO can produce Gold Medalist Flux-cored wires.

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2. **Kobelco has highly reliable production management system and quality assurance system which is sometimes called “Kobelco Standard” by major heavy industries.**

3. **Kobelco Flux-cored wire know-how’s were developed based on 100% CO₂ shielding gas market. Accordingly, you can get super results when used in Ar-CO₂ mix shielding gas in terms of less spatter and low fume levels.**

4. **Kobelco has the largest Research and Development Organization that enables us to create a product just right for specific demands.**

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**DW Stainless Series (for all major stainless alloys)**

Our DW Stainless Flux-cored wire series are the Best Selling Stainless FCW in the United States. KOBELCO DW Stainless Flux-cored wires have excellent low fume level, less spattering, arc stability, slag removal, wetting and bead appearance. KOBELCO DW Stainless Flux-cored wires are the benchmark for stainless FCW.

**DW-50 (AWS E71T-1/1M)**

DW-50 is an All Position Flux-cored wire with fast-freeze formulation. DW-50 has the Lowest Fume Level compared to other brands and has excellent weldability not only in flat and horizontal position but in vertical and overhead welding as well.

**Frontiarc-711 (AWS E71T-1/1M, 12/12M)**

Frontiarc-711 is an All Position Flux-cored wire with medium-freeze formulation. Because of its Stable Arc and Fluid Nature, Frontiarc-711 is excellent for long, continuous welds that demand consistency. Fluid Weld Puddle allows Frontiarc-711 to be more forgiving when welding through mill scale or rust.

**MXA-70C6 (AWS E70C-6M)**

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New President to Head Kvaerner Philadelphia Shipyard

Gunnar Skjelbred was recently named president and chief executive officer of Kvaerner Philadelphia Shipyard, Inc. He replaces Ron J. McAlear, who resigned his position.

Skjelbred had been chief operating officer at the shipyard. He has many years of experience in international shipbuilding and has held a variety of top management positions with Aker and Kvaerner.

Airgas Sponsors Second AWS Foundation Scholarship

Airgas, Inc., Radnor, Pa., recently announced it will sponsor a second AWS Foundation college scholarship. The scholarship will honor Jerry Baker, a former owner and president of a company he continues to work for Airgas Mid America in Bowling Green, Ky.

The Airgas-Jerry Baker Scholarship will be offered for the school year beginning September 2003 to an undergraduate student pursuing a minimum four-year bachelor’s degree in welding engineering or welding engineering technology. Priority will be given to welding engineering students interested in pursuing a career with an industrial gas or welding equipment distributor.

Baker sold his business, Southern Welding Supply Co., to Airgas in 1986. He continues to work for Airgas Mid America, one of Airgas’s 12 regional companies, as director of Corporate Development.

“Jerry Baker is the kind of entrepreneur that has helped Airgas succeed through strong local customer service,” said Peter McCausland, chairman and chief executive officer of Airgas.

“Through this scholarship, we hope to encourage others to get the education they need to have a successful career with an industrial gas or welding equipment distributor,” said Andrew R. Cichocki, senior vice president, Human Resources.

Airgas sponsors a similar scholarship offered through the AWS Foundation, the Terry Jarvis Memorial Scholarship. It honors Terry Jarvis, who died at the age of 39 in 1999. Jarvis started with the company as a truck driver and became assistant branch manager in the Pelham, Ala., store.

Northrop Grumman Sells Cruise Ship Assets to Norwegian Cruise Line

Northrop Grumman recently announced it is selling all structures and material that were part of the Project America cruise ship program in Pasagoula, Miss., to Norwegian Cruise Line Ltd. (NCL).

NCL agreed to buy the nearly half-complete first ship and all associated equipment and material, as well as material acquired for a planned second ship. The company plans to move the hull to Europe for completion, but has not announced which European shipyard would complete the 1900-passenger ship.

Northrop Grumman had been under contract to American Classic Voyages Co. to construct the two ships, which were supposed to operate in Hawaii after completion. It halted work in October 2001 when American Classic Voyages filed for Chapter 11 bankruptcy protection.

AISC Names Vice President of Engineering and Research

Louis F. Geschwindner, Jr., professor of architectural engineering at The Pennsylvania State University, was recently named vice president of engineering and research for the American Institute of Steel Construction, Inc. (AISC).

Geschwindner will be responsible for establishing AISC’s long-range technical objectives and initiatives, as well as coordinating technical activities between AISC and other organizations. Geschwindner will remain at Penn State; Charles J. Carter, AISC’s chief structural engineer, will retain responsibility for the day to day operation of the department.
Relief for robotic indigestion.

Robotic indigestion doesn’t come from jalapeño peppers. It comes from welding wire with poor arc stability and inconsistent feedability. It clogs liners and tips. You get jam-ups and burnbacks. Welding stops. Then you get indigestion, too.

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Welding wire to robotic standards.
OSHA Seeks Data on Hexavalent Chromium Exposure

The Occupational Safety and Health Administration (OSHA) has issued a request for data, comments, and other information on issues relevant to occupational exposure to hexavalent chromium. The agency is seeking information regarding the relationship between occupational exposure and adverse health effects, industry profiles of use, and populations at risk. OSHA is also seeking comments on the potential impact of reducing occupational exposure to hexavalent chromium, e.g., costs of controls, effects on revenue and profit, and changes in worker productivity. Presumably, OSHA is considering such a reduction. The OSHA notice appears in the Federal Register, 67 Fed. Reg. 54389.

Executive Order Issued to Support Small Business

President Bush has issued an Executive Order that directs all federal agencies to develop policies and procedures for protecting and considering the needs of small businesses when promulgating regulations. Specifically, the order states each agency shall “issue written procedures and policies to ensure that the potential impact of agency’s draft rules on small businesses, small governmental jurisdictions, and small organizations are properly considered during the rule-making process.” Agencies have until late November to submit their proposed rules to the chief counsel for advocacy of the Small Business Administration. Final policies and procedures should be in place by March 1, 2003.

It has been estimated small businesses spend as much as 60% more time and money complying with federal regulations than do large firms.

Small Business Ombudsman to Aid Small and Minority-Owned Businesses

Bipartisan legislation is proceeding rapidly through Congress that would create an ombudsman in the Small Business Administration to assist small and minority-owned businesses in securing federal contracts and grants. The small business community has long complained agencies tend to show a bias toward large companies in the federal procurement process; one purpose of the ombudsman would be to ensure small businesses have a fair opportunity to participate as well. Currently, the target for federal contracts awarded to small businesses, as a percentage of all contracts, is 23%. This legislation would increase that goal to 30% by 2006.

OSHA has issued a request for data, comments, and other information on issues relevant to occupational exposure to hexavalent chromium.

OSHA Issues Final Rule on Hearing Loss

The Occupational Safety and Health Administration has issued a final rule revising the criteria for reporting work-related hearing loss. Effective January 1, 2003, employers will be required to record work-related hearing loss cases when an employee’s hearing test shows a marked decrease in overall hearing. Employers will be able to make adjustments for hearing loss caused by aging and may seek the advice of a physician or licensed healthcare professional to determine if the loss is work related. Under the new rule, the criteria will record 10-decibel shifts from the employee’s initial hearing test. The old criteria recorded 25-decibel shifts.

In a related development, OSHA has issued an Advanced Notice of Proposed Rulemaking to revise construction noise standards. The notice is to include a hearing conservation component for the construction industry that provides a similar level of protection to that afforded to workers in general industry. This notice appears in the Federal Register, 67 Fed. Reg. 50610.

Regulation of Political Organizations Remains Unsatisfactory

The U.S. General Accounting Office has issued a report titled “Political Organizations: Data Disclosure and IRS Oversight of Organizations Should Be Improved.” The report criticizes the Internal Revenue Service for its oversight of political action committees and other organizations qualified under Section 527 of the Internal Revenue Code. Congress has made numerous attempts to regulate, and increase disclosure requirements on, these organizations for the past several years. These efforts have become more urgent as the recently enacted campaign finance reform legislation significantly increased the importance of political action committees in federal elections.

Electronic Rule Making Proposed

Strong efforts are currently under way to make all records related to the federal rulemaking process available electronically through each federal agency’s Web site. Currently, much of the valuable information related to a federal rule making, or any regulatory decision, is accessible only by a Freedom of Information Act request or by physically visiting a federal docket room in an agency’s Washington, D.C., headquarters. This information includes comments made by the public, scientific studies, cost benefit analyses, etc. The Office of Management and Budget is pushing federal agencies to change the current system so relevant information will be available to anyone electronically via the Internet. Such a system already exists within the U.S. Department of Transportation; the goal is for other agencies to follow this model.
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A Golden Opportunity Awaits

Everyone has heard of “white collar” workers and “blue collar” workers, but now there is another type of worker who is coming into his or her own. These “gold collar” workers have the opportunity of a lifetime.

A gold collar worker is an individual who pursues additional vocational training after high school and whose earning potential is often greater than that of college graduates. The wonderful thing about these workers is their career opportunities over a lifetime can provide security, reward, and comfort for their families.

So, how can high school students become aware of and pursue these great opportunities when educators and parents know little or nothing about, and fail to encourage, their students or children in vocational careers? The answer is through us. We who have made careers in the welding and joining industry not only have the opportunity but also an obligation to help those who are coming behind us. We would be helping these young people find rewarding careers and, at the same time, ensuring the future of our industry by helping develop a qualified, skilled work force.

How can we accomplish this? We can provide this help through the AWS Foundation. The Foundation exists to help produce the future welding and joining manpower throughout manufacturing in industries such as construction, mining, and petroleum. None of these industries could exist without welding and materials joining. Through the Foundation’s District and National Scholarship Programs and its Graduate Research program, AWS grants more than $300,000 annually to nearly 200 students. However, more needs to be done if we are to prevent having to turn qualified students away because of a lack of funds.

In keeping with the importance of the gold collar worker, the Foundation recently approved its newest program: the Gold Collar Scholarship Program. Through this program, new scholarships will be implemented focusing on students who want to enter welding-related careers. These scholarships will emphasize vocational training in technical schools and community colleges. This new category of scholarships will support students with funding where scholarships are not normally available. To support vocational scholarships, the AWS Foundation’s trustees are now allowing individuals or corporations to sponsor their local District Scholarship Program for three years. Nation-wide recognition will be given to those sponsors.

Through the Gold Collar Scholarship Program, we have an opportunity to create more scholarships and give direction to students at a critical time in their lives. Each of you can be a part of this important work by becoming either an individual or corporate Foundation partner. I urge you to support the AWS Foundation and our industry’s future.

Ronald C. Pierce
Chair, AWS Foundation Board of Trustees
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Circle No. 44 on Reader Info-Card
Space Shuttles Undergo Weld Repairs to Flow Liners

Weld repairs were recently made to several small cracks in the liquid hydrogen flow liners inside the main propulsion system of the space shuttles Atlantis and Endeavor. The liners, which are found inside the fuel lines, prevent liquid hydrogen and oxygen turbulent flow into the engines during launch and the climb to orbit.

Engineers determined high-cycle fatigue, which was attributed to combined environments such as vibration, thermal, and acoustics, was the likely cause of the cracks.

United Space Alliance, the NASA subcontractor responsible for the flow liners, elected to use the gas tungsten arc welding process to make the repairs because it produces low amounts of spatter and minimal debris on the backside of the weld where access would be limited. The liquid hydrogen lines require a 400-micron cleanliness level, meaning no particles bigger than 400 microns (0.016 in.) could be observed in the line after the repairs were made.

The 0.05-in.-thick flow liners on Atlantis, Endeavor, and Discovery are made from Inconel® 718. The flow liners on Columbia, the first orbiter built, are made from corrosion-resistant 321 stainless steel. The weld process for the repair of the flow liners was developed at the Marshall Space Flight Center, Huntsville, Ala. It consisted of several autogenous heat passes to reduce...
and eliminate any residual stress created by the actual filler weld pass. Complete joint penetration welds were made for the actual repair.

To develop the weld process, more than 100 coupon samples were created with slots stamped in them just like the actual part. The coupons were then run on a cyclic load-testing device until they developed cracks similar in size and location to those on the actual orbiter parts. The cracked coupons were subjected to a variety of weld repair techniques then placed back into the testing machine to attempt to create the crack again. The GTAW technique was selected in part because it performed as well as the base material in the cyclic load testing.

Following welding, the holes in the flow liner were carefully polished to relieve any of the residual stress resulting from the stamping of the holes into the liner and to reduce the probability of microcracks growing into larger cracks. During and after welding, a number of nondestructive inspections using X-ray, ultrasonic, and eddy current testing were conducted.

**MRi Acquires Large Scanning Acoustic Microscope**

Material Resources International (MRi), Lansdale, Pa., recently entered into a partnership with Matec Micro Electronics, Yardley, Pa., whereby the two companies will work closely together to provide nondestructive acoustic imaging services and support to scanning acoustic microscope users. MRi has acquired a state-of-the-art scanning acoustic microscope from Matec. This acquisition will allow the company to add high-resolution, ultrasonic imaging services that will complement its active solder and braze joining products and services.

The Matec unit features a large tank, high resolution, and high speed. It is capable of detecting flaws as small as 5 microns in diameter and detecting gaps as thin as 0.1 microns.

**Future of Welding Engineering Education Focus of Workshop**

Representatives from ten institutions of higher education involved in welding and materials joining engineering met on August 16 and 17 at a workshop hosted by LeTourneau University, Southern Methodist University, and the American Welding Society (AWS). The purpose of the meeting was to examine anticipated trends in welding and materials joining engineering over the next decade, possible changes in curricula, and possible collaboration between institutions.

Ernest Levert, AWS president and senior staff engineer at Lockheed Martin Missiles and Fire Control, opened the workshop, which took place at the Center for Advanced Manufacturing at Southern Methodist University, Richardson, Tex. Levert emphasized the importance of education in this critical engineering field. While it was noted welding engineering programs in general have problems recruiting talent, keeping up with escalating equipment costs, and finding research funding, 15 major U.S. universities do offer advanced degrees related to welding and materials joining.

Several trends were identified such as welding's perceived loss of relevance compared to new areas such as bio-engineering, nano-engineering, and electronic materials engineering. It was suggested materials joining engineering is a more inclusive term to describe the type of education needed and that no single university will be able to teach all the courses required.
Distance learning may be an effective means for developing and delivering on-line degrees based on collaborative efforts among universities. The need to increase the number of welding and materials joining graduates, improve course content, and recognize the role of lifelong training and continuous educational improvement were recognized. Teams were organized to work on these and other topics and to improve communication concerning welding and joining engineering activities to the public.

Utah State University will host the next workshop. For more information, contact Dr. Yoni Adonyi of LeTourneau University at (903) 233-3918 or via e-mail at YoniAdonyi@letu.edu.

North American Robot Orders Fall in Second Quarter

North American robotics companies saw orders from North American customers fall 4% in the second quarter of 2002 vs. the same period last year, according to statistics from the Robotic Industries Association.

Through the first six months of 2002, new robot orders from North America totaled 4859 units valued at $337.9 million, a decline of 1% in units and an increase of 2% in revenue when compared with the first half of 2001. When orders from outside North America are included, unit sales fell 6% and revenue declined 2% in the first half of this year.

There was an upturn in orders for material handling, arc welding, and dispensing/coating robots in the second quarter; however, spot welding orders fell 46%. “Spot welding robots are sold primarily to the automotive industry, where customers often place large orders of several hundred units at a time,” explained Donald A. Vincent, RIA executive vice president. “This application is very cyclical, and one large order can produce big swings in the quarterly comparisons.”

MANITOWOC CRANES INSTALLS ADVANCED PLATE CUTTING MACHINES


The two thermal machining centers are equipped with Messer PC-based CNC units; two Hypertherm HT4400 400-A, dry-oxygen, plasma torches; and two Messer Turboflame oxyfuel torches. The machines run on a common rail over a self-cleaning, downdraft support table. One of the plasma torches on each machine is mounted in Messer’s compound skew bevel rotator, which allows cutting of various weld preparation bevels at the same time as the part’s contour is being cut.

Manitowoc Cranes manufactures customized lattice boom cranes, excavators, and crane attachments. The company reports use of a plasma-based cutting technology has more than doubled the productivity of its plate cutting operators.

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HOBART INSTITUTE OF WELDING TECHNOLOGY

Correction

In the August issue, several people were incorrectly identified in the caption of a photo showing representatives from National-Standard receiving a Supplier Quality Award from Subaru-Isuzu Automotive, Inc. The photo and corrected caption follow.

Shown from left to right are Naofumi Horie, executive vice president, Subaru-Isuzu Automotive (SIA); Jim Harbaugh, regional manager, and Jerry Hays, district sales manager, National-Standard; and Masayoshi Nagano, president, SIA.

In the August issue, several people were incorrectly identified in the caption of a photo showing representatives from National-Standard receiving a Supplier Quality Award from Subaru-Isuzu Automotive, Inc. The photo and corrected caption follow.

Manitowoc Cranes Installs Advanced Plate Cutting Machines


The two thermal machining centers are equipped with Messer PC-based CNC units; two Hypertherm HT4400 400-A, dry-oxygen, plasma torches; and two Messer Turboflame oxyfuel torches. The machines run on a common rail over a self-cleaning, downdraft support table. One of the plasma torches on each machine is mounted in Messer’s compound skew bevel rotator, which allows cutting of various weld preparation bevels at the same time as the part’s contour is being cut.

Manitowoc Cranes manufactures customized lattice boom cranes, excavators, and crane attachments. The company reports use of a plasma-based cutting technology has more than doubled the productivity of its plate cutting operators.

Employees Receive Westinghouse Award

Several workers at PCI Energy Services, a subsidiary of Westinghouse Electric Co., were recently awarded the George Westinghouse Signature Award of Excellence. The award recognizes the outstanding accomplishments of Westinghouse employees worldwide. The award winners include the following:

• Pat Will and Mike Okolita were honored with the Nuclear Services highest award for their participation in the alloy 600 reactor vessel head inspection and repair program. This is a critical program developed to repair power water stress corrosion cracking in nuclear power plants.

• David Baker and John Qualizza were recognized for their participation in the Palisades control rod drive mechanism replacement program. This was the first time in the nuclear power plant industry that this type of mechanism was replaced on a reactor vessel head. Baker also received a second Signature Award for his contributions to the Waterford permanent cavity seal ring design and installation project.

• Timothy Grubbs, Kenneth Nance, and Steve Ray were honored for their participation in the Tihange Unit #2 steam generator replacement project. Tihange is a three-loop pressurized water reactor located in Huy, Belgium. Several records were established during this project, including shortest instal-
PCI Energy Services is headquartered in Lake Bluff, Ill. It has remained at the forefront of field machining and welding for 32 years, specializing in remote applications.

**Motoman Wins Supplier Award**

Motoman Inc., Dayton, Ohio, was recently named 2001 Capital Equipment Supplier of the Year by GKN Automotive, Inc., one of the world’s largest suppliers of automotive drive line components. The robotics company is the award’s first recipient.

GKN Automotive has approximately 200 Motoman robots installed in three plants located in North and South Carolina. The award was judged on criteria from ten categories, including service, support, pricing, quality, overall value, engineering initiatives, delivery, spare parts (timeliness and availability), technical support, and operational performance, said John Hiovich, senior executive, GKN Group Procurement.

**Industry Notes**

- Abrasive power tool manufacturer Dynabrade, Inc., Clarence, N.Y., recently acquired Nu-Matic Grinders, Inc., Cleveland, Ohio. Nu-Matic manufactures air-inflated backup wheels and machine leveling jacks and related products. Terms were not disclosed.

- Liburdi Dimetrics recently expanded its product line and restructured its sales network. The company acquired the rights to manufacture Graham Arc’s 45/550 tube-to-tubesheet weld heads and its M and MH open arc, wire feed weld heads. Previously, the company had purchased the weld heads for use with its power supplies, but it will now manufacture them in its Davidson, N.C., plant. In addition, in response to a customer survey, the company will be expanding its sales force by partnering with manufacturers’ representatives and distributors worldwide and opened a new office in Tianjin, China.

- Unitek Miyachi International, Ltd., Monrovia, Calif., recently acquired assets of Microjoin Inc., a manufacturer of resistance welding, reflow soldering, and heat seal bonding equipment and systems, from the Palomar Companies of Carlsbad, Calif. The assets acquired include intellectual property, all products, systems, equipment and designs, patent rights, trademarks, brand, and company and domain names. Microjoin, which was based in Poway, Calif., will cease operations.

- Yaskawa Motoman Canada recently moved to a larger facility in the same city of Mississauga, Ontario, Canada. The 32,835-sq-ft facility doubles the company’s manufacturing space. The demonstration labs increased by 25% and will house fully operational arc welding: spot welding; twin-wire, heavy-deposition welding; palletizing; and material handling systems. Training classrooms were also expanded and updated.

- Sciaky, Inc., Chicago, Ill., recently received certification for its electron beam welding services from the National Aerospace and Defense Contractors Accreditation Program. Sciaky has committed more than 10,000 sq ft to its welding bay, which includes electron beam welding machines, an Acuweld® 1000 arc welding system, several resistance welding machines, and a complete testing and evaluation laboratory.

- Preco Industries, Lenexa, Kan., recently acquired Laser Machining, Inc. (LMI), Somerset, Wis. LMI is a $20 million manufacturer/integrator of high-power laser systems for the metals, nonmetals, and converting markets. The company has been renamed Preco Laser Systems.

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Laser Institute Offers On-Line Tutorial

Laser Institute of America (LIA). The organization recently added an on-line tutorial titled “Laser Safety in Educational Institutions” to its laser safety Web site. The tutorial takes approximately two hours to complete and is designed to help eliminate laser accidents at institutions.

The tutorial discusses the basics of lasers; biophysics; laser safety standards, regulations, and educational environments; control measures; accident scenarios; and sample laboratory settings used in education institutions.

Registration fees are $99 for LIA members and $149 for nonmembers. Requirements are Microsoft® Internet Explorer 4.0 or better or Netscape 4 or better, Real Player, and speakers or headphones. The course is best viewed at 800 x 600 pixel screen size and at least 256 colors. Enrollees receive a user name and password good for seven days, an ANSI Z136.5-2000 Safe Use of Lasers in Educational Institutions standard, a LIA Laser Safety Guide, and a certificate upon completion. LIA ships the standard and guide to enrollees. They are not necessary to begin the course but are intended to be used as reference materials.

Although enrollees can take the sections in any order they wish, it is best to take the tutorial in order. If it is necessary to interrupt training, exit and log back on later. Clicking the “take me back” link takes the student back to where he or she left off.

Web Site Upgraded to Integrate Filtration Products

Donaldson Co., Inc. The company recently redesigned the Web site for its Industrial Air Filtration Group, previously known as the Donaldson Dust Collection Group, which offers the Torit line of products. The new Donaldson Torit site was developed in conjunction with the redesign of the Donaldson Company’s corporate Web site, which provides links to all of the company’s divisions. Customers now may enter the Industrial Air Filtration Web site directly or through a link on the corporate site located in the “Filtration Solutions” section under “Industrial Air.”

Site Highlights Welding Safety Products

Jackson Products, Inc. The Web site for this St. Charles, Mo., based company, offers plenty of information about its Jackson and Morsafe lines of safety products and welding accessories. Visitors can fill out a short questionnaire that will guide them in selecting the correct EPC filter for their application. They can also select their nearest distributor by typing in their zip code.

The site offers a “Parts Breakdown” section that helps visitors locate replacement part numbers for Jackson products such as welding helmets, welding goggles, electrode holders, and cup adapters and springs. A long list of FAQs answers general questions regarding eye, hearing, head, and face protection and more specific questions regarding particular products. Examples include the following: “What is the OSHA noise standard?” Answer: “The Occupational Safety and Health Administration (OSHA) standard defines the amount of noise a worker in industry can be exposed to in a work day without the use of some sort of protection from that noise. Amount of exposure is limited to 90 dBA times the weighted average over an 8-h shift, 5 days per week. Some exceptions do apply. OSHA approves a hearing protector only in accordance to the noise level where it is being used. A protector may be approved in one noise work area but not in another due to the level or frequency of noise present.”

In addition, the site offers a variety of literature that can be downloaded, employment information, and links to a number of welding-related organizations and publications such as the American Welding Society and Welding Journal.

Laser Info Now Available in Several Languages

GSI Lumonics Inc. The company recently translated key portions of its Web site into seven languages to enhance communications with its customers around the world. Users can now get technical information about each of the company’s product lines, customer support, and training in English, German, French, Italian, Japanese, Korean, and both simplified and traditional Chinese. Users click on the icon for the language they need to access the translations.
GENSTAR TECHNOLOGIES

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Friends and Colleagues:

We’re into the tenth year of the program, and 98 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, 2003. The Committee looks forward to receiving numerous Fellow nominations for 2004 consideration.

Sincerely,

Dr. Alexander Lesnewich
Chairman, AWS Fellows Selection Committee
CLASS OF 2004
FELLOW NOMINATION FORM

DATE_____________________________ NAME OF CANDIDATE ____________________________

AWS MEMBER NO._________________________ YEARS OF AWS MEMBERSHIP ____________________________

HOME ADDRESS ____________________________

CITY ___________________________________ STATE __________ ZIP CODE __________ PHONE ______

PRESENT COMPANY/INSTITUTION AFFILIATION ____________________________

TITLE/POSITION ____________________________

BUSINESS ADDRESS ____________________________

CITY ___________________________________ STATE __________ ZIP CODE __________ PHONE ______

ACADEMIC BACKGROUND, AS APPLICABLE: ______________________________________________________

INSTITUTION ____________________________________________________________

MAJOR & MINOR ____________________________________________________________

DEGREES OR CERTIFICATES/YEAR ____________________________________________

LICENSED PROFESSIONAL ENGINEER: YES ______ NO ______ STATE ______

SIGNIFICANT WORK EXPERIENCE: ____________________________________________

COMPANY/CITY/STATE _______________________________________________________

POSITION ______________________________________________________________

YEARS ________________________________________________________________

COMPANY/CITY/STATE _______________________________________________________

POSITION ______________________________________________________________

YEARS ________________________________________________________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS: ______________________

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

**MOST IMPORTANT**

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

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

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

SUBMITTED BY: PROPOSER ___________________________ AWS Member No. ____________________________

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

NOMINATING MEMBER: ___________________________ NOMINATING MEMBER: ___________________________

AWS Member No. ___________________________ AWS Member No. ___________________________

NOMINATING MEMBER: ___________________________ NOMINATING MEMBER: ___________________________

AWS Member No. ___________________________ AWS Member No. ___________________________

SUBMISSION DEADLINE FEBRUARY 1, 2003
Nomination of AWS Fellows

I. 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 reputation and outstanding accomplishments of the individual. Such accomplishments will have advanced the science, technology and application of welding in specific areas such as research and development, education, manufacturing, design and other areas the Society may determine, 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

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

III. NUMBER OF FELLOWS TO BE ELECTED
Maximum of 10 Fellows selected, as determined by the selection committee

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

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Dear Mr. Anderson:

I just finished reading your interesting article dealing with the prevention of porosity in aluminum welds. Based upon my experience, I want to mention one more likely source of porosity. That is most pneumatic cleaning tools. The air that powers these tools usually contains lubricants such as oil and moisture, as does the exhausting air. Since it is difficult for the operator to make sure none of this exhaust is sprayed on the aluminum as it is being cleaned, another condition that can result in weld porosity is likely to have been created. I suggest only electrically powered grinding and machining tools be employed for typical aluminum field welding applications.

Harry W. Ebert, P.E., FAWS
Madison, N.J.

You are absolutely correct; the use of pneumatic tools for metalworking or material preparation for aluminum prior to welding should be given serious consideration before use since it can be a source of contamination that can lead to a porosity problem. Using this type of equipment for backchipping and/or initial joint preparation, for example, or blowing down the weld joint with compressed air to remove debris can introduce moisture, oil, and rust contamination. Avoiding this problem through the use of electrically operated tools is an excellent proposal.

We teach the above precaution as part of the porosity prevention section at the AlcoTec School for Aluminum Welding Technology, but I overlooked its inclusion in my column. I apologize and thank you for bringing it to my attention.

Tony Anderson
Technical Services Manager
AlcoTec Wire Corp.
Traverse City, Mich.

Dear Readers:

The Welding Journal encourages an exchange of ideas through letters to the editor. Please send your letters to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. You can also reach us by FAX at (305) 443-7404 or by sending an e-mail to Doreen Yamamoto at yamamoto@aws.org.
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When you have a choice, make it Metabo...and make more.
Book on Doing Hot Work in Confined Spaces Evaluated


The author's stated purpose for writing this book was to provide a guide "for the industrial hygienist or safety professional with limited experience in hot work operations involving confined spaces." He adds, "Welding supervisors having limited experience with safety inspections will also find this guide useful, as will fire inspectors, compliance officers, and insurance investigators."

In an easy-to-read style, the author covers the basics of fire and explosion technology, preparing a confined space for hot work, control of flammability hazards, emergencies, and something he calls "confined space appurtenances" (i.e., the "stuff" inside the confined space).

Sprinkled throughout the text are descriptions of incidents the author has encountered in his practice as a Certified Marine Chemist.

The final chapter of the book includes frequently asked questions, a glossary, a list of references, and a number of helpful appendixes.

Unfortunately, the index is shallow. There are 24 major topics and 16 minor topics for a total of 40 entries for a text of 60 pages, 34 of which are the text prose and appendixes. (Incidentally, "fire watch" is out of place alphabetically. It follows "flammable range" instead of preceding it.)
The author also states: “OSHA regulations are vague or nonexistent on requirements for hot work operations in confined spaces.” In spite of the welding photo on the cover of the book and several mentions of welding in the text, the author fails to reference several welding and cutting hot work OSHA regulations. In fact, they are completely missing from the list of references. For example, the OSHA General Industry Standard 29CFR1910, Subpart Q, “Welding, Cutting, and Brazing,” contains several sections on confined spaces and the OSHA Construction Industry Standard 29CFR1926, Subpart J, “Welding and Cutting,” refers to American National Standards Institute’s (ANSI) Z49.1, Safety in Welding, Cutting, and Allied Processes, which contains a complete section on confined spaces.

There is no mention of the National Fire Protection Association (NFPA) 51B, Standard for Fire Prevention during Welding, Cutting, and Other Hot Work – 1999 Edition. This NFPA standard has become the de facto hot work standard for industry. Earlier editions of NFPA 51B and ANSI Z49.1 serve as the basis for most, if not all, OSHA’s regulations concerning welding and cutting hot work. Most of the welding precautions mentioned by the author are derived from ANSI Z49.1, which was first published as an “American War Standard” in 1944. Neither Z49.1, or 51B, both of which are major hot work consensus documents, are mentioned in the text or listed in the references.

The definitions concerning welding in the glossary indicates the author’s unfamiliarity with welding. For example, one entry defines “MIG welding — Metal-inert-gas welding; a welding process that produces a very large flux of UV radiation. (See TIG welding.)” If the reader looks up the entry’s suggestion to “See TIG welding,” the following entry will be found: “TIG welding — Tungsten-inert-gas welding; a specialized form of MIG welding that produces a very large flux of UV radiation.”

As every reader of the Welding Journal should know, TIG welding has nothing to do with MIG welding. They are two distinct processes and should preferably be referred to as GMAW and GTAW, respectively.

In another example, the author defines air arc as “A specialized form of metal cutting using a hollow carbon electrode instead of the usual solid metal electrode used in electric arc welding. Generates a high temperature and cuts through metal by introducing air through the center of the hollow electrode, etc, etc.” Instead of the term “air arc,” the American Welding Society (AWS) prefers “air carbon arc cutting (CAC-A).” It is practiced with a solid graphite/carbon electrode with a jet of air introduced from an orifice in the electrode holder. The jet of air passes along the side of the electrode, not through a passage in the electrode as the author’s definition states.

If the author intends to write another edition of this book, he should seek the assistance of someone well versed in the technology of welding and cutting and knowledgeable of the safe practices contained in ANSI Z49.1, NFPA 51B, and OSHA and AWS documents. This book is best suited as a companion to the ANSI, NFPA, and OSHA standards mentioned here. By itself, it is an incomplete reference for hot work in confined spaces. Readers are encouraged to obtain the previously named standards for their own use to supplement the information contained in this book.

A. F. MANZ is a Fellow of the American Welding Society, Miami, Fla.
The company provides its SuperArc GMAW wires in the intermediate-sized, 250-lb AccuTrak drum. The drum ensures the wire is completely enclosed and protected from contaminants and dust. The drum packaging also forms a safety barrier between electrically hot wire and the operator; in addition, the package facilitates precise feeding because the design accurately places the wire in the weld joint throughout the welding process without twisting.

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bobw@aws.org
http://www.aws.org
Equipment manufacturers in the metal forming and fabricating industries will showcase their most prized products at Fabtech International 2002. Cosponsored by the Society of Manufacturing Engineers (SME) and the Fabricators & Manufacturers Association, International (FMA), this year’s event will be held October 29-31, at the I-X Center in Cleveland, Ohio.

The exhibits will be segmented into four broad areas of forming and fabricating, stamping, tube and pipe, and welding. The show will highlight a broad range of technology including automation/robotics, bending and folding, coil processing, controls, cutting, finishing, hydroforming, lasers, material handling, punching, roll forming, safety, software, stamping, tooling, and metal joining. The emphasis is on products that improve efficiencies, cut costs, and increase productivity. Many demonstrations will be staged over the course of the event.

Show Hours and Special Events

The show will be active from 9 a.m. to 5 p.m. on October 29 and 30 and from 9 a.m. to 4 p.m. on October 31.

A keynote presentation will be made by John J. Ferriola, executive vice president, Sheet Mill Group, Nucor Corp., on October 30, from 8 to 9 a.m. He will offer his perspective on the current global steel marketplace and where he feels it is heading. This address offers an opportunity to learn of changes in steel-making technology, the impact of globalization, the effects of Section 201 on steel consumers, and ways to benefit from changes in the steel industry. The event includes breakfast. Admission is free with advance registration.

A special luncheon will be held from 11:30 a.m. to 1:00 p.m. on October 30, where attendees can discuss industry issues and seek answers to challenges in their profession. Each luncheon table will be assigned a specific topic of current interest along with a facilitator who will encourage participation and maintain focus. Topics of discussion will be implementing lean manufacturing, workforce challenges, competitive strategies for management, and production problem-solving. Seating will be limited for this $25 luncheon.
Register for Product Technology Forums, gatherings that will offer a question-and-answer opportunity with manufacturers concerning their latest technology. Your buying decision will be better informed by this opportunity to compare features and benefits. Welding automation will be the focus on October 29, from 11:30 a.m. to 1:00 p.m.; tube and pipe bending will be on stage October 31, 11:30 a.m. to 1:00 p.m.

Conferences

Attendees will have an opportunity to treat themselves to a variety of technical sessions where in-depth presentations will explain the latest technology in metal forming and fabricating, as well as current business strategies. Below is the daily schedule, the main topics, and a few points of emphasis.

Tuesday, October 29
9 to 11 a.m.
- Lean Manufacturing
  - How to implement lean manufacturing
  - Increase profits
  - "Real world" examples
- Methods for Increasing Mill Speed and Efficiency
  - Cost-saving ideas
  - Low-investment changes that yield high returns
  - Available upgrade options
  - Coordination and control of equipment
- Laser Welding
  - Lessons learned with tailored-blank welding
  - World market situation
  - New application direction and technology
  - Implementing laser welding
  - Pros and Cons
11:30 a.m. to 1 p.m.
- Welding Automation Forum
- 12:30 to 2:30 p.m.
- Laser Cutting
  - Features that increase productivity

3:00 to 5:00
- Increasing Effectiveness of the Web
  - Establishing a Web presence
  - Web marketing tactics
  - Justifying the return on investment
  - Great appeal of the Web for purchasing products and services
- Automated Robotic Welding
  - Dedicated automation or robotics?
  - How to adapt your shop
  - Reduce inventory, streamline production
- Roll Forming Fundamentals
  - Basic functions of the process
  - Design considerations
  - Tooling for existing or future roll formers
- Economical Production of Sheet Metal Parts with Mechanical Presses
  - Requirements of a modern press shop
  - Decision criteria for improving production
  - The latest in technology and equipment

Wednesday, October 30
9:00 to 11:00 a.m.
- Forming and Fabricating of Stainless Steel
  - Characteristics of stainless steel
  - Fabrication properties
  - Successful shop practices
- Advanced Roll Forming
  - Producing parts with holes, slots, and notches
- Resonator technology
  - Assist gas techniques
  - High-speed drive systems
- Aluminum 101
  - Easy-to-understand explanation of properties and characteristics of aluminum and its alloys
  - Alloy and temper designations
- Machine Safeguarding
  - Recognize machine hazards
  - Protection
  - Risk assessment and reduction
- Cutting to length
  - System integration
- Kaizen for Setup
  - Time Reduction
  - Ways to attack wastes and bottlenecks
  - Basics of the Kaizen process
  - Lessons learned
- Robotic Welding Applications
  - Gas metal arc welding with robots
  - Advantages and disadvantages
- Today’s Waterjet Technology
  - Improvements to waterjet systems
  - Growing use and what it means to manufacturing

12:30 to 2:30 p.m.
- Sheet Metal Punching
  - How C-frame tooling helps
  - Ways to reduce costs and increase throughput
- Aluminum Welding
  - Filler metal selection
  - Characteristics of the welding wire
  - Considerations for robotic applications
  - Case histories
- Working with Precoated Materials
  - Technology of both liquid and powder coatings
  - Advantages they offer
  - Slitting precoated materials and special situations that come along

3:00 to 5:00 p.m.
- Introduction to Hydroforming
  - Current uses and technology advances
  - Benefits of the process
  - Design options for tubular parts
- Plasma Cutting
  - Nesting software
  - Case histories
  - Positive and negative impact
- Coil Slitting
  - Know a good edge and how to achieve it
  - Picking the right tooling for the application
  - Improve your slitting accuracy
- Implementing Six Sigma
  - Is Six Sigma right for your business?
  - Ensure a positive response from your work force
  - Real-life applications
- Machine Safeguarding

Get All the Information

To register for Fabtech or learn more about the events, contact SME Customer Service at (313) 271-1500, ext. 1600; FAX (313) 271-2861; www.sme.org/fabtech; or contact FMA at (815) 399-8700 or the FMA Web site, www.fmafabetech.com.
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April 8-10, 2003
Detroit, Michigan USA
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, 2003. The committee looks forward to receiving these nominations for 2004 consideration.

Sincerely,

L. W. Myers
Chairman, Counselor Selection Committee
CLASS OF 2004
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, 2003
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 participation 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 be held in strict confidence.
G. Candidates who have been elected as Fellows of AWS shall not be eligible for election as Counselors. Candidates may not be nominated for both of these awards at the same time.

III. NUMBER OF COUNSELORS TO BE SELECTED

2001 Class of Counselors:
Year one, maximum of 20 Counselors selected, as determined by the committee

2002 Class of Counselors:
Year two, maximum of 20 Counselors selected, as determined by the committee

2003 Class of Counselors:
Year three, maximum of 15 Counselors selected, as determined by the committee

2004 Class of Counselors:
Year four, and thereafter: 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, 2003
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n today's economy, it is more important than ever to receive the maximum possible return from your capital equipment investments. The cost effectiveness of a brazing process can be considered as the number of parts manufactured vs. the cost of the capital equipment and consumable supplies. Historically, much of the brazing of multijoint assemblies has taken place in the furnace. Lengthy, slow-ramping heat cycles allow the parts to come up to temperature in a consistent, even manner. However, furnaces, in particular controlled-atmosphere brazing furnaces, can be expensive to purchase, operate, and maintain. In order to maximize your return on a furnace investment, a very high production rate may be required.
Choosing the type of brazing equipment to purchase is heavily dependent on production rate requirements. High production rates are best suited for a continuous brazing furnace. A fully automated system can flame braze multijoint assemblies in a fraction of the time needed by conventional furnaces. For example, a fully automated rotary index brazing table typically produces parts at a rate of 300 to 450 per hour — Fig. 1. If the required production rate is only 45 to 60 parts per hour, a semiautomated cell brazing unit or single-station brazing machine may be the most cost-effective way to automate production — Fig. 2.

 Rotary index tables provide a great deal of heat pattern flexibility. Typically, they have two to five heat stations. The heat pattern is set up so the initial one or two stations are preheat and the next several stations progressively heat the part to brazing temperature. The semiautomated cell brazing unit has only a single station. The heat pattern remains the same throughout the cycle. Heat intensity can be altered by using high and low gas settings, but burner positioning cannot be changed. Oscillation or rotation is nearly always required when brazing a multijoint assembly on a single-station brazing machine.

### Types of Multijoint Assemblies

Multijoint assemblies fall into two basic types. The first type features many joints of the same configuration, such as in marine oil coolers, radiators, and trumpet valve assemblies. To the casual observer, assemblies with many joints having the same configuration should pose no challenge to the trained braze operator. This, however, is not necessarily the case. Although the tubes and pierced holes may be of the exact same dimensions and the filler metal may be applied in precise increments, the various joints reside in distinctly different environments that influence the amount and nature of the heat they come into contact with.

The second type of multijoint assembly features several different joint configurations on a single complete part. These assemblies can be quite challenging, in particular when they are made of three or more different base metals. In general, this type is handled as individual joints that happen to be in close proximity to one another. Multijoint assemblies having different joint configurations on one assembly include can assemblies, tub faucets, and torch handles.

### Key Points

Flux and filler metal application, parts fixturing, and heat application are the key factors involved in automated flame brazing of multijoint assemblies. While these same factors come into play in all types of brazing, in multijoint assemblies the number and type of joints involved further complicate the processes.

### Flux and Filler Metal Application

Multijoint assemblies pose two distinct challenges when it comes to the application of the flux and filler metal. When joints are in close proximity to one another, which is often the case with type one assemblies, it may be difficult or impossible to get traditional automated pasting guns into the area. The joints may also lie in different planes, so positioning of the brazing materials is important. This importance extends from application to
heating. Gravity plays an undeniable role in brazing and must also be taken into consideration.

Just as production rate requirements help guide the choice of automated brazing equipment, position of the joints in multijoint assemblies influence the decision on which flux and filler metal form to employ. Filler metals come in both paste and solid forms. Brazing paste contains both the flux and the filler metal intimately combined in a paste form. This paste can be applied in carefully measured increments directly on the part prior to introduction of heat and has the distinct advantage of being fully automatable. Application of the paste is done by hand syringe, a paste gun mounted on a slide, an xyz applicating system, or by robot arm.

Brazing wire is another medium that can be fully automated in several ways. First, a dispensable brazing flux can be automatically applied onto the part, then a preheated brazing wire is introduced into the joint area when the part is at or near brazing temperature and a joint is made. The use of flux cored wire is quite like the solid wire and flux approach with one obvious difference: the flux is within the wire and thus is introduced when the part is at or near brazing temperature. When brazing multijoint assemblies that must be positioned with a joint upside down, the use of flux cored brazing wire can be advantageous. The wire is only liquid when the part is up to brazing temperature. At that point, it is being actively drawn into the joint by capillary attraction, so is less vulnerable to the pull of gravity.

The other solid forms are rings or preforms. Like the wire, these can be flux cored, solid, or flux coated. Flux cored and flux coated rings do not require additional fluxing. Solid forms are used with a separate flux. If a dispensable flux is used, that portion of the process can be automated. Rings or preforms are generally placed onto the assembly by hand.

**Parts Fixturing**

Fixturing of parts is also an important issue, particularly when the joints lie in more than one plane. Type one assemblies tend to have many joints in a single plane. It is not unusual for a marine oil cooler to have as many as 80 joints per assembly (Fig. 3), which sounds like a fixturing nightmare. Fortunately, type one assemblies are often self-fixturing. The purpose of the fixture when brazing marine oil coolers or radiators is to hold the entire assembly in the proper position for filler metal application and heating rather than to hold the tubes in place. Trumpet valve assemblies are generally wired together prior to processing. In that case as well, the fixture is employed as a means to present the part in the proper orientation to the brazing machine processes.

Type two assemblies rely on proper fixturing to maintain the required tolerances of the finished part, as well as maintain part position in respect to brazing machine functions. If the assembly involves more than one base metal or the mass of the parts differs dramatically, fixturing can also be used to heat sink the lighter parts and eliminate heat sinking of heavier components. However, altering the heat pattern would be the preferred method.

**Heat Application**

The final issue is application of the heat. Many different burner types are
available that allow the heat to be pinpointed; others are more diffused. Also important is the distance the burners are from the part. Type one multifluted assemblies have many similar joints that reside in distinctly different environments. For example, the tube-to-header joints of a radiator assembly can easily be broken down into three quadrants — Fig. 4. One obvious quadrant is the end joints. Another is all areas having additional components heat sinking the part. A third quadrant is the center joints.

The end joints are unique. They receive heat from the heat source, the same as the other joints, but are supplied heat through the base metal from other burners on one side only. On the other side, they lose heat out of the end of the assembly. To compensate for these differences, these joints tend to require more heat than the center joints. It is wise to avoid fixture contact with the ends of the assembly. The center joints are in a much better position to overcome the extra heat sinking that will occur.

The next quadrant includes all areas that contain assembly components other than the tube to pierced hole, in other words, areas containing inlet and outlet tubes or brackets. These additional components cause heat sinking of the part in the general vicinity of where they are attached. Once again, this is not a good place to position fixture contact points due to the heat sinking already present. Because of the inherent heat sinking in this quadrant, the heat will be in excess of that required to braze or solder the central joints of the same assembly.

The third quadrant to consider is the center joints. These include all joints that have no additional components in their general vicinity and are not on the ends of the unit. These joints have the benefit of receiving additional heat from their neighbors through the base metal. Therefore, they need the least intense heat of the whole assembly. If the heating apparatus does not have the ability to supply high heat to some areas and low heat to others, it will be necessary to heat sink the center joints to prevent them from coming up to temperature prior to the rest of the assembly. If one quadrant is allowed to come up to joining temperature prematurely, it is likely the part will be distorted or burned through in that area by the time the completed assembly can be removed from the heat.

Oscillation of the part in the heat source is a popular method for supplying balanced heat to a radiator. This method applies maximum heat to the part without concentrating it to the point where the tubes are burned through. One note of caution: The heat source must extend beyond the farthest point of oscillation. Do not allow the part to oscillate out of the flame, otherwise it is nearly impossible to consistently bring the end joints up to temperature before the part becomes distorted or destroyed. If the joints are clustered in a circle, rather than in a row, the part can be rotated in the heat. For instance, when brazing a marine oil cooler, the heat is applied to the top of the assembly in order to reach the center joints and aimed at the perimeter in order to heat the outer joints. As with oscillation, rotation will provide even heat to the part, eliminating hot and cool zones.

Type two assemblies contain several joints that differ in configuration. An example is a can assembly made up of a lightweight, thin-walled can with components that must be brazed to it. The components are typically of a heavier mass than the can.

Planning ahead is imperative for successful brazing of type two assemblies. Most important is positioning the part in the fixture. Wherever possible, orient the part in a manner that avoids upside down joints. It is advantageous to orient the part so the heaviest mass components are situated above the lighter mass components. Heat naturally wants to travel up through an assembly. By orienting the part in this manner, nature’s laws will work in your favor. Attempt to provide more heat where needed by altering the gas flows, the number and type of burners, and the distance from the burner to the part, rather than by adding additional heat sinks. Typically, assemblies of this nature are awkward in shape. Additional fixturing tends to get in the way of the burners. Not only is it detrimental to block the flame, even blocking the flame wash will prevent the intended heat from reaching the target area. Keep in mind it is not enough for the separate pieces of the assembly to come up to brazing temperature, they must achieve that temperature at nearly the same time.

Type two assemblies made of more than one base metal create special challenges. A helpful rule of thumb is to put all or nearly all the heat into the base metal having the highest melting temperature. When joining copper to aluminum, for example, heat the copper and allow the heat to transfer to the aluminum rather than heating it directly. If the aluminum part has a much higher mass than the copper part, some heat may need to be put into the aluminum, but very little. Keep in mind improper part fitup will cause brazing problems. A too wide joint clearance will inhibit heat transfer from one part of the assembly to the other; too tight fitup will prevent most braze alloys from pulling through the joint properly.

Troubleshooting the Process

Following brazing, visual inspection can reveal many clues to the status of the brazing process. Analysis of the flux residue pattern and fillet shape can be directly related to heat time, burner placement, and fixture design. When brazing a single joint, flux residue should be in a consistent pattern around the joint. When brazing multiple joints, the residue pattern should be consistent from one joint to another. The fillet should also be uniform. It is important for the fillet to fill the joint completely and adequately, but not spread unnecessarily over the rest of the assembly. Also, inspect the part for orange peel, distortion, or burned areas. Uniformity of the flux residue and alloy fillet are not enough if these conditions are also present.

By considering each of these important factors and setting up process parameters based on all applicable considerations, a consistent process can be achieved.

Works Consulted

York International is testing a less costly, nonsilver brazing alloy to replace the phosphorus-copper, 5% silver alloy currently being used.

BY JOSEPH W. HARRIS
York International, worldwide manufacturer of air conditioning and refrigeration equipment and large user of phosphorus-copper brazing alloy containing 5% silver, believes it can save several hundred thousand dollars by using a new patent-pending, silicon brazing alloy called Blockade™ developed by J. W. Harris Co., Inc., Mason, Ohio.

Brazing, Front and Center

The company's Norman, Okla., half-million-sq-ft plant does a lot of brazing. A wide range of copper coils are torch brazed on line with 5040°F oxygen-natural gas. Several autobrace lines equipped with preform brazing rings hourly produce thousands of cherry-red brazers. Brazers — 265 of them — are everywhere, torches hissing, small clouds of steam rising from water quenching, and torch repair work mending a never-ending supply of leaking copper coils.

Put to the Test

Needless to say, since brazing is a major part of York's manufacturing process, the company undertakes any change in procedures with caution and only after serious consideration. Careful and thorough testing of all aspects of the new alloy was performed before making a decision to go forward with actual trial production. Copper braze joints were made and cut open to inspect capillary penetration. Burst tests of 2300 to 2450 lb/in.² were exceeded before satisfaction was ensured. An independent laboratory tested and passed the new alloy's compatibility with various refrigerant gases according to ASHRAE Standard 97. York performed "rough ride" shake tests on units joined with the new braze material until the company was satisfied with the strength and durability of the connections. The test equipment used was strong enough to destroy the units being tested.

Lower Costs, Less Coil Leaks

Blockade, composed of tin, silicon, phosphorus, and copper, was an attractive alternative to York because it offered lower alloy costs. The alloy's manufacturer, furthermore, claimed it offered even greater value because its use would reduce coil leaks. Although there is no official cost estimate, Larry Allison, York engineer and trainer, estimates every leaking coil costs the company $100. Minimizing leaking coil percentages could translate into huge savings for the company. York officials are hopeful substantial savings can be realized by using the new alloy and are in the process of running small lots of actual production for further assessment.

Tin-Silver Cap

The alloy forms a bright tin-silver cap on copper brazes and does not discolor the copper immediately adjacent on either side of the braze. The result is a braze that
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Bright Cap and Penetration vs. Penetration Alone

The universal tenet in copper coil brazing has always been penetration. Since torch operators must perform hundreds of brazes daily and because inspecting blackened braze alloy areas is so difficult, York has invested in the idea a visually bright cap, or seal, works to better advantage than penetration alone.

The new brazing alloy can form a substantial cap and also enter and fill the capillary area. The alloy melts in a preferential manner; before the alloy is completely molten, certain parts of the alloy are more fluid than others. Thus, when the alloy flows around a tube joint forming a cap, more fluid parts of the alloy penetrate deeply into the capillary without the cap having to fully melt and disperse.

York believes production speeds could increase and fuel costs be reduced by using the new brazing alloy, which has a liquidus temperature of 1247°F, about 250° cooler than the published 1500°F liquidus temperature of BCuP-3.

Small quantities of nickel may soon be added to the new brazing alloy to increase corrosion resistance and add to its toughness. Testing of this addition is nearly complete.
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  2. Everyday Pocket Handbook for Fillet Welding
  3. Everyday Pocket Handbook for Gas Metal Arc Welding
  4. Everyday Pocket Handbook for Gas Tungsten Arc Welding
  5. Everyday Pocket Handbook for Gas Metal Arc Welding

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INDPENDENT SHOPS!
Modern railway carriages are increasingly produced from longitudinal aluminum extrusions with integrated stiffeners. The whole body shell can be made from either single-wall or hollow double-skin extrusions using this concept. This design approach can enhance the crashworthiness of vehicles because of the absence of transverse welds and the high buckling strength of the panels under longitudinal compression (Ref. 1).

Friction stir welding (FSW) was invented and patented (Refs. 2, 3) in 1991 at TWI, Cambridge, United Kingdom. Currently, 72 organizations hold licenses to use the process. Since the initial invention, there has been much activity throughout the world in the development of tool designs, applications, and friction stir welding machines resulting in more than 550 patent applications (Ref. 4).

An important aspect that generates increasing interest in FSW is its potential to enhance the crashworthiness of aluminum vehicles that can otherwise fail in the heat-affected zone along weld joints. This has been observed in European accidents, notably in Eschede in Germany in June 1998 and Ladbroke Grove in Great Britain in October 1999. It was recommended in the report on the latter that consideration be given “to the use of alternatives to fusion welding” and “the use of improved grades of aluminum, which are less susceptible to fusion weld weakening” (Ref. 5).

The Scandinavian aluminum extruders Sapa and Hydro Aluminium were the first in Europe to commercially apply the friction stir welding process for the manufacture of single-wall aluminum roof panels for rolling stock applications. Since 1997, Alstom LHB in Salzgitter, Germany, has purchased these prefabricated panels for Copenhagen suburban trains — Figs. 1, 2. Since early 2001, they have used friction-stir-welded aluminum side walls and, since 2002, FSW floor panels for Munich suburban trains. These panels are made by Sapa.
In March 1999, Alstom LHB engineers considered friction stir welding hollow aluminum profiles for making floor and side panels, but calculated a three-shift operation would be necessary to achieving return on investment in an acceptable time span. They estimated the most significant technical and economic benefits could be achieved by applying FSW to aluminum joints of more than 12 mm thickness. This would replace mechanized gas metal arc welding, which necessitates the associated activities of preheating and grinding of intermediate heads. Additionally, it would lead to improved quality of the welds. Therefore, successful FSW experiments were conducted on up to 23-mm-thick aluminum plates to demonstrate how gas metal arc welds could be replaced in the underframe area of rolling stock.

Bombardier in Derby, United Kingdom, has carried out FSW experiments for butt-joint and lap welds and has conducted fatigue tests at TWI (Ref. 6). It has stated one of the major advantages of FSW is the ability to weld larger joints with reduced distortion. However, it concluded investment in large purpose-built FSW machines is currently difficult to justify, partly due to insufficient volume of work. Using a subcontractor or job shop is now being considered.

Up to 16-m-long SuperStir™ machines have been designed, built, and commissioned by ESAB in Laxå, Sweden. One has been installed at Sapa and is used for the production of large panels and heavy profiles with a welding length of up to 14.5 m and a maximum width of 3 m — Fig. 3. This machine has three welding heads, which means it is possible to weld from two sides of the panel at the same time or to use two welding heads (positioned on the same side of the panel) starting at the center of the workpiece and welding in opposite directions. ESAB’s newest gantry machine has now been installed at DanStir in Copenhagen, Denmark (15 x 3 x 1 m) — Fig. 4.

**The EuroStir® Project**

A number of European companies requested the provision of job shop services and low cost feasibility studies to share the cost of capital investment, licensing, and R&D efforts. Some of them proposed teaming up in a collaborative project with the overall objective of accelerating the use of friction stir welding in Europe. This EuroStir® project was launched in December 2000 and will last for five years. It is partially funded by EUREKA, which is a pan-European initiative for promoting collaborative research in advanced technology.
The research and development phase of the 6.8 million Euros project will take 2½ years. Deliverables will be proven welding procedures for test pieces and prototypes in comprehensive detail. Equally important will be the detailed comparison between types of equipment (Figs. 5, 6), which will enable potential users to make informed investment choices. In a EuroStir® case study funded by Railway Safety, United Kingdom, and two rolling stock leasing companies, it is planned to compare the quality of friction stir and gas metal arc welding in appropriate aluminum alloys. It has been proposed to undertake small-scale static and dynamic tests, i.e., high strain rate tensile and drop-weight tests.

The dissemination phase of the EuroStir® project will be funded mainly by industry for two and one half years. It will involve seminars, workshops, and demonstrations. Manufacturing economics will feature strongly in this phase. A vital project achievement will be the establishment of at least 25 user organizations across Europe within five years. The project currently has 34 collaborators and is open to additional participants from EUREKA countries.

**Friction Stir Welding in Japan**

Hitachi of Japan uses the double-skin design of the car, which is constructed from friction-stir-welded aluminum extrusions. One of the reasons for this is the exceptionally low distortion of the FSW process. This contrasts markedly with the distortion that can occur when arc welding thin-gauge aluminum and eliminates the need for straightening and filling. To date, Hitachi has delivered a range of vehicles for both commuter and express use (Figs. 7, 8). These efforts have been recognized in Japan by the presentation of the prestigious Okouchi Award jointly to Hitachi and TWI.

Nippon Sharyo and another Japanese company have been using friction-stir-welded panels produced by Sumitomo Light Metal Industries (Ref. 7) for the floor panels of the new Shinkansen — Figs. 9, 10. Some of these trains operate at speeds up to 285 km/h. Nippon Light Metals has also made use of friction stir welding for subway rolling stock. By 1998, it reported more than 3 km of welds had been produced. The weld quality was confirmed to be excellent based on microstructural, X-ray, and tensile test results.
Conclusions

Friction stir welding is being commercially applied to aluminum rolling stock around the world. Several machine manufacturers can provide suitable welding machines.

Thirty-four companies have teamed up in the EuroStir® project to get friction stir welding out of the laboratories and into industrial manufacturing workshops. This activity will generate additional applications for FSW within the rail industry.

Acknowledgments

The authors wish to thank the companies mentioned for permission to publish photographs and information on their use of friction stir welding.

References


Solder interconnects are the primary method for providing electrical continuity and mechanical attachment in commercial and military-grade electronic products. Solder joints that form connections directly to the silicon device are categorized as level 1 interconnects (Fig. 1A). The traditional circuit board solder joint is classified as a level 2 interconnect — Fig. 1B. Soldering is also used to construct the connectors that link together the various daughter- and mother-board assemblies into a single product; these solder joints are often referred to as the level 3 interconnects — Fig. 1C. Finally, soldering provides a means to actually construct electromechanical and electromagnetic devices such as relays, switches, and transformers — Fig. 1D.

**Development of soldering as a means to assemble electronics for use in ultrahigh-temperature environments begins with solder alloy selection**

**By Paul T. Vianco**

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The variety of currently available commercial and military electronics is accompanied by an equally wide range of service environments and reliability requirements. In fact, some standards organizations have used service environments and, specifically, maximum and minimum temperature conditions, as well as product reliability requirements, to establish general categories for electronics and, as such, for solder interconnects (Ref. 1). Unfortunately, electronics used in ultrahigh-temperature applications such as oil and gas well exploration or the data logging of geothermal wells are not represented in established categories. The reliability requirements of ultrahigh-temperature electronics are comparable to that for space and satellite hardware. That is, although lives are not endangered in the event the electronics should fail, there is an enormous cost burden associated with replacing faulty equipment.

**Solder Alloys for Electronics Assembly**

In spite of a wide range of service environments and reliability requirements, today's electronic products are assembled with only a small number of solder materials. By and large, level 2 and 3 interconnects made for commercial, military, and space electronics are done with the 63Sn-37Pb (wt-%) solder having a eutectic temperature of 183°C (360°F) (Ref. 2). Organic circuit board laminates and packaging materials can readily accommodate the processing temperatures associated with the Sn-Pb solders (Ref. 3). Higher-melting-temperature solders are used for a number of level 1 interconnects; those solders include the Pb-rich compositions such as 90Pb-10Sn, which has a solidus and liquidus temperature of 268°C (515°F) and 302°C (575°F), respectively. A second group of solders for level 1 interconnects are the so-called "die-attach" solders, three Au-rich, eutectic alloys and their single melting temperatures: 80Au-20Sn (280°C, 536°F); 88Au-
Solders for Ultrahigh-Temperature Applications

It is important to define, explicitly, the temperature conditions described by “ultrahigh temperature” in order to identify solder materials and processes with which to design and manufacture electronic assemblies for these applications.

For this article, the term “ultrahigh-temperature” will be used to refer to environments having sustained temperatures as high as 300°C (572°F) and momentary temperature excursions to levels as high as 350°C (662°F).

The successful development of a soldered interconnect for these environments must consider the following tasks:

- The next-assembly processes and subsequent service conditions must be identified as the first criteria for solder alloy selection.
- The selection of solder alloy(s) must also address the substrate materials and any coatings used to enhance solderability.
- An appropriate soldering process must consider precleaning treatments, the type of heat source, fluxes, controlled atmospheres, and postassembly cleaning steps.
- Prototype solder joints must be exposed to an accelerated aging program to determine the long-term reliability of the interconnects.

These steps are described in greater detail in the sections that follow.

Next Assembly Processes and Service Environments

The conditions considered with respect to the survivability of the electronics and, specifically, the solder interconnects, are temperature, shock and vibration, humidity, and atmosphere. First and foremost, it is important to understand the relationship between the temperature properties of the solder composition, the service temperature, and the process temperatures used to make the joint. This relationship can be understood using the schematic diagram in Fig. 2 and two guidelines.

The first guideline is once an interconnect has been fabricated, the solder shall not remelt during the next assembly process nor while the interconnect is in service. Once the solder is no longer entirely solid, it is incapable of supporting a mechanical load, so the integrity of the joint is considered lost. The maximum service temperature should remain less than the solidus temperature of the solder by 25°C (45°F). This margin ensures the solder maintains an adequate high-temperature strength.

The second guideline from Fig. 2 describes the relationship between the solder alloy liquidus temperature and the minimum process temperature. The minimum processing temperature should exceed the solder liquidus temperature by 20° to 40°C (36° to 72°F). This margin ensures an adequate temperature rise in the substrate material.
Materials Selection

Next-assembly processes and service temperature(s) determine the minimum solidus temperature specification placed on the solder alloy. In this application, the service environment often becomes shipment and storage conditions. The electronics may be exposed to diurnal or even route to the well head. Then, the actual-use environments to which the solder interconnects are exposed must be identified. Computational models help predict the levels of degradation expected from solder joints under specified service environments (Refs. 5, 6).

Soldering Process Development

Successful implementation of a new solder alloy for ultrahigh-temperature electronic applications begins by demonstrating a soldering process can be developed for it. The molten solder must show good wetting and spreading behavior, that is, good solderability, on the substrate surface. Use of metal coatings can overcome poor solderability: the solder wets and spreads over the coating referred to as a solderable layer or solderable finish. A layer of gold deposited over the surface of the solderable layer protects it from excessive oxidation or contamination prior to soldering. The methodology behind the solderable and protective coatings is illustrated in Fig. 4.

A solderable finish/protective finish system that has been used in a wide range of applications is the Ni solderable layer and the Au protective finish. Nominal thicknesses of the two layers are 1.3–3.8 μm (50–150 μm) Ni and 1.3–2.5 μm (50–100 μm) Au (Refs. 13, 14). Poor solder spreading can also be overcome by mechanically assisting the movement of molten solder over the substrate surface(s). As shown in Fig. 5, forcing the two surfaces together causes the molten solder to spread within the gradually decreasing gap.

An alternative approach uses sound waves to cavitate the molten solder at the substrate surface, resulting in removal of the oxidation layer. Ultrasonic energy can be introduced into the joint via an ultrasonic (electric) soldering iron, or a hot-solder dipped coating can be applied prior to actual assembly by immersing the substrate surface into a molten solder bath contained in an ultrasonic pot.

A number of potential soldering processes could be developed for ultrahigh-temperature solders. If a potential solder requires high processing temperatures, a localized heating technique, such as a soldering iron, torch, or laser is preferred. With those methods, heat is delivered only to the immediate joint area. Both manual soldering and semi-automated localized heating processes can be developed. Oxidation of the substrate and molten solder surfaces during the soldering process can be addressed by introducing an inert nitrogen atmosphere.
(50–100 ppm residual oxygen) around the joint area (Ref. 16).

Solder Joint Reliability

Once the appropriate solder composition and assembly processes have been realized, an evaluation is conducted to assess long-term reliability of the solder interconnects. The properties of the interconnects are evaluated using accelerated aging tests. Present-day accelerated aging methodologies do not address the types of conditions found in down-hole applications. Therefore, appropriate test protocols have to be developed so critical acceleration factors can be identified for converting accelerated aging data to the prospective service conditions.

Summary

1. The term “ultrahigh-temperature” refers to environments having sustained temperatures as high as 300°C (572°F) and momentary temperature excursions to levels as high as 350°C (662°F). These conditions are typically encountered in down-hole applications such as oil, gas, and geothermal well exploration and monitoring.

2. Development of soldering as a means to assemble electronics for use in ultrahigh-temperature environments begins with selection of one or more solder alloys. The primary criterion is the solder have a minimum solidus temperature of 375°C (707°F) and a maximum liquidus temperature of 400°C (752°F).

3. A survey of binary alloy compositions and commercially available solders resulted in the 95Zn-5Al alloy, T_{solidus} = 382°C (720°F), as the only available material to meet the specifications.

4. Localized heating techniques, such as hand soldering with an iron or microtorch, would be preferred. The substrate surfaces can be made solderable prior to assembly through use of protective or solderable-plus-protective coatings.

5. Accelerated aging protocols will be developed for assessing the long-term reliability of electronics used in these applications. Besides solder joint strength, the integrity metrics would include electrical continuity and microstructural evolution exhibited by the alloy composition.

Acknowledgment

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On August 6 and 7, the Navy Joining Center (NJJC) held the University Welding Research Conference for Defense Applications in Columbus, Ohio. The conference was designed to promote awareness of current materials joining research activities performed by NJJC university team partners to industry and the Department of Defense (DoD). The research presented highlighted enabling technology to improve future survivability, mission capability, and affordability of Navy and DoD weapon systems. Researchers from Lehigh University, Portland State University, The Pennsylvania State University, Massachusetts Institute of Technology (MIT), The Ohio State University (OSU), and University of South Carolina gave presentations on their respective research. Topics included friction stir welding (FSW), arc weld process control, laser processing, weldability testing/weld metal characterization, and modeling of residual stress and distortion.

The friction stir welding presentation spotlighted the University of South Carolina’s research activities directed toward steels for Navy shipyard applications. Investigations are being performed in joining mild steels (DH-36, HSLA 65), stainless steel (304L), and AL6XN.

The Pennsylvania State University presented laser processing research activities in laser drilling/microdeposition and thermal plate forming. The laser drilling/microdeposition research was brought about by a need to develop an automated system for the Department of Defense for the remanufacture of outdated or unavailable printed wiring boards or of those too costly to remanufacture by other methods. The research in laser forming is directed at developing an automated system for forming ship hull components. This task is being carried out by the development of an integrated system and synthesis of path planning algorithms for laser-assisted forming of plate. Ongoing laser processing research is being performed at The Ohio State University to explore a new method of using low-power laser beams to initiate, guide, and concentrate the welding arc.

Portland State University, Lehigh University, and The Ohio State University presented research in the areas of process control and/or weld testing and characterization. Research in high-heat-input welding on the properties of high-performance steels and solidification cracking of low-carbon steel weld metal was presented by Portland State. Lehigh presented research in modeling of residual stress/distortion for welded stainless steel, double-hull structures, fatigue reduction in gas metal arc welding, and fatigue strength of welded AL6XN super austenitic stainless steel. Recent developments in weldability testing for structural materials was presented by OSU, which also presented its research in the area of efficient experimentation for optimal control in robotic arc welding.

The conference featured presentations by Raymundo Arroyave and Matthew Perricone, recipients of NJJC/AWS education fellowships for the 2001-2002 academic year. Arroyave presented his research conducted at MIT on “Use of Thermodynamic and Kinetic Tools to Understand Ceramic/Metal Joining.” Perricone presented his thesis work conducted at Lehigh University titled “Weld Solidification Behavior of Stainless Steel and Ni-Base Alloys for Advanced Double Hull Applications.”

For more information about the conference, contact Larry Brown at (614) 688-5080 or via e-mail at larry_brown@ewi.org.
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Soldering: Tin-Lead Solders

Solders have melting points below 840°F (450°C) and normally require a flux. Flux cleans the metals and lowers surface tension between the molten solder and solid substrate, improving wetting of the filler metal. The surfaces to be joined should first be cleaned of dirt, oxides, or other contaminants since flux is not meant to be a substitute for prior cleaning.

Tin-lead-alloy solders are widely used to join metals. Most commercial fluxes, cleaning methods, and soldering processes can be used with tin-lead solders.

It is customary to describe these solders with tin content first. For example, 40/60 solder is 40% tin and 60% lead. The behavior of tin-lead solders is illustrated in a constitutional diagram shown as Fig. 1. The diagram is explained using the following terms.

Solidus temperature. This is the highest temperature at which a metal or alloy is completely solid. This is seen as the ACEDB curve in Fig. 1.

Liquidus temperature. This is the lowest temperature at which a metal or alloy is completely liquid. It is illustrated as the curve AEB in the figure.

Eutectic alloy. This is an alloy that melts at one temperature and not over a range. The eutectic temperature is the solidus temperature at curve CED in Fig. 1. The eutectic alloy is the composition noted at point E in the figure.

Melting range. This is the temperature difference between solidus and liquidus. It can be seen in the diagram as the temperature between solidus ACEDB and liquidus AEB, where the solder is partially melted.

As seen in the figure, pure lead melts at 621°F (327°C) (point A), and pure tin melts at 450°F (232°C) (Point B). Solders containing 19.5% tin (Point C) up to 97.5% tin (Point D) have the same solidus temperature, namely the eutectic temperature, which is 361°F (183°C). Any other composition will contain some solid metal in equilibrium with the liquid. These compositions do not melt completely until above the liquidus temperature. For example, 50-50 solder has a solidus temperature of 361°F and a liquidus of 417°F, which is a melting range of 56°F.

The 5/95 tin-lead solder has a relatively high melting temperature with a small melting range. This solder has less attractive wetting and flow characteristics compared to higher tin content alloys. Its high soldering temperature limits use to organic-based fluxes. Applications include sealing, coating, and joining in moderately elevated temperature conditions.

The 10/90, 15/85, and 20/80 tin-lead solders have lower liquidus and solidus temperatures and liquidus temperatures than 5/95. They also have better wetting characteristics. Applications include heater cores, radiators, and coating.

The 25/75 and 30/70 alloys have lower liquidus temperatures than the above solders. These alloys are used in radiator manufacturing and repair.

The 35/65, 40/60, and 50/50 solders have low liquidus temperatures and good wetting characteristics. These alloys are used on sheet metal applications, and the 50/50 finds use in nonpotable water plumbing applications.

The 60/40 alloy and the 63/37 eutectic solder are used on delicate instruments and electronic assemblies. All methods of cleaning, fluxing, and heating may be used with them.

The 70/30 solder is a special purpose type used where a high-tin content is required. All soldering techniques apply.

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Fundamentals of Corrosion and Its Control. October 21-23, LaQue Center for Corrosion Technology, Inc., Wrightsville Beach, N.C. Contact: LaQue Center for Corrosion Technology, Inc., P.O. Box 656, Wrightsville Beach, NC 28480, (910) 256-2271, FAX: (910) 256-9816, e-mail: info@laque.com; www.laque.com.

Failures, Failure Prevention, Maintenance and Repairs of Pressure Vessels, Boilers, Piping, and Rotating Machinery. October 21-23, Sheraton Providence Airport Hotel, Warwick, R.I. Presented by Thielsch Engineering. Contact: Kathy Hackett, Thielsch Engineering, Inc., 195 Frances Ave., Cranston, RI 02910-2211, (401) 467-6454, FAX: (401) 467-2398, e-mail: khackett@thielsch.com; www.thielsch.com.


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

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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.

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AWS International Certification Events

SEOUl, KOREA
CWI Training: October 22–25,
CWI Examination: October 26
Location: International Welding Technology Research Lab.
Contact: Chon L. Tsai, 886-22-363-3663, FAX: 886-22-363-6275,
e-mail: iwtrl@ms15.hinet.net or tsai.l@osu.edu

DUBAI, U.A.E.
SCWI Training: October 25–30,
SCWI Examination: November 1
Location: Cleveland Bridge and Engineering
Contact: Bernard D'Silva, 971-4-883-5551, FAX: 971-4-883-5304,
e-mail: contact@clevelandbridge.co.ae

MEXICO
CWI Training: November 4-8 Examination: November 9
Location: DALUS S.A., Monterrey, N.L.
Contact: Martha Laura Garcia, (5281) 83861717, FAX: (5281) 83864700, e-mail: martha.garcia@ dalus.com

CHENNAI, INDIA
CWI Training: November 11–17, CWI Examination: November 19
Industrial Quality Concepts
Contact: V. Raghavendran, 44-499-3826, FAX: 44-499-3826, e-mail: iqc.in.org@vsnLcom

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Circle No. 47 on Reader Info-Card
Q: I need to weld aluminum base metal 6061-T6. What filler metal should I use for welding this base material?

A: This question is characteristic of many I receive on a regular basis. The base metal type may vary but, in essence, the question remains the same: "How do I choose the most suitable filler metal for welding a particular base material?"

A fundamental difference between arc welding of steel and aluminum is the evaluation method used during the filler metal selection process. Many aluminum base materials can be successfully welded with any number of different filler metals. For instance, 6061-T6, the base metal referenced in the above question, is commonly welded with at least four totally different filler metals and can be successfully welded with even more.

So how do you choose the filler metal that will work best? The answer is the most appropriate filler material cannot be selected with any certainty without understanding the welded component's ap-

Fig. 1 — A weld made using 6061-T6 base metal and 4043 filler metal would not produce a good color match after anodizing.
application and expected performance in service. When an aluminum filler metal is chosen, you need to ask yourself which of the variables associated with weld performance are most important. Also, you must realize selection of a filler metal not recommended for specific application may result in inadequate service performance and possibly premature failure of the welded joint. Filler metals for arc welding aluminum are evaluated against the following variables:

- **Ease of Welding.** This is the relative freedom from weld cracking. By use of hot cracking sensitivity curves for the various aluminum alloys, and through the consideration of dilution between filler metal and base metal, the filler metal/base metal crack sensitivity rating can be established.

- **Strength of Welded Joint.** Consideration of the tensile strength of groove welds and shear strength of fillet welds when welded with different filler metals, can prove to be extremely important during weld design. Different filler metals, which may both exceed the as-welded tensile strength of the base metal, can be significantly different in shear strength performance.

- **Ductility.** This is a consideration if forming operations are to be used during fabrication and may also be a design consideration for service if fatigue and/or shock loading are of importance.

- **Corrosion Resistance.** This is a consideration for some environmental conditions and is typically based on exposure to fresh and salt water.

- **Sustained Temperature Services.** The reaction of some filler metals at sustained elevated temperatures (above 150°F). This may promote premature component failure due to stress corrosion cracking.

- **Color Match.** Base metal and filler metal color match after anodizing can be of major concern in some cosmetic applications.

- **Postweld Heat Treatment.** The ability of the filler metal to respond to postweld heat treatment associated with filler metal chemistry and joint design.

As an example of the extent and complexity of this situation, let’s take a look at one aluminum base metal and three of the many applications in which it may be used. If you consider the base metal in the original question, 6061-T6, and its use in the following applications, you can appreciate how the filler metal selected can seriously affect the component’s performance.

1. **The first application uses 6061-T6 tubing for a hand railing that is to be clear coat anodized after welding. You will need to select a filler metal that will provide the best color match after anodizing. With color match as the prime consideration, the most appropriate filler for this application is alloy 5356. If you selected filler metals 4043, 4047, or 4643, which are often shown as being suitable for this base material, you would find that after anodizing, the weld would become dark gray in color and would not provide a suitable match to the bright silver appearance of the hand rail tubing — Fig. 1.**

2. **The second application uses 6061-T6 extruded angle bar as a welded attachment bracket for a heating component that will be operating consistently at 250°F. For this application, investigate filler metals suitable for elevated temperature service such as 5554, 4043, or 4047. If 5356, 5183, or 5556 filler metals are used, which are often shown as being suitable for this base metal, the possibility of sensitization of magnesium in these metals would be introduced, running the risk of stress corrosion cracking and premature failure of the welded component.**

3. **The third application uses 6061-T6 to fabricate a large safety-critical lifting device that is required to undergo extensive welding during fabrication, followed by postweld solution heat treatment and artificial aging to restore strength and return the structure to the -T6 temper. For this application, our concern would be the strength of the weld after it has been exposed to postweld heat treatment. Most filler metals commonly used for welding this base material will not respond favorably to this type of heat treatment. The 5356, 5183, and 5556 filler metals are nonheat treatable alloys that may undergo undesirable changes if subjected to this form of heat treatment. The 4043 filler metal, on its own, is nonheat treatable and would be totally dependent on dilution with the base material in order to achieve any significant response to the heat treatment. For this application, you should seriously consider the use of filler metal 4643, which is a heat-treatable filler metal and will, therefore, respond to the heat treatment after welding and provide a weld of comparable strength to that of the base material.**

### Making The Choice

Each variable specific to your application should be evaluated in detail to establish the most suitable filler metal. Fortunately, there are aluminum filler metal selection charts available that have been developed to help you make the most appropriate filler metal choice. These charts have been developed through careful consideration of all the variables and often provide a rating system for each variable to help with the selection process. If you are unsure what the most suitable filler metal is, consult the experts.

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

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Circle No. 22 on Reader Info-Card
**BRAZING**

**Q&A**

Q. We have some questions on brazed diffusion, which was the subject of an earlier column. It was stated that when the boron in BNI-2, and similar filler metals, fully diffuses into base metals such as 304 and 347, the filler metal has a hardness of around HRC 20–25. When boron from the same filler metal is fully diffusion brazed in 410, 403, 430, and similar base metals, the filler metal hardness is around HRC 70. BNI-2 is a low-carbon filler metal and BNI-1 is a high-carbon filler metal. Would the results change with the carbon content? Also, why are the fillets so hard in the HRC readings?

A. First, let us dispose of the carbon question. While the BNI-2 carbon is low — 0.06% maximum, nominal 0.03% C — BNI-1, the original nickel filler metal, has a carbon content of 0.60–0.90%. It would be expected the carbon content would make a profound difference in joint filler metal hardness. Actually, many tests have revealed the joint hardness of both filler metals is the same after full diffusion in the same base metal. We must remember carbon has a smaller atomic size than boron. The original filler metal hardness of both filler metals is around HRC 60, so the carbon content makes essentially no difference in the hardness. To drop from their original hardness, a melting point depressant, and hardening agent, boron, is diffused into the base metal and out of the joint filler metal. Since the carbon atom is slightly smaller than the boron atom, it can also migrate out of the joint filler metal.

Boron from the joint filler metal appears to more rapidly and completely diffuse into the iron-chromium 400 series base metals than the base metals of the joint filler metal hardness. Thus, the final joint hardness of the fully diffused joint filler metal in a 400 series base metal will be around HRC 70, while the final joint hardness of the fully diffused joint filler metal in a 300 series base metal will be around HRC 20–25. We should also remember diffusion takes place in both directions. The base metal elements will diffuse into the brazed joint. Since the atomic size of the base metal elements is larger than boron, their mobility or rate of diffusion is much slower.

Each brazing filler metal will have a different diffusion rate with each different base metal, depending on chemical composition, the mutual degree of solubility, and the atomic size of the melting point depressant. For example, the atomic size of boron is small, so it has high mobility at the brazing temperature. Filler metals such as BNI-5 have silicon as the melting point depressant. Silicon has a larger atomic size than nickel, chromium, iron, etc., and thus has very low mobility, so the diffusion rate is very low.

Now to address the fillet hardness. Most people think large fillets are better. Unfortunately, this is not true with nickel filler metals. With large fillets, there is a very large excess of boron to be diffused. When all the boron has been diffused out of the thin brazed joint, there is still an excess of boron in the fillet that keeps the hardness level high. If there is a bending stress at the fillet or a bending fatigue stress, the hard fillet will crack. For this reason, it is important to keep the fillets in nickel brazing filler metals to the very minimum. With small fillets, much, or all, of the boron will be diffused out of the fillet, lowering its hardness and increasing its ductility.

While we have talked a lot about diffusion and hardness, the main reason I developed the nickel brazing filler metals back in the mid-1940s was to specifically develop a filler metal that would not remelt when the jet engine overheated. At that time, the only high-temperature filler metal was BAg-23, 85 silver-15 manganese with a liquidus of 1780°F (970°C). This filler metal would melt and be blown out the jet engine on overheating. Diffusion of the BNI-1 filler metal raised the remelt temperature to above 2500°F (1370°C), which was as high as it was tested, and the cantilever joint did not fail.

Diffusion brazing has given the industry the ability to braze joints used at service temperatures far above the solidus of the original brazing filler metals.

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**BY R. L. PEASLEE**  
Colmonoy Corp., Madison Heights, Mich. This article is based on a column prepared for the *AWS Detroit Brazing and Soldering Division's newsletter. Reader may send questions to Mr. Peaslee c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126 or via e-mail to bobpeaslee@wallcolmonoy.com.
American Welding Society District 18 Director John Mendoza presented the AWS Historical Welded Structure Award to the USS Lexington (CV-16, later CVA-16, CVS-16, CVT-16, and AVT-16) on July 22. The ceremony was held aboard the Lexington in Hangar Bay 2 at the USS Lexington Museum on the Bay in Corpus Christi, Tex. Accepting the award on behalf of the Lexington were Lexington Hull Technician Rick Black and Lexington Exhibits Director Tommy Campbell — Fig. 1. Other dignitaries attending the ceremony included AWS Corpus Christi Section Chairman Tommy Campbell and Texas State College AWS Student Chapter Advisor Raul Robles.

The USS Lexington, a 27,000-ton Essex-class aircraft carrier, was commissioned on September 23, 1942, and launched on February 17, 1943, from the Bethlehem Steel Shipyard in Quincy, Mass. — Fig. 2. She is the fourth U.S. naval ship to be named the USS Lexington. Originally slated to be named the USS Cabot, a petition was submitted to the Secretary of the Navy by the vessel's construction work force that asked she be named the USS Lexington in honor of the CV-2 aircraft carrier of the same name that was mortally damaged by fires and explosions on the afternoon of May 8, 1942, during World War II's Battle of the Coral Sea — Fig. 3.

The USS Lexington (CV-16) served the United States longer and set more records than any other carrier in the history of naval aviation. After her launch, she participated in training maneuvers then joined the 5th Fleet at Pearl Harbor. During World War II, she took part in most major operations in the Pacific Theater and spent 21 months in combat.

Her first combat operation was in the September-October raids on Tarawa and Wake. In November and December 1943, she participated in the campaign to seize bases in the Gilbert Islands and batter down Japanese forces in the Marshalls. It was during the attacks on Kwajalein on December 4, 1943, that she was hit in the stern with a torpedo during a night air attack, knocking out her steering gear.

By March 1944, after two months of shipyard repairs, Lexington was back in the war zone and took part in raids in the central Pacific and New Guinea over the next few months. In June, she supported the Marianas invasion and won the Battle of the Philippine Sea —
USS LEXINGTON

Fig. 4, Lexington continued her strikes on enemy targets in the central and western Pacific, including the October 24 Battle of Leyte Gulf, where her planes joined in sinking Japan's super-battleship and scored hits on three cruisers, and the February 1945 Iwo Jima operation, until she headed to Puget Sound for an overhaul. Lexington was once again combat bound in May when she returned to participate in the last two months of the Pacific War. After hostilities ended, Lexington remained in the Pacific in a support capacity, flying precautionary patrols over Japan and dropping supplies to prisoner of war camps on Honshu, until leaving Tokyo Bay on December 3, 1945, carrying homeward bound veterans to San Francisco. During her World War II service, she received the Presidential Unit Citation and 11 battle stars.

Lexington was nicknamed "The Blue Ghost" by propagandist Tokyo Rose because she never wore the camouflage paint of the other U.S. carriers, and because she was reported by the Japanese as sunk four times.

Lexington was decommissioned in Bremerton, Wash., in April 1947, and "mothballed" for the next six years. In 1953, an extensive, two-year modernization of the carrier was undertaken. In August 1955, Lexington was recommissioned as an attack aircraft carrier (redesignated CVA-16). She now featured an angled flight deck and other improvements to accommodate high-performance aircraft. Assigned to San Diego as her home port, she operated off California until May 1956, when she left for a six-month deployment with the 7th Fleet. In all, Lexington was deployed five to the western Pacific between 1956 and 1961.

In 1962, Lexington was ordered to relieve the USS Antietam in the Atlantic as the Navy's training carrier and was redesignated CVS-16. However, she resumed her duty as an attack carrier during the Cuban Missile Crisis and did not relieve the Antietam at Pensacola until December 29, 1963.

In July 1969, Lexington was redesignated CVT-16 and AVT-16 in 1978. For 29 years, she operated in the Gulf of Mexico as a training carrier for student naval aviators. She was decommissioned on November 26, 1991.

Since October 14, 1992, USS Lexington has served as the USS Lexington Museum on the Bay in Corpus Christi, Tex. She is now used to educate, entertain, and inspire. The museum offers Science-Abord-

Fig. 4 — An F6F-3 "Helcat" fighter prepares to land aboard USS Lexington (CV-16) during the "Marianas Turkey Shoot" phase of the Battle of the Philippine Sea, June 19, 1944. Note the manned 40-mm guns in the foreground, and 20-mm guns along the starboard side of the flight deck. (Official U.S. Navy photograph, now in the collections of the National Archives.)

The Extraordinary Welding Award Program

The AWS Historical Welded Structure Award is part of AWS's Extraordinary Welding Award Program, which also includes the Outstanding Development in Welded Fabrication Award. The Historical Welded Structure Award honors structures at least 35 years old that have had a significant impact on history. It celebrates the advances made in welding and the importance it plays in the development of key products. The Outstanding Development in Welded Fabrication Award acknowledges more recent technological breakthroughs in welding.

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 Townsend at the American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126, telephone (800) 443-9353 ext. 308, outside the U.S. dial (305) 443-9353 ext. 308, or e-mail her at townsend@aws.org.

The American Welding Society (AWS) announced the appointment of David J. Landon of the Vermeer Manufacturing Co. as chairman of the Welding Industry Network (WIN), a Standing Committee of the American Welding Society. The goals of WIN are to provide a forum for industry leaders to identify best practices and to address materials-joining managerial, scientific, technical, and operational issues that impact competitiveness with the manufacturing industry as a whole.

As chairman, Landon has already begun to restructure WIN to increase its strength and clout within the industry. Part of WIN's revitalization is in the area of member eligibility. WIN membership is composed exclusively of end users. End users are defined as any company that uses welding to add value to their products or services. To that end, it was decided that gas manufacturers are eligible for membership in WIN as well as steel companies, educational institutions, and research facilities. Landon believes this will broaden the membership base and add to networking opportunities and the free exchange of information between industries.

Additionally, membership benefits were expanded and now include quarterly newsletters, four VIP plant tours, increased networking opportunities, and a stronger presence at the AWS Welding Show.

AWS Indiana Section To Host Student Night

On November 18, the AWS Indiana Section will hold its Annual Student Night at the McKenzie Career Center. The event will begin at 6:00 p.m. in the Center's welding lab. AWS President Ernest Levert of Lockheed Martin Missiles and Fire Control in Dallas, Tex., will be the featured speaker at the event. Also on hand will be master blacksmiths and students to perform demonstrations.

For more information on the AWS Indiana Section's Annual Student Night, visit the McKenzie Career Center's Web site at www.msdlt.k12.in.us/mckenzie/welding/awasnight.htm or contact Ed Wyatt at (317) 576-6420, e-mail: williamwyatt@msdl.t.k12.in.us.
Fourth Annual Leadership Symposium
Held at AWS Headquarters

To foster the exchange of ideas between AWS Sections and Districts, the American Welding Society held the Fourth Annual Leadership Symposium on July 14-16. This yearly event is designed to strengthen leadership skills, give tips on planning activities, provide an opportunity to meet AWS staff, and provide a chance for participants to learn about helpful resources available from the Society.

Past AWS President Lee Kvidahl, who is also AWS National Membership Committee chairman, worked with Member Services Associate Executive Director Cassie Burrell on the Symposium itinerary.

In addition to the hard work and long hours attendees had to put in at the Symposium, they were treated to a sightseeing cruise around Biscayne Bay aboard the Island Queen and an evening of shopping and dinner in Coconut Grove, Fla.

Representatives from 21 AWS Districts and 27 of the AWS Sections attended the Symposium. Representing their district at the Symposium were District 1, Thomas Ferri, Boston; District 2, Gary Atherton, Philadelphia; District 3, Dan Marino, Lehigh Valley; District 4, Spencer Aycock, Triangle; District 5, Uwe Aschemeyer, Cincinnati; District 6, Mike Krupnicki, Rochester; District 7, Jay Dalamarter, Cincinnati; District 8, David Hamilton, Chattanooga; District 9, Oliver Myers, Baton Rouge, and Darren Haas, Pascagoula; District 10, David Hughes, Mahoning Valley; District 11, William Neill, Northern Michigan; District 12, Michael Rosensteel, Milwaukee, and Sean Moran, Fox Valley; District 13, Kathleen Jefford, Peoria; District 14, Timothy Pinson, Lexington; District 15, Loren J. Kantola, Arrowhead; District 16, Troy Miller, Central Nebraska; District 17, Jim Bridwell, Ozarks, and William E. Overshiner, Tulsa; District 18, Tommy Campbell, Corpus Christi; District 19, Gary Diseth, Puget Sound; District 20, Thomas Kienbaum, Colorado; District 21, Stan Luis, California Central Coast; District 22, Dale Flood, Kansas City; District 23, Dennis Horsa of Sacramento and Kent Baucher of Fresno.

Leadership Symposium attendees pose for a group photograph at AWS headquarters in Miami, Fla.

Spencer Aycock and his wife during the group's sightseeing tour around Biscayne Bay aboard the Island Queen.

AWS National Membership Committee Chairman Lee Kvidahl presenting Kathy Jefford of the Peoria Section with her Leadership Excellence Award Certificate.
Twenty-one educators from across the United States arrived at the American Welding Society's Miami headquarters on July 17 to participate in the second AWS Instructors' Institute. The Institute, which ran from July 17 through the 21st, was coordinated by AWS Vice President James Greer, a welding professor and coordinator of the welding program at Moraine Valley Community College, who served as instructor of the Institute, and AWS Education Director Chris Pollock.

The twenty-one attendees were all secondary or postsecondary welding instructors who directly teach welding. Each was selected during the AWS District Conferences that are held in May and June. Twenty one of the AWS Districts sent representatives. Attending this year were Douglas Desrochers, District 1; Bill Campbell, District 2; David Schnalzer, District 3; Roger Snider, District 4; Martha Vann, District 5; Frank Schweers, District 6; Kevin Langdon, District 7; Glen Wade, District 8; Charles Lewis, District 9; Don Leonard, District 11; Dale Lange, District 12; Rick Potanin, District 13; Donald Kimbrell, District 14; Dale Szabla, District 15; Jeffrey Pelster, District 16; Jim Bidwell, District 17; Raul Robles, District 18; Sue Caldera, District 19; Dale Murtensen, District 20; Gilbert Callender, District 1; Robert Purvis, District 22.

AWS Deputy Executive Director Jeff Hufsey said the goals of the program were "to bring together welding instructors from all over the United States, let them learn more about AWS, give them the opportunity to get some hands-on welding practice using the latest and best welding equipment, and provide them with the support and encouragement to be the best instructors they can be."

The instructors' time while at the Institute was split between classroom discussions and hands-on learning in the Glenn J. Gibson Memorial Welding Laboratory. While in the lab, they had the opportunity to try some of the latest technology and learn instructional techniques for processes such as welding aluminum. Manufacturers' representatives were on hand to demonstrate their companies' newest welding equipment and allow the instructors to test it.

Classroom time was spent identifying challenges and finding solutions. Topics were presented to the class, which then broke up into smaller groups to address the issues. This group setting gave instructors the opportunity to meet with their counterparts from across the United States and discuss the issues they contend with and possible solutions.

Martha Vann, a welding instructor at Trident Technical College in Charleston, S.C., enjoyed the group interaction and stated, "We share a common responsibility...recruiting new students, marketing the career field, keeping current with technology, and teaching welding skills, blueprint reading skills, metallurgy, weld quality, and math. To have the opportunity to meet welding educators from across the country and share ideas, problems/solutions, and technical information was like being recharged."

Companies that contributed to the Institute's success by generously lending or donating supplies and equipment included ESAB Welding & Cutting Products, Hanover, Pa.; The Lincoln Electric Co., Cleveland, Ohio; Miller Electric Mfg. Co., Appleton, Wis.; Sellstrom Mfg. Co., Palatine, Ill.; and Welding Engineering Supply Co., Prichard, Ala. Representatives from the companies gave demonstrations of the latest technology, then helped the educators with new techniques. Vann felt it was beneficial for the group to meet with industry representatives. She said, "Welding instructors tend to be isolated from their peers. Our world revolves around instruction, students, and schedules...occasionally we get to interact with industry."

When asked if the AWS Instructors' Institute was beneficial, Vann said, "I was in the middle of a very heavy workload at the time of the Institute and didn't want to take the time off to go to Miami. What a mistake that would have been. I think the experience is priceless."
**AWS Welcomes New Supporting Companies**

**New Supporting Companies**

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Spokane, WA 99217

Jackson Welding, Inc.
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Johnston, IA 50131

Southern Ohio Fabricators, Inc.
2565 Old State Rt. 32
Batavia, OH 45103-3205

Utility Coatings & Fabrication
5481 W. Bagley Park Rd.
West Jordan, UT 84088

**New Educational Institutions**

Centro Federal de Educação Tecnológica - CEFET
Av. Maracana 229
Rio de Janeiro, RJ 20271-110
Brazil

High Institute of Administrative & Technical Science LLC
P.O. Box 1135
Salalah, Dhofar 211
Sultanate of Oman

Indian Institute of Welding Technology OPP TVS.
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Kerala 682017
India

John Handley High School
425 Handley Blvd.
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Kuo-Han Science and Technology Ltd. (KHST) provides technical consulting services in advanced welding technologies and engineering training in Taiwan. KHST also conducts AWS certified welding inspector tests for Taiwan, China, and Korea under the auspices of International Welding Technology Research Laboratory, which is an official AWS representative and agent for those areas.

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**AWS Honors Distinguished Member**

The following American Welding Society member has attained the status of Distinguished Member for his participation in the Society's leadership, professional development activities, and membership recruitment.

**Oliver W. Myers**
Baton Rouge Section

To qualify for distinguished membership status, applicants must accrue 35 points or more from at least four categories: national AWS leadership, local AWS leadership, professional development, and AWS membership recruitment. If you believe you qualify, contact the AWS Membership Department at (800) 443-9353 ext. 480 or, outside the United States, (305) 443-9353 ext. 480 or FAX (305) 443-7559.
DISTRICT 1
Director: Geoffrey H. Putnam
Phone: (802) 439-5916

Central Massachusetts/Rhode Island Section Vice Chairman Doug Desrochers, left, with District 1 Director Geoffrey Putnam at the District 1 Conference.

AWS Associate Executive Director of Member Services Cassie Burrell with Walter Chojnacki of the Connecticut Section at the District 1 Conference.

Attending the District 1 Conference are, from left, Maine Section members Russ Norris and Greg Bushey, District 1 Director Geoffrey Putnam, and Maine Section member Tom Cormier, holding his daughter Olympia.

BOSTON
JUNE 21–23
Activity: Boston Section members attended the District 1 Conference in Montreal, Quebec, Canada. Incoming Section Chairman Tom Ferri presented outgoing Chairman Tony Greico with a Certificate of Appreciation for his term as chairman.

CENTRAL MASSACHUSETTS/ RHODE ISLAND
JUNE 21–23
Activity: Members attended the District 1 Conference. Conference attendees enjoyed visits to great European restaurants.

CONNECTICUT
JUNE 21–23
Activity: Walter Chojnacki presented the Section’s events and meetings held during the 2001–2002 year to attendees of the District 1 Conference.

GREEN & WHITE MOUNTAIN
JUNE 21–23
Activity: Members attended the District 1 Conference in Montreal, Quebec, Canada. Section members discussed their past year’s meetings and District scholarship winners were selected.

MAINE
JUNE 21–23
Activity: While at the District 1 Conference, past Section Chairman Russ Norris was selected for nomination as the District 1 director for the 2004–2007 term.

MONTREAL
JUNE 21–23
Activity: The Section hosted the
District 1 Director Geoffrey Putnam, left, presenting the District 1 Director Award to Montreal Section Vice Chairman Augustin Marisca, center, with Montreal Section Treasurer Michel Marier looking on.

District 1 Conference. District 1 Director Geoffrey Putnam presented the District 1 Director Award to Augustin Marisca.

DISTRICT 3
Director: Alan J. Badeaux, Sr.
Phone: (301) 535-4709

YORK-CENTRAL PENNSYLVANIA
JUNE 20
Activity: The Section’s Executive Board’s Strategic Planning Committee members met to discuss Chairman George Bottenfield’s plans for the upcoming year.

JULY 25
Activity: The Executive Board met to finalize plans for the Section’s annual golf outing with the Lancaster Section.

AUGUST 16
Activity: The Section held the Annual Woody Rowland Memorial Golf Outing at Cool Creek Country Club in Wrightsville, Pa. The event was held in conjunction with the Lancaster Section. Attendance was the highest ever with 136 golfers taking part. Past Chairman Mike Brunnell and Lancaster Chairman Dave Kriner were the official photographers for the day.

LANCASTER
AUGUST 16
Activity: Section members and guests joined the York-Central Pennsylvania Section for the Annual Woody Rowland Memorial Golf Outing. New to the event this year was a door prize for every attendee. Prizes were donated by various businesses.
Johnstown/Altoona Awards Chairman John Kish presenting awards to welding students from various area vo-tech schools.

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

**JOHNSTOWN/ALTOONA**
April 24
Activities: The Section toured the Johnstown Welding & Fabricating plant. Awards Chairman John Kish, who is a welding instructor at Admiral Peary Area Vo-Tech School in Ebensburg, Pa., presented awards to the top welding students from Admiral Peary, Somerset, Altoona, and Fulton County vo-tech schools.

May 24
Activities: The Section held its 35th Annual Joint Pittsburgh-Johnstown/Altoona Golf Outing. Chairman Elden Snyder was presented with a plaque in honor of his service as chairman of the Johnstown/Altoona Section and his many years as the Section technical representative and librarian.

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

**NORTHEAST MISSISSIPPI**
June 20
Activity: A planning meeting was held to discuss the upcoming year.

July 25
Activities: Members met for a barbeque and further discussion on plans for the upcoming year.

August 15
Activities: Section members toured the Taylor-Wharton plant. Plans for the upcoming year were finalized.

**GREATER HUNTSVILLE**
July 25
Speaker: Wallace E. Honey.
Affiliation: AWS District 8 director.
Activity: The Section held its annual student welding contest and barbeque. A welding machine was raffled off with proceeds from the sale going to the Section's scholarship fund.

**WESTERN CAROLINA**
August 7
Activity: Section members held a planning meeting.

**DISTRICT 14**
Director: Hil Bax
Phone: (314) 644-3500, ext. 105

**CENTRAL INDIANA**
July 20
Activity: Members held their annual golf outing at the Crooked Creek Golf Club. The event was sponsored by The Lincoln Electric Co., Miller Electric Mfg. Co., Siotton-Garten, and Vulcan Systems. AWS Past President Harry Prah attended.

**DISTRICT 22**
Director: Mark Bell
Phone: (209) 387-1398

**SACRAMENTO VALLEY**
June 3
Activity: Local welding companies hosted a barbeque dinner for the community and students and their families at Butte Community College in northern California. The purpose of the dinner was to raise awareness of welding as a career option and to promote the American Welding Society.

June 15 and 16
Activity: Section members hosted AWS CWI/CWE/SCWI examinations for more than 100 people. Section members Henry Roias, Dale Fluid, and Emmanuel Ezenwa acted as examiner, supervisor, and proctor, respectively.

**INTERNATIONAL SECTION**

Attending the Emirates Welding Section's June meeting are, from left, Committee member Narinder Pal, Secretary B. Bashkar, and Chairman Bernard D'Silva.

**EMIRATES WELDING**
June 26
Activity: Thirty-five members of the Section met for a general meeting at the Sea Shell Inn. Programs for the upcoming year were discussed. Following the meeting, a buffet dinner was held.
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Summary of Changes in ASME Section IX, 2002 Addenda

BY WALTER J. SPERKO

The following is a summary of the changes that appear in the 2002 addenda of ASME Section IX. These changes and related discussion are reported by Walter J. Sperko, P.E., vice chairman of Subcommittee IX. Readers are advised the opinions expressed in this article are those of Mr. Sperko, not the official opinion of Subcommittee IX.

Introduction

Nobody ever reads the introduction to a code, yet the introduction to ASME Section IX was written specifically to give the novice an introduction to the Section IX Code. The Introduction provides critical insights into the historical development, the organization and structure of Section IX, and some key terms. Those who have successfully used Section IX can vouch for the fact that understanding how it is organized and its terminology are critical to using it properly. The only change in the Introduction in these addenda was to document the addition of “Standard Welding Procedures” in the 2000 Addenda. Although this is only a small change, novices and experienced users are encouraged to read the Introduction.

Welding Procedure (QW-200) Rule Changes

A small adjustment was made to plasma arc welding (PAW) gas variables. Previously, when using the keyhole or melt-in technique, the orifice gas and shielding gas flow rate was limited to the flow rate qualified. Since the flow rate has no effect on mechanical properties, it made no sense to keep flow rates as an essential variable. This means the welding engineer may specify the correct shielding gas and orifice gas flow rates as necessary to suit production conditions. Shielding and orifice gas composition, however, may not be changed without requalification of the Welding Procedure Specification (WPS).

Welder Qualification (QW-300) Changes

In the 2000 addenda, Subcommittee IX answered questions regarding the continuing validity of WPSs and PORs when one business is purchased by another business. At that time, QW-201.1 was added. It states WPSs and PORs of the purchased business could be used by the new owner without requalification provided the new owner identified them with his name, took responsibility for them, and maintained a historical record of their source. In the 2002 addenda, parallel provisions were added in paragraph QW-300.2 covering welders and welding operators; parallel changes were also made in the brazing section.

The simplest approach to satisfying these requirements is to enter the name of the new owner on the existing POR, sign and date it, and describe these steps in the QA program. If your company is one of many that does not have a QA program but still follows Section IX, describe the process in company operating procedures or a memo that can be kept with your qualification records. If the previous owner’s data is transferred to a new form, be sure to identify the POR as originating with the previous owner either on the POR or on a separate list in the QA program.

QW-304.1, which deals with qualification of welders by radiography, was revised to clarify that welds made in the 5G and 6G positions had to be radiographed over their entire circumference, not just for a length of 6 in. Since 5G and 6G are multiposition qualifications containing portions of overhead, vertical, flat, and, for 6G, horizontal welding, more than 6 in. of weld length is needed to get adequate representation of each position welded. However, if a welder tests in the 2G position, only 6 in. of weld length needs to be radiographed. Parallel changes were also made for welding operators.

When a welder takes an immediate retest (i.e., without further training or practice), the rule of thumb was he had to pass double the number of test coupons or double the radiographed weld length used for his original test. Although this philosophy was clear for mechanical testing, it was not clear for coupons that had been radiographed, particularly given the changes described in the previous paragraph. QW-321.3 was revised from specific dimensions of weld length to be radiographed for an immediate retest to simply requiring twice the length or number of welds required for the original test be radiographed.

When considering using an immediate retest, one should always consider that giving the welder any type of additional training or requiring him to practice for a time before welding another test coupon allows the new coupon to be considered a “new” test, and doubling up is not required. Section IX does not define how much training or practice is required (See QW-321.4); that is left up to the qualifier’s engineering judgement.

QW-452.1, which addressed welder test coupons, is now two tables. Table QW-452.1(a) specifies the visual examination and testing requirements, and QW-452.1(b) is used to determine the thickness of weld metal the welder is qualified to
deposit. The previous version of the table always required some historical understanding of intent to use properly, but it became really unfriendly in the 2000 addenda when the thickness that a welder had to deposit to be qualified for “Max. to be welded” was changed from ⅜ in. to ⅝ in.

The only technical change in QW-452.1(a) is that it is again mandatory to use side bend specimens for test coupon thicknesses over ⅜ in. rather than over ⅝ in. Although it appears another technical change was made by the addition of a column for visual examination of the coupon, visual examination of coupons that are mechanically tested has been a requirement since 1992. Visual examination of coupons that will be radiographed is not required, but it is a smart thing to do.

Table QW-452.1(b) only addresses the thickness for which a welder is qualified. It has one technical clarification from the previous version; a separate “t” has to be used not only for each welder and for each process that is used in the coupon but also for each F-number filler metal. For example, if a welder uses E6010 (F-3) in a test coupon and also E7018 (F-4), the thickness he deposited with each F-number type must be used separately to determine the thickness he may deposit with that F-number type electrode. It should be noted that “t,” as used in this table, is also addressed in QW-306 and QW-350. QW-306 not only requires a separate “t” be determined for each welder, process, and F-number, but also anytime there is a change in an essential variable. This means if a welder welds a root downhill and the fill passes uphill using one process, “t” must be documented separately for the downhill and uphill portions of the test coupon, and each “t” must be applied separately to QW-452.1(b) to determine the thickness a welder is qualified to deposit for each direction of progression.

QW-350 specifies the thickness of weld metal used in QW-452 is exclusive of weld reinforcement. The technical basis for this limitation is that reinforcement is usually removed when testing the specimens, so it can’t be counted. Since reinforcement may also be removed on production welds, reinforcement does not have to be considered as part of the weld thickness when evaluating a production weld. That is, if the welder is qualified to weld up to 1⅝ in. thick, he may make a groove weld that is ⅝ in. thick, and any reinforcement on that weld does not have to be considered.

According to Table QW-452.1(b), a welder has to deposit at least ⅜ in. thickness in his test coupon to be qualified for unlimited thickness, and that thickness must contain at least three weld layers. An inquirer asked if it was necessary to document that three layers or more had been used since there was unlimited thickness, and that thickness must contain at least three weld layers. A version of the old form with an appropriate note is available on my Web site at www.sperkoengineering.com.

Standard Welding Procedures Specification

A small change was made in QW-520 regarding welding process limitations when adopting a Standard Welding Procedures Specification (SWPS) without performing a demonstration test for that SWPS. Previously, QW-520(a) permitted use of SWPSs with more than one welding process when the demonstration had been performed for only one of the processes in the new SWPS. Although this expanded the number of SWPSs that could be adopted based on a particular demonstration test, it was contradictory to the general philosophy that SWPSs must be used exactly as written. The new requirement is that all processes in a new SWPS have to be demonstrated before the SWPS can be used in production.

A small change was made to the SWPS form QW-485 in the row that addresses the weld position. Since the demonstration weld has to be on a test coupon, the test coupon positions (2G, 5G, etc.) should be recorded, not the welding positions (vertical, horizontal, etc.). The examples in the form were changed. A copy of the form and some simple instructions for completing it are available on my Web site at www.sperkoengineering.com.

Brazing (QB) Changes

There has always been some confusion in brazing about when section tests were permitted in lieu of peel tests. QB-141.4 has been revised to make it clear that section tests may be substituted for peel tests when peel tests “are impractical to perform.” That means if the test coupon geometry is such that a peel test cannot be done, a section test may be substituted. It should be noted this substitution is one-for-one substitution for each required peel test specimen.

QB-402.3 was revised to refer to QB-452 for performance qualification. This was always intended but was either inadvertently dropped or simply overlooked for many years.

Figure QB-463.1(e) was revised to allow the same bend and section specimen removal for smaller pipe sizes that was changed for brazer coupons in the last Addenda. This change was made for consistency between coupons used for procedure and performance qualification.

The brazing forms have been revised to bring them more up to date. It should be noted the forms in Section IX are not required to be used.

Coming Attractions

Exciting things in the works by Subcommittee IX include reassignment of nickel alloys into a more consistent grouping system, the addition of nonessential variables for corrosion-resistant and hardfacing, revision to Note 1 of QW-451.1, and consolidation of QW-452.2 (longitudinal bends) into QW-452.1.

Readers are advised the ASME Code Committee meetings are open to the public; the schedule is available on my Web site at www.sperkoengineering.com.

Walter J. Sperko is President of Sperko Engineering, a company that provides consulting services in welding, metallurgy, corrosion, and ASME Code issues, which are described at www.sperkoengineering.com. He also teaches publicly offered seminars sponsored by ASME on how to efficiently and competently use Section IX. Mr. Sperko can be reached at (336) 674-0600, FAX at (336) 674-0202 and by e-mail at sperko@asme.org.
Standards Notices

ISO Draft Standards for Public Review

Copies of the following Draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., Fourth Fl., New York, NY 10036; telephone (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body.

In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis at AWS, 550 NW LeJeune Rd., Miami, FL 33126; telephone (800) 443-9353; e-mail: adavis@aws.org. Otherwise, contact your national standards body.

ISO/DIS 6848, Arc welding and cutting — Nonconsumable tungsten electrodes — Classification.


ISO/DIS 15296, Gas welding equipment — Terminology — Terms used for gas welding equipment.

New Standard Approved by ANSI


Revised Standards Approved by ANSI


Ordering AWS Publications

AWS publications are now being distributed by Global Engineering Documents. To order publications, call Global at (800) 854-7179 or, outside the United States, (303) 397-7956. Publications can also be ordered from e-store at the AWS Web site at www.aws.org.

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.

October 2, Subcommittee on Earthmoving and Construction Equipment. Rhinelander, Wis. Standards preparation and general meeting. Staff contact: Peter Howe, ext. 309.

October 3, Subcommittee on General Design and Practices. Rhinelander, Wis. Standards preparation and general meeting. Staff contact: Peter Howe, ext. 309.

October 3, Subcommittee on Welding of Rotating Equipment. Rhinelander, Wis. Standards preparation and general meeting. Staff contact: Peter Howe, ext. 309.

October 4, Committee on Machinery and Equipment. Rhinelander, Wis. Standards preparation and general meeting. Staff contact: Peter Howe, ext. 309.

October 7, Subcommittee on Friction Stir Welding. Columbus, Ohio. Standards preparation meeting. Staff contact: Harold P. Ellison, ext. 299.

October 8, Committee on Resistance Welding. Detroit, Mich. Standards preparation and general meeting. Staff contact: Harold P. Ellison, ext. 299.

October 9, AWS/SAE Joint Committee on Automotive Welding. Detroit, Mich. Standards preparation and general meeting. Staff contact: Harold P. Ellison, ext. 299.


October 16, Subcommittee on Fumes and Gases. Columbus, Ohio. Standards preparation meeting. Staff contact: Stephen P. Hedrick, ext. 305.


November 13, Subcommittee on Reactive Alloys. Columbus, Ohio. Standards preparation meeting. Staff contact: Edward F. Mitchell, ext. 254.

November 13, Subcommittee on Titanium and Zirconium Filler Metals. Columbus, Ohio. Standards preparation meeting. Staff contact: Edward F. Mitchell, ext. 254.
JOM to Host Third International Conference on Education in Welding

The Institute for the Joining of Materials (JOM) will host the Third International Conference on Education in Welding from October 13 through 16 at the LO-Skolen Centre for Conferences and Adult Education in Helsingør, Denmark. This is the third in a series of educational conferences with the goal of enhancing the transfer of welding technologies through education, helping meet industrial needs for qualified personnel, improving knowledge in codes and standards for fabrication, and presenting guidelines for qualification programs and instructor effectiveness. The series was designed to provide an open forum to explore the various approaches to education and training currently in practice throughout the world. In addition to the Conference, there will be an exhibition of teaching aids, standards, and software relevant to welding education and training.

Contributions in the way of papers, workshops, and other presentations are cordially invited. To submit a short abstract and brief description of your intended paper, workshop, video, software, or presentation, or for registration information, contact: Osama Al-Erhayem, JOM Institute, Gilleleje Strandvej 28, DK-3250 Gilleleje, Denmark, FAX: 45 48355457, e-mail: jom_aws@post10.tele.dk.

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. 490.

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. Merzhal, Peru**
B. A. Mikeska, Houston*
R. L. Penslee, 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 on Individual Member has achieved Winner's Circle status. Status will be awarded at the close of each membership campaign year.

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.)

F. Luening, Houston — 5
G. Baum, Detroit — 3
R. Corsaro, Niagara Frontier — 3
G. Mulee, Rochester — 3
G. O'Connor, New Jersey — 3
P. Zannini, Spokane — 3
G. W. Taylor, Pascagoula — 3
A. M. Mechanisal, Holston Valley — 2
J. Biegas, Rochester — 2
A. Duschere, Long Island — 2
R. Howard, Louisville — 2
S. Hunt, Shreveport — 2
D. Moulton, Saginaw Valley — 2
J. Norrish, International — 2
R. Robles, Alaska — 4

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

D. Scott, Peoria — 35
C. Wesley, Northwestern Pa. — 23
G. Woomer, Johnstown/Altoona — 18
R. Fuimer, Twin Tiers — 14
S. Caldera, Portland — 10
P. Baldwin, Peoria — 10
E. Norman, Oark — 4

Ordering Information

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

AWS Publications

Guide Evaluates Critical Brazed Components

The American Welding Society (AWS) has issued the revised and updated edition Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components (AWS C3.3:2002). This ANSI-approved standard identifies and explains the necessary steps to ensure the suitability of brazed components for critical applications in the areas of materials, design, manufacture, and inspection. These areas share common considerations among a variety of applications.

Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components supersedes the previously published AWS C3.3-80 standard of the same name. New additions to AWS C3.3:2002 include Table 1, which summarizes the filler metal selection process; Table 2, which identifies design considerations with respect to brazability; and Annex B, which presents a matrix on brazing risk management.

Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components (AWS C3.3:2002) is 24 pages long and lists for $60; $45 for AWS members.

Guide to Welding Aluminum Released

AWS has released The Practical Reference Guide to Welding Aluminum in Commercial Applications by Frank Armao. Armao is group leader of non-ferrous application for The Lincoln Electric Co. and for the AWS DIG Subcommittee on Aluminum Structures. This is the sixth topic in the AWS Practical Reference Guide Series.

The guide emphasizes the practices that are both common and effective in high-volume situations. It covers mechanical properties of aluminum affected by welding, alloy, and temper designations, filler metal selection, prewelding preparation, GTAW, GMAW, and SMAW, as well as defects and problems in qualifying welding procedures.

The Practical Reference Guide to Welding Aluminum in Commercial Applications is 38 pages long and includes 14 tables and 24 figures. The price is $33 for AWS members and $44 for non-members.

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. 490.

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E. H. Ezell, Mobile**
J. Merzhal, Peru**
B. A. Mikeska, Houston*
R. L. Penslee, Detroit*
W. L. Shreve, Fox Valley**
G. Taylor, Pascagoula**
T. Weaver, Johnstown/Altoona*
G. Woomer, Johnstown/Altoona*
R. Wray, Nebraska*

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G. Mulee, Rochester — 3
G. O'Connor, New Jersey — 3
P. Zannini, Spokane — 3
G. W. Taylor, Pascagoula — 3
A. M. Mechanisal, Holston Valley — 2
J. Biegas, Rochester — 2
A. Duschere, Long Island — 2
R. Howard, Louisville — 2
S. Hunt, Shreveport — 2
D. Moulton, Saginaw Valley — 2
J. Norrish, International — 2
R. Robles, Alaska — 4

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

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C. Wesley, Northwestern Pa. — 23
G. Woomer, Johnstown/Altoona — 18
R. Fuimer, Twin Tiers — 14
S. Caldera, Portland — 10
P. Baldwin, Peoria — 10
E. Norman, Oark — 4

Ordering Information

To order AWS publications, call (800) 854-7179 or, outside the United States, (303) 397-7956 or visit the AWS Web site at www.aws.org.
GUIDE TO AWS SERVICES
550 NW LeJeune Rd., Miami, FL 33126
Phone (800) 443-9353; (388) 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
Ernest D. Lever, Senior Staff Engineer
Lockheed Martin Missiles and Fire Control
R.O. Box 658083, Mail Stop WT-48
Dallas, TX 75265-0883

ADMINISTRATION
Executive Director
William A. Rice, Jr. ....................................... (210)

Deputy Executive Directors
Richard D. French ........................................ (218)
Jeffrey R. Husey ...................................... (264)
John J. McLaughlin ...................................... (215)

Assistant Executive Director
Debbie A. Cadavid ...................................... (222)

Corporated Director of Quality
Management Systems and Human Resources Administration
Linda K. Headerson .................................. (298)

Chief Financial Officer
Frank R. Tarafa .......................................... (252)

INFORMATION SERVICES
Corporate Director
Joc Cilli .................................................. (258)

HUMAN RESOURCES
Director
Luiza 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) 467-2975
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)

Association Executive Director of Convention Sales
Richard L. Alley ......................................... (217)

Director of Convention & Exhibitions
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 Saltstein .......................................... (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 production of the Welding Journal, Inspection Trends, the annual Welding Show Program, and other AWS promotional publications.

COMMUNICATIONS/PUBLIC RELATIONS
Manager
Amy Townsend ......................................... (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. Fullock .............................. (219)

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

CONFERENCES & SEMINARS
Director
Giselle I. Husey ....................................... (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 certification, welding, and brazing inspectors, and educators ........................................ (273)

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

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

Coordinates AWS Fellow and Counselor nominations.

AWS AWARDS
Senior Coordinator
Vicki Pinsky .......................................... (212)

Coordinates awards nomination.

TECHNICAL SERVICES
Department Information .............................. (340)

Manager
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)

Resistence Welding, High-Energy Beam Welding and Cutting, Oxyfuel Gas Welding & Cutting, Automation, Welding, Aircraft and Aerospace
Peter Howe ............................................. (309)

Arc Welding & Cutting, Pipe & Tubing, Machinery and Equipment, Robotics and Automatic Welding, Food Processing Equipment
Technical Editor
Cynthia Jenney ......................................... (304)

Definitions & Symbols, Brazing & Soldering

Senior Publications Coordinator
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
Manager
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.

The National Nominating Committee shall hold an open meeting, preferably at the Annual Meeting, at which members may appear to present and discuss the eligibility of all candidates.

To be considered a candidate for positions of President, Vice President, Treasurer, or Director-at-Large, the following qualifications and conditions apply:

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

Vice President: To be eligible to hold the office of Vice President, an individual must have served at least one year as a Director, other than Executive Director and Secretary.

Treasurer: To be eligible to hold the office of Treasurer, an individual must be a member of the Society, other than a Student Member, must have 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 2003, in Detroit, Mich. The terms of office for candidates nominated at this meeting will commence June 1, 2004.

Honorary-Meritorious Awards

The Honorary-Meritorious Awards Committee has the duty to make recommendations regarding nominees presented for Honorary Membership, National Meritorious Certificate, William Irgang 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 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 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 Irgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irgang. 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.
Participate in the
84th Annual AWS Convention
Poster Competition
Detroit, Michigan April 8–10, 2003

Students, educators, researchers, engineers, technical committees, consultants, and anyone else in a welding- or joining-related field are invited to participate in the world's leading annual welding event by visually displaying their technical accomplishments in a brief graphic presentation, suitable for close, first-hand examination by interested individuals.

Posters provide an ideal format to present results that are best communicated visually, more suited for display than verbal presentation before a large audience; new techniques or procedures that are best discussed in detail individually with interested viewers; brief reports on work in progress; and results that call for the close study of photomicrographs or other illustrative materials.

Two Categories

There are two categories: Student and Commercial.

Professional category is available to display recent advances in welding technology. Blatant advertisement or sales-oriented posters will not be accepted. Prizes will be awarded for first, second, third, and honorable mention where warranted. No prize will be awarded solely because of number (or lack thereof) of entries in a category.

Awards

Judging is based equally on presentation/clarity and technical merit. Awards are made, where warranted, in two categories; Student and Commercial. All first place winners will be recognized at the following year's AWS Authors' Breakfast and Awards Luncheon.

<table>
<thead>
<tr>
<th>Category</th>
<th>First Place</th>
<th>Second Place</th>
<th>Third Place</th>
<th>Honorable Mention</th>
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<tr>
<td>Professional</td>
<td>Plaque</td>
<td>Ribbon</td>
<td>Ribbon</td>
<td>Ribbon</td>
</tr>
<tr>
<td>(in each of 3 levels)</td>
<td>$200 + Plaque</td>
<td>$100 + Ribbon</td>
<td>$50 + Ribbon</td>
<td>Ribbon</td>
</tr>
</tbody>
</table>

Expenses: Up to a maximum of $1,000 travel expenses will be reimbursed for the top student winner in each level to attend and be recognized at the following year's AWS Authors' Breakfast and Awards Luncheon. (NO travel expenses will be paid for the top winner in the Professional Division.)

Rules

1. Complete the Poster Session Application on the back of this page and mail it with a 200-word description (i.e., abstract) of your poster topic by December 1, 2002, to Technical Papers Coordinator, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, or electronically to <dorcas@aws.org>. You may also obtain an application by visiting our website at www.aws.org. You will be notified in February if your proposed Poster Session topic has been accepted. If so, you should do the following:
   - Mount your material on either 22 x 28-in.-wide or 44 x 28-in.-wide (maximum) poster board, or prepare your material so that it can be mounted for you on one of those sizes of poster board. Laminated digital prints, or digital prints already mounted on backing, may be 40 X 30 in. wide (maximum).
   - plan to use a flat display format that is large enough to read from 6 to 8 ft away.

2.
POSTER APPLICATION
84th Annual AWS Convention
Detroit, Michigan April 8–10, 2003

Complete form and mail with 200-word abstract by December 1, 2002, to Technical Papers Coordinator, American Welding Society, 550 N.W. LeJeune Rd., Miami, FL 33126, or e-mail to <dorcas@aws.org>

DEADLINE: December 1, 2002.

POSTER TITLE OR TOPIC:

CATEGORY: (Check One) □ Professional □ A – Certificate or 2-year degree student
□ B – Undergraduate (4-year) degree student □ C – Graduate degree student

School Name__________________________
Degree/Certificate you are seeking__________________________
Professor’s name__________________________
School Mailing Address__________________________
City________ State____ Zip____ Country____

POSTER AUTHORS
Name__________________________
Title or position__________________________Company or organization__________________________
Mailing address__________________________
City__________________________ State____ Zip/Postal Code____ Country____
Area/Country Code____ Telephone____ FAX____ e-mail address__________________________

For joint authors, give names and FULL MAILING address of other authors (list separately and attach if necessary):

1st Name__________________________Area/Country Code____ Telephone____ FAX____
Title or position__________________________Company or Organization__________________________
Mailing address__________________________
City__________________________ State____ Zip/Postal Code____ Country____

2nd Name__________________________Area/Country Code____ Telephone____ FAX____
Title or position__________________________Company or Organization__________________________
Mailing address__________________________
City__________________________ State____ Zip/Postal Code____ Country____

Abstract
The 200-word abstract should include the following:
◆ Overall significance to welding (or, in Category A only, materials science) community.
◆ Newness or originality of poster content
◆ What your illustrations (if any) show
◆ Important points stressed in poster
◆ Where relevant, potential economic impact of the work described by the poster

Poster Presentation
The presence of a personal representative is not mandatory.
Bulletin Highlights High-Pressure Application Hose

The company’s 721TC hose designed for high-pressure applications requiring superior flexibility is featured in the four-color product bulletin. Hose specifications and features are provided, including its one-half SAE 100R12 minimum bend radius, 4000 lb/in.² constant working pressure in sizes ¾- through 1-in. diameter, neoprene rubber inner tube, high-tensile steel wire reinforcement, Tough Cover for abrasion resistance, and more.

Parker Hannifin Corp.
Fluid Connectors Group
8940 Tyler Blvd., Mentor, Ohio 44060

Machine-Related Manuals Offered on Web and CD-ROM

The company has made available on the Web (in PDF format) and on CD-ROM more than 150 of their machine-related manuals. This includes 37 archived manuals; 21 manuals on large gantry machines; 20 computer numerical control (CNC) manuals; 20 schematic package manuals; 21 small gantry machine manuals; 8 waterjet manuals; 4 shape library manuals; and 20 manuals covering other miscellaneous machines and processes. Twenty-six of the manuals are available on CD-ROM. Manuals are available in English; some are available in German, Spanish, and Portuguese. To order the manuals on CD-ROM, call (843) 664-4394, or visit the company Web site at www.esabservice.com.

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

Catalog Describes Flexible Hose and Ducting Products

Thermoplastic hose and ducting products for evacuating dust, dirt, fumes, chips, and leaves, as well as light material handling applications, are featured in the company’s 16-page catalog. A full range of products manufactured from engineering polymers that do not use solvents, glues, or adhesives that can produce odors and delaminate are described. Products include a lightweight, 0.20-in. wall highly compressible urethane, an abrasion-resistant heavy-wall urethane, and an all-urethane reinforced hose with a smooth interior and no wire. A reference guide is included and each product is pictured and described.

Hi-Tech Hose, Inc.
400 E. Main St., Georgetown, MA 01833
American Welding Society
Founded in 1919 to Advance the Science, Technology and Application of Welding

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

AWS’ Authoritative Seminars prepare you for the CWI or CWE examination.

### SEMINAR AND EXAM SCHEDULE FOR NOVEMBER 2002 THROUGH FEBRUARY 2003

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<thead>
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<th>NOVEMBER 2002</th>
<th>SEMINAR DATES</th>
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<tr>
<td>ATLANTA, GA</td>
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<td>BEAUMONT, TX</td>
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<td>COLUMBUS, OH</td>
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<th>DECEMBER 2002</th>
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<td>MIAMI, FL</td>
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<table>
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<th>JANUARY 2003</th>
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<td>BATON ROUGE, LA</td>
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<tr>
<td>DALLAS, TX</td>
<td>1/19-24</td>
<td>1/25/2003</td>
</tr>
<tr>
<td>FRESNO, CA</td>
<td>1/26-31</td>
<td>2/1/2003</td>
</tr>
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<td>PHILADELPHIA, PA</td>
<td>1/26-31</td>
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<th>FEBRUARY 2003</th>
<th>SEMINAR DATES</th>
<th>EXAM DATES</th>
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<tr>
<td>COLUMBUS, OH</td>
<td>2/3-7 AT NBBPVI</td>
<td>2/8/2003</td>
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<td>CORPUS CHRISTI, TX</td>
<td>2/9-14</td>
<td>2/15/2003</td>
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<tr>
<td>NORFOLK, VA</td>
<td>2/2-7</td>
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<td>SEATTLE, WA</td>
<td>2/9-14</td>
<td>2/15/2003</td>
</tr>
<tr>
<td>TAMPA, FL</td>
<td>2/2-7</td>
<td>2/8/2003</td>
</tr>
</tbody>
</table>

### Seminar and Exam Schedule

- **Course**
  - D1.1 Code Clinic: Sunday, 1 p.m.- 5 p.m.
  - API 1104 Code Clinic: Monday, 8 a.m.- Noon
  - Welding Inspection Technology: Tuesday-Thursdays, 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 based on an insufficient number of registrations are received. Prices are subject to change without notice.
Steiner Industries Appoints COO

Steiner Industries, Inc., Chicago, Ill., has appointed Jack McCulloch chief operating officer. He brings 25 years of experience in the welding industry to his new position. Prior to joining the company, McCulloch served as president of JD Industries, Inc., St. Louis, Mo., and executive vice president of Thermadyne Industries, St. Louis, Mo., responsible for the Victor Equipment Company and Specialty Markets divisions.

Longview Inspection Names Regional Manager

Randy Sweet has been named Southeast regional manager of Longview Inspection, a Rockwood Company. His responsibilities include overseeing operations in the newly expanded Southeast region, which consists of Charleston, S.C.; Savannah, Ga.; Virginia Beach, Va.; Kingsport, Tenn.; and Tuscaloosa, Ala. Sweet's previous positions include manager of strategic alliances for Welding Services, Inc.; corporate radiation safety officer, QA manager, and operations manager for SGS Industrial Services. Sweet also served with various other companies including Conam Inspection and GE Inspection Services in positions that included national utility operations manager, vice president NDE, and business leader inspection services.

Hypertherm Announces Appointments

Franck Lyaudet has been appointed district sales manager for southern France. He joins the company after ten years as sales manager for SPX Power Team. Lyaudet holds a BTS degree in mechanical and industrial automatism from Mécanique et Automatismes Industriels.

Kenneth Potocki has been named district sales manager for northern Illinois and northern Indiana. He previously served as territory manager for Messer Eutectic. Potocki holds a BS degree in biology from Drake University in Des Moines, Iowa.

In addition, the company has appointed Lucio Oliva sales manager in Mexico. Oliva previously served with ESAB Mexico, where he headed up regional sales of welding equipment, filler metals, and technology. He earned a degree in mechanical electric engineering from Universidad Aähauac.

EWI Names Market Leader

Edison Welding Institute (EWI), Columbus, Ohio, has appointed Stanley L. Ream [AWS] market leader for the automotive market sector. Prior to joining EWI, Ream served as general manager of Worthington Beam Alloys, a subsidiary of Worthington Industries, Inc. He also led laser processing at TWB, another Worthington Industries Operation. A welding engineering graduate of The Ohio State University, Ream also held positions at GE FANUC, Amada, Battelle, IIT Research Institute, Aveo Everette Research Labs, and Sciaky Brothers.

Member Milestone

Cassel Retires from National-Standard

After a 40-year career in the welding wire industry, Carlis Cassel [AWS], sales and marketing director for welding wire with National-Standard, retired on June 1.

Cassel joined National Standard in 1961 and worked as a metallurgical technician for the next two years. Following a three-year Army tour in Italy, he rejoined the company in 1966, as a welding technician. In 1973, Cassel was appointed welding wire product manager. In 1981, he was named welding wire marketing director.

Cassel was active in welding technology development and served on various AWS filler metal committees. An AWS member, Cassel frequently gave presentations as a guest speaker at many AWS Section meetings. He wrote several articles for the Welding Journal and Welding Engineer (now Welding Design & Fabrication). Cassel was an active member of AWS and had served as chairman of his local Section.
AWS FELLOWSHIPS

To: Professors Engaged in Joining Research

Subject: Request for Proposals for AWS Fellowships for the 2003-04 Academic Year

The American Welding Society (AWS) seeks to foster university research in joining and to recognize outstanding faculty and student talent. We are again requesting your proposals for consideration by AWS.

It is expected that the winning researchers will take advantage of the opportunity to work with industry committees interested in the research topics and report work in progress.

Please note, there are important changes in the schedule which you must follow in order to enable the awards to be made in a timely fashion. Proposals must be received at American Welding Society by January 6, 2003. New AWS Fellowships will be announced at the AWS Annual Meeting, April 8-10, 2003.

THE AWARDS

The Fellowships or Grants are to be in amounts of up to $25,000 per year, renewable for up to three years of research. However, progress reports and requests for renewal must be submitted for the second and third years. Renewal by AWS will be contingent on demonstration of reasonable progress in the research or in graduate studies.

The AWS Fellowship is awarded to the student for graduate research toward a Masters or Ph.D Degree under a sponsoring professor at a North American University. The qualifications of the Graduate Student are key elements to be considered in the award. The academic credentials, plans and research history (if any) of the student should be provided. The student must prepare the proposal for the AWS Fellowship. However, the proposal must be under the auspices of a professor and accompanied by one or more letters of recommendation from the sponsoring professor or others acquainted with the student’s technical capabilities. Topics for the AWS Fellowship may span the full range of the joining industry. Should the student selected by AWS be unable to accept the Fellowship or continue with the research at any time during the period of the award, the award will be forfeited and no (further) funding provided by AWS. The bulk of AWS funding should be for student support. AWS reserves the right not to make awards in the event that its Committee finds all candidates unsatisfactory.

DETAILS

The Proposal should include:

1. Executive Summary
2. Annualized Breakdown of Funding Required and Purpose of Funds (Student Salary, Tuition, etc.)
3. Matching Funding or Other Support for Intended Research
4. Duration of Project
5. Statement of Problem and Objectives
6. Current Status of Relevant Research
7. Technical Plan of Action
8. Qualifications of Researchers
9. Pertinent Literature References and Related Publications
10. Special Equipment Required and Availability
11. Statement of Critical Issues Which Will Influence Success or Failure of Research

In addition, the proposal must include:

1. Student’s Academic History, Resume and Transcript
2. Recommendation(s) Indicating Qualifications for Research
3. Brief Section or Commentary on Importance of Research to the Welding Community and to AWS, Including Technical Merit, National Need, Long Term Benefits, etc.
4. Statement Regarding Probability of Success

The technical portion of the Proposal should be about ten typewritten pages. Proposal should be sent electronically by January 6, 2003, to:

Richard D. French (rfrench@aws.org)
Deputy Executive Director
American Welding Society
550 N. W. LeJeune Rd., Miami, FL 33126

Yours sincerely,

William A. Rice, Jr.
Executive Director
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**POSITION AVAILABLE**

Research Staff

Oak Ridge National Laboratory (ORNL) is seeking a scientist or engineer to work on welding processes, process modeling, and microstructure modeling of ferrous and nonferrous alloys. The candidate must have a Ph.D. in welding engineering or materials science with expertise in process modeling, microstructure modeling, stress analysis, and friction stir welding. A few years of R&D experience in industry including proposal project development is essential. Knowledge of neutron scattering application to welding is desirable. Please send your resume to Dr. Stan A. David before December 1, 2002 at the following address:

Oak Ridge National Laboratory
Metals and Ceramics Division
Building 4508, MS-6095
P.O. Box 2008
Oak Ridge, TN 37831-6095

---

**THE LOS RIOS COMMUNITY COLLEGE DISTRICT**

is accepting applications for the following position with the closing date as noted:

Welding Technology Assistant Professor
American River College
Closing Date 10/7/02

Applications are available on-line at www.losrios.edu or call (916) 568-3112, EOE.

---

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American River College
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Applications are available on-line at www.losrios.edu or call (916) 568-3112, EOE.

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AWS' Standard Welding Procedure Specifications are supported by PQRs provided by the AWS Welding Procedures Committee. This Committee needs spray transfer welding PQRs on stainless steels, carbon to stainless steels, and aluminum alloys. Also needed are SMAW, FCAW, GTAW, and GMAW PQRs for:

- carbon to stainless steel
- carbon to chromium-molybdenum steels
- chromium-molybdenum to stainless steels

If you want to help, your PQRs, held in the strictest confidence until ultimately destroyed after Committee validation, should be sent to Committee Chairman Dr. W. D. Doty, W. D. Doty & Associates, Post Office Box 98243, Pittsburgh, PA 15227.

Questions? Contact Leonard P. Connor, Managing Director, Technical Activities, AWS (lconnor@aws.org).
Aging of Brazed Joints — Interface Reactions in Base Metal/Filler Metal Couples — Part 1: Low-Temperature Ag-Cu-Ti Filler Metal

A study of filler metal/base metal interactions was conducted on brazements of alloys used in advanced heat engines


ABSTRACT: The effects of aging were examined for brazed joints made with 63.3Ag-35.1Cu-1.6Ti filler metal and Thermo-Span™ (24.5Ni-29.0Co-5.5Cr-4.8Nb-(Si, Ti, Al)-bal. Fe) and Inconel™ 718 (55Ni-21 Cr-5.5 (Nb + Ti)-3.3Mo-bal. Fe) base metals. In a companion study, the aging of 81Au-17.5Ni-1.5Ti brazed joints made of Thermo-Span™ and AISI Type 347 stainless steel (18Cr-11Ni-2Mn-1.8Ti, Nb)-0.08C-bal. Fe) was examined, the results of which will be presented in Part 2. Excellent wetting and spreading was shown by the Ag-Cu-Ti filler metal on both substrates, as determined by contact angle measurements. The Thermo-Span™/Ag-Cu-Ti couple interface was comprised of two sublayers having the same composition, 90[(Fe, Ni, Co, Cu)2(Nb, Ti, Si, Cr)]10 Ag, which were separated by a Ag-rich layer. Aging reduced the interface structure to a single phase having the composition (Fe, Ni, Co, Cu)2(Nb, Ti, Si, Cr). The interface reaction zone in the as-fabricated Inconel™ 718/Ag-Cu-Ti couples contained two sublayers having the compositions (Fe, Ni, Cu)2(Ti, Cr, Nb, Mo) and (Fe, Ni, Cu)2(Ti, Cr, Nb, Mo). Solid-state aging caused the overall reaction layer to thicken and the composition of the second sublayer to change to (Fe, Ni, Cu)2(Ti, Cr, Nb, Mo). The bend bar fracture strengths measured for Thermo-Span™/Ag-Cu-Ti and Inconel™ 718/Ag-Cu-Ti couples were not significantly affected by the solid-state aging processes.

Introduction

Advanced heat engines are being developed that operate at higher combustion temperatures for improved fuel efficiency. Ceramic components and, in particular, engineered ceramics such as silicon nitride (Si₃N₄) and partially stabilized zirconia (PSZ) can provide the necessary physical and mechanical properties that will allow for higher operating temperatures in future power plants (Refs. 1-3). Consequently, the use of metal and ceramic components in advanced heat engines will require the development of suitable joining techniques for all three categories: 1) metal-to-metal, 2) ceramic-to-ceramic, and 3) metal-to-ceramic.

The foremost challenge of making metal-to-ceramic joints rests with accommodating the thermal expansion mismatch between metal substrate materials and the engineered ceramics, and minimizing the resulting residual stresses. Ceramics and glasses tend to have relatively low thermal expansion coefficients. For example, Al₂O₃ and the engineered ceramic Si₃N₄ have thermal expansion coefficients of 7-9 ppm/°C (4-5 ppm/°F) and 3.2-3.5 ppm/°C (1.8-1.9 ppm/°F), respectively (Refs. 4-6). Several metal alloys have been developed to have a reduced thermal expansion coefficient; the traditional trade names and compositions include Kovar™ (Fe-29Ni-17Co), Invar 36™ (Fe-36Ni), and Alloy 42™ (Fe-40.5Ni) having coefficients of 6.2 ppm/°C (3.4 ppm/°F) averaged over 25° to 500°C (77° to 932°F), 7.2 ppm/°C (3.4 ppm/°F) for 25° to 371°C (77° to 700°F), and 8.1 ppm/°C (4.5 ppm/°F) for 25° to 500°C (77° to 932°F), respectively (Refs. 7, 8).

The mechanical performance of the brazed joint also depends strongly on its microstructure. The joint has three major components: 1) the filler metal region, 2) the interface(s) between the filler metal and the base metal, and 3) the base metal. The postprocess microstructure of the joint is a function of the filler metal and base metal compositions, as well as the so-

KEY WORDS
Long-Term Aging Brazing Brazement Ceramic Heat Engines Inconel™ Thermo-Span™
Thermo-Span™ Solution treated and aged

Table 1 — Arithmetic Average Roughness (RA) of the Base Metal Specimens with a √32 Finish

<table>
<thead>
<tr>
<th>Base Metal</th>
<th>Condition</th>
<th>RA (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo-Span™</td>
<td>Solution treated</td>
<td>0.19 ± 0.02</td>
</tr>
<tr>
<td>Thermo-Span™</td>
<td>Solution treated and aged</td>
<td>0.09 ± 0.02</td>
</tr>
<tr>
<td>Inconel™ 718</td>
<td>As-received</td>
<td>0.12 ± 0.03</td>
</tr>
<tr>
<td>Inconel™ 718</td>
<td>Solution treated and aged</td>
<td>0.034 ± 0.005</td>
</tr>
</tbody>
</table>

Note: Surface Profilometry Data (Med. Scan Speed)

The properties of the interface reaction face between the base and filler metals. During processing, including aging time, potential phase changes can lead to solidification process (Refs. 9-11). While in service, the brazed joint can face elevated temperatures over a long operating period, potentially affecting joint performance. The long-term aging of brazed joints has not been extensively studied. Shimoo et al., have not been extensively studied. Shimoo et al., has not been extensively studied. Shimoo et al., has not been extensively studied. Shimoo et al., has not been extensively studied.

The two base metals selected for this study were the precipitation-hardened Thermo-Span™ (24.5Ni-29.0Co-5.5Cr-4.8Nb-(Si, Ti, Al)-bal. Fe wt-%) and Inconel™ 718 (55Ni-21Cr-5.5 (Nb+Ti)-3.3Mo-bal. Fe alloys (Refs. 19, 20). The Thermo-Span™ was received in the solution-annealed condition [1093°C (2000°F), 1 h, air cool]; the condition of the as-received Inconel™ 718 stock was not documented. In order to assure consistent material properties, the Inconel™ 718 alloy was subjected to a solution annealing treatment. The Thermo-Span™ and Inconel™ 718 materials were then exposed to an aging (precipitation-anneal) heat treatment. The condition of each base metal was assessed using Rockwell C (HRC) hardness measurements. Six measurements were performed on three sample blanks. The heat treatment schedules and hardness data follow.

Thermo-Span™ (As-received HRC = 23-2, solution annealed). Solution annealing (at the mill): hold at 1093°C (2000°F) for 1 h; air cooling. Precipitation annealing: holding at 718°C (1324°F) for 8 h; furnace cooling at 0.015°C/s (0.027°F/s) to 621°C (1150°F); hold at 621°C (1150°F) for 8 h; air cooling. Postheat treatment HRC = 39 ± 1.

Inconel™ 718 (as-received HRC = 22.5 ± 0.5, unknown condition). Solution annealing: holding at 954°C to 1010°C (1750°F to 1850°F) for 0.5 to 1 h, air cooling. Precipitation annealing: hold at 718°C (1324°F) for 8 h, furnace cooling to 621°C (1150°F), holding for 10 h, air cooling. Postheat treatment HRC = 42 ± 2.

All brazing experiments were performed on base alloy surfaces that had been ground to a nominal √32 finish as determined by profilometer measurements. Four profilometer traces, two in one direction and the other two in a perpendicular direction, were made over a distance of 6 mm on each of duplicate samples. The arithmetic average roughness, or RA numbers (mean and ± one standard deviation) are shown in Table 1. The solution and aging heat treatments caused both substrates and materials to have a lower surface roughness after grinding as compared to that of the as-received material.

Experimental Procedures

Materials: Base Metals

The brazing filler metal Cusi™ ABA (63.3Ag-35.1Cu-1.6Ti) was evaluated in this study (Ref. 21). The filler metal was in the form of 0.051-mm-thick (0.002-in.) strip. The Ag-Cu-Ti alloy has a nominal melting range of 780°C to 815°C (1436°F to 1499°F). The composition of the material batch used in this study was verified by atomic emission spectroscopy (AES); the chemical composition was 61.8 ± 4.2 Cu, 35.1 ± 0.7 Ag, and 1.7 Ti (wt-%). The chemical analysis was performed in triplicate; the error terms represent a 95% confidence interval. The onset (solidus) temperature of the Ag-Cu-Ti alloy was

Fig. 1 — Configurations of the test specimen.

Fig. 2 — Schematic diagram of the sessile drop test specimen used to assess filler metal wetting and spreading. The quantitative metric is the contact angle, ϒ. The symbol r is the effective spread radius assuming a circular footprint to the area of spread, and h is the height of the filler metal mound.

Fig. 3 — Time and temperature parameters for the Ag-Cu-Ti brazing process.
measured by differential thermal analysis (DTA). The DTA specimen was initially preconditioned by melting it with a heating ramp from 25° to 1160°C (77° to 2122°F) at a rate of 10°C/min (18°F/min). The sample was then cooled. A second heating cycle, which was performed on the same sample but at a ramp rate of 5°C/min (9°F/min), provided the actual data. For the Ag-Cu-Ti filler metal, a solidus temperature of 774°C (1425°F) was recorded as the average of two tests. This value is close to the nominal solidus temperature of 780°C (1436°F) cited by the manufacturer.

**‘Parent’ Block, Brazed Joint Assembly**

The test specimen configuration used to evaluate the brazed joint microstructures, and from which the mechanical strength test pieces were fabricated, is shown in Fig. 1. The “parent” block of each alloy measured 25.4 x 25.4 x 6.4 mm (1.0 x 1.0 x 0.25 in.). Two parent blocks were joined along a 25.4-x 6.4-mm (1.0-x 0.25-in.) face that was ground to a nominal √32 finish. A preform of filler metal measuring 25.4 x 6.4 mm (1.0 x 0.25 in.) was placed between the two parent block surfaces. Control of the joint clearance was provided by the placement of two 0.051-mm-diameter (0.002-in.) tungsten (W) wires in the clearance. The parent blocks, W wires, and filler metal foil were stacked within a graphite fixture that maintained their alignment during the furnace brazing process. A weight was placed on top of the stack to assure formation of the target joint-clearance thickness.

**Brazing Process**

An extensive development effort was conducted to determine suitable brazing process parameters. First, an assessment was made of the impact of brazing time and temperature on wettability and joint strength using an Inconel® 718 alloy specimen. The furnace cycle was replicated five times. The furnace brazing process using the Ag-Cu-Ti filler alloy was performed under a 1.3-Pa (10-mtorr) partial pressure, flowing argon to prevent oxidation of the higher vapor pressure silver constituent. The argon flow was begun once the sample temperature had reached 600°C (1112°F).

As a result of the preliminary evaluations, the nominal conditions for Ag-Cu-Ti filler metal brazing were set at a peak temperature of 830°C (1526°F) and duration of 7 min. The measured furnace cycle parameters were 830±1°C (1526±2°F) and 8.0±0.7 min, respectively.

Sessile drop (area-of-spread) experiments were performed in order to assess the sensitivity of the braze alloy wettability and spreading behavior to the peak temperature and time process parameters. These measurements were performed on postsolidified filler metal following removal of the sample from the furnace. The parameter for assessing wettability/spreading was the calculated contact angle, 𝜃, that formed at the droplet front — Fig. 2. The value of 𝜃 was calculated from the volume, V, of filler metal used to make the drop and the physical dimensions of the drop. Observing that the sessile drops were approximately circular, an effective radius, r, of the footprint area was calculated from the image. Next, it was assumed the sessile drops formed a spherical cap. Therefore, the maximum height, h, of the droplet was calculated using the data and Equation 1 below

\[ h = \left\{ \frac{(3V/\pi r^2) + r^3}{(3V/\pi r)^2 + r^2}\right\}^{\frac{1}{3}} - 3V/(\pi r^2) \]  

(1)

The contact angle was then calculated using Equation 2, which follows

\[ \theta = \tan^{-1}\left( \frac{2hr}{r^2 - h^2} \right) \]  

(2)

The values of the contact angles for each of the two base metals and peak process temperature combinations are given in Table 2. The low contact angles indicate excellent wetting/spreading by the braze alloy on the substrate materials. The reduced data scatter indicated the Ag-Cu-Ti alloy was relatively insensitive to the brazing temperature in the range of 830° to 850°C (1526° to 1562°F), using a 7-min processing time.

The effect of brazing time was of particular concern with the Ag-Cu-Ti filler metal based upon ancillary studies. Therefore, experiments were conducted in which the brazability of the Ag-Cu-Ti alloy was examined on thermo-spin®, Inconel® 718, and Type 347 stainless steel base metals. The brazing temperature for these experiments was 850°C (1562°F), while the brazing time was varied at 2, 7, 15, 30, and 60 min. The results of a qualitative evaluation appear in Table 3. It is apparent the wetting/spreading performance by the Ag-Cu-Ti filler metal on the selected base metals degraded when the time duration was reduced from 7 to 2 min. Therefore, instead of lengthening the time to 15 min, an alternative approach was to raise the peak temperature to 900°F.
Table 2 — Sessile Drop Contact Angle Data Brazing Peak Temperature Analysis

<table>
<thead>
<tr>
<th>Base Metal</th>
<th>Material Condition</th>
<th>830°C (1520°F)</th>
<th>850°C (1562°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo-Span™</td>
<td>Solution treated</td>
<td>3.6</td>
<td>4.2</td>
</tr>
<tr>
<td>Thermo-Span™</td>
<td>Solution treated and aged</td>
<td>—</td>
<td>(0.2)</td>
</tr>
<tr>
<td>Inconel™ 718</td>
<td>As-received</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Inconel™ 718</td>
<td>Solution treated and aged</td>
<td>—</td>
<td>4.6</td>
</tr>
<tr>
<td>Type 347 SS</td>
<td>As-received</td>
<td>4.4</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Note: ± one standard deviation.

Table 3 — Qualitative Assessment of Brazability of Ag-Cu-Ti Filler Metal on Base Metals

<table>
<thead>
<tr>
<th>Brazing Time (min)</th>
<th>Thermo-Span™</th>
<th>Inconel™ 718</th>
<th>Type 347 SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>poor</td>
<td>satisfactory</td>
<td>poor (dewet.)</td>
</tr>
<tr>
<td>7</td>
<td>satisfactory</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>15</td>
<td>very good</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>30</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>60</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
</tr>
</tbody>
</table>

Note: Brazing temperature at 850°C (1562°F).

Table 4 — Mean Concentration and Scatter of the Sublayers

<table>
<thead>
<tr>
<th>Sublayer No. 1 (at.-%)</th>
<th>Si</th>
<th>Ti</th>
<th>Cr</th>
<th>Fe</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Nb</th>
<th>Ag</th>
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<td>4.4</td>
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<td>19</td>
<td>7</td>
<td>6</td>
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<td>(2)</td>
<td>(0.6)</td>
<td>(4)</td>
<td>(2)</td>
<td>(1)</td>
<td>(3)</td>
<td>(2)</td>
<td>(10)</td>
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<tr>
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<td>Cr</td>
<td>Fe</td>
<td>Co</td>
<td>Ni</td>
<td>Cu</td>
<td>Nb</td>
<td>Ag</td>
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<td>(3)</td>
<td>(5)</td>
<td>(7)</td>
<td>(0.8)</td>
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</tr>
</tbody>
</table>

Note: Scatter is in parentheses.

The four-point bend test setup (per MIL-STD-1942A) is shown in Fig. 5. The test specimen was placed on top of two outer support rollers that were separated by a distance of 40 mm; the ground surface was in contact with the rollers. The two inner or “loading” rollers that were separated by a distance of 20 mm (0.79 in.) were positioned on top of the specimen. No significant preload was applied prior to the start of testing. The specimen was subjected to a constant cross head displacement rate of $3.3 \times 10^{-3} \text{ mm/s} (3.3 \times 10^{-4} \text{ in/s}).$ The flexure strength, $S$, was computed according to the following equation:

$$S = \frac{3F_{\text{max}}}{4bd^2}$$  (3)

where $F_{\text{max}}$ is the maximum force (load); $L$ is support roller span of 40 mm (1.6 in.); $b$ is the specimen width of 4.0 mm (0.16 in.); and $d$ is the specimen thickness of 3.0 mm. The 900°C (1652°F), 7-min brazing conditions produced excellent results.

The selected time/temperature brazing profile for the Ag-Cu-Ti filler metal is illustrated in Fig. 3. The process began with a temperature rise of 10°C/min (18°F/min), to a subsolidus temperature of 730°C (1364°F) with a 5-min hold time. The temperature was then raised at 5°C/min (9°F/min) to the peak brazing value. Brazing was performed at 900°C (1652°F) for 7 min. The sample temperature was then slowly ramped down at 5°C/min (9°F/min) through the filler metal solidus temperature to the previous hold value of 730°C (1364°F). The cooling rate was then increased to 10°C/min (18°F/min) until a temperature of approximately 400°C (752°F) was reached, after which the assembly was allowed to cool at a rate of <10°C/min (18°F/min) to room temperature.

It is important to note the selected brazing cycle for the Ag-Cu-Ti filler metal overlapped the precipitation annealing conditions of both Thermo-Span™ and the Inconel™ 718 base metals. Consequently, in the event the brazing process was performed after precipitation annealing, an overaging condition could arise in base metals resulting in changes to their respective mechanical properties.

Microstructural Analysis of Sessile Drop Samples

Sessile drop samples were used in some assessments of the interface reactions in the aged couples. The aged samples were evaluated using optical microscopy, scanning electron microscopy (SEM), and electron microprobe analysis (EMPA) techniques.
Aging Environments

The aging treatments were performed at temperatures of 150°C (302°F), 350°C (662°F), and 575°C (1067°F) and time periods of 100, 200, and 300 days. The specimen was placed in a quartz ampoule along with a piece of Ta foil. The ampoule was then backfilled with Ar at 10-mtorr (1.3-Pa) pressure and sealed. The Ta foil served as a getter for residual O₂. Sessile drop specimens were fabricated to evaluate microstructural changes due to these aging treatments.

A more limited range of aging parameters was used for the four-point bend specimens. Those aging conditions were temperatures of 350°C (662°F) and 575°C (1067°F) and time durations of 100 and 200 days.

Results and Discussion

Sessile Drop Morphology from the Wetting/Spreading Experiments

The process development experiments did not reveal any distinguishable features accompanying the wetting/spreading behavior of the Ag-Cu-Ti alloy.

Brazed Joint Microstructure: As-Fabricated Condition

The composition of the Thermo-Span™ base metal/Ag-Cu-Ti filler metal interface was examined by electron microprobe analysis (EMPA). An SEM micrograph and representative EMPA trace taken from the five scans made across the interface are shown in Fig. 6A and B, respectively. The interface structure was comprised of two sublayers. The first sublayer, termed No. 1, was centered approximately at the 24-μm position in Fig. 6B, between the base metal and a Ag-rich layer. Sublayer No. 1 had a nominal thickness of about 8 μm (3 x 10⁻⁴ in.). The second sublayer, termed No. 2, was centered approximately at the 31-μm (0.0012-in.) position in Fig. 6B, between the Ag-rich layer and the filler metal. Sublayer No. 2 had a nominal thickness of approximately 5 μm (2 x 10⁻⁴ in.).

A composition (at-%) was determined for each of the two sublayers. The composition value was determined from element levels that were measured at the midpoint of that sublayer. The mean concentration and a scatter term in parentheses that was
Table 5 — Mean Compositions and Standard Deviation of the Sublayers

<table>
<thead>
<tr>
<th>Sublayer No. 1 (at.-%)</th>
<th>Ti</th>
<th>Cr</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Nb</th>
<th>Mo</th>
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<td>(2)</td>
<td>(2)</td>
<td>(3)</td>
<td>(3)</td>
<td>(2)</td>
<td>(0.5)</td>
<td>(0.2)</td>
<td>(0.2)</td>
</tr>
<tr>
<td>Sublayer No. 2 (at.-%)</td>
<td>Ti</td>
<td>Cr</td>
<td>Fe</td>
<td>Ni</td>
<td>Cu</td>
<td>Nb</td>
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<td>(3)</td>
<td>(4)</td>
<td>(0.4)</td>
<td>(9)</td>
<td>(4)</td>
</tr>
</tbody>
</table>

Note: Standard deviation is in parentheses.

± one standard deviation are shown in Table 4.

Specific compositions were derived from the binary phase diagrams of pairwise element combinations. First, sublayer No. 1 was examined. It was assumed iron, nickel, and cobalt would combine as a single, pseudo-element based upon the mutual solubility of these transition elements over a wide composition-temperature range (Ref. 22). Next, the roles of copper and niobium were assessed. First, copper exhibits complete solid solubility with nickel but nearly complete insolubility with iron and cobalt (Ref. 23). Also, copper forms an extensive series of compounds having narrow composition ranges when combined with titanium (Ref. 24). Therefore, it was assumed copper would join iron, nickel, and cobalt as the pseudo-element (Fe, Ni, Co, Cu). Niobium forms compounds of limited composition range with iron, nickel, and cobalt, but has complete solid solubility with titanium over an extensive area of the phase diagram (Ref. 25). Thus, it was surmised niobium would join with titanium as the pseudo-element, (Ti, Nb).

It was more difficult to hypothesize the behaviors of the other three elements, silicon (0.6 at-%), chromium (4.4 at-%), and silver (12 at-%). It was assumed the chromium and silicon atoms would behave like titanium and niobium because of their similar refractory natures. Silver would form a separate constituent because there was no obvious interaction between it and the other elements or pseudo-elements.

The above analyses resulted in a two-phase composition for sublayer No. 1. The first phase had the approximate formula (Fe, Ni, Co, Cu)\(_2\)(Nb, Ti, Si, Cr); the second phase was Ag. The volume fraction of the two phases was nine to one, respectively.

A similar analysis performed on sublayer No. 2 showed it to have the same composition as sublayer No. 1, given the experimental error.

Electron microprobe analysis scans were also performed within the Thermo-Span™ base metal, parallel to the base metal/filler metal interface, at distances of approximately 10 \(\mu\)m (3.9 x 10\(^{-4}\) in.) and 25 \(\mu\)m (9.8 x 10\(^{-4}\) in.) away from that interface. The purpose of this analysis was to identify bulk and/or grain boundary transport mechanisms by the molten filler metal. The filler metal elements copper, silver, and titanium were observed in the Thermo-Span™ grain boundaries at the 10 \(\mu\)m (3.9 x 10\(^{-4}\) in.) distance from the interface. However, the EMFA trace at 25 \(\mu\)m...
Fig. 10 — Representative EMPA trace of the Thermo-Span™/Ag-Cu-Ti brazed joint after aging at 575°C (1067°F) for 300 days.

(9.8 x 10⁻⁴ in.) revealed only the constituents of the Thermo-Span™ alloy.

The microstructure of the interface formed by the Inconel™ 718 base metal and the Ag-Cu-Ti filler metal was examined. An SEM micrograph and representative EMPA trace from this couple are shown in Fig. 7A and B, respectively. Two sublayers were identified. Sublayer No. 1 was located next to the substrate and sublayer No. 2 was situated next to the filler metal field. The two sublayers were separated by a small iron peak. Sublayer No. 1 was approximately 2 µm (7.9 x 10⁻⁵ in.) thick; sublayer No. 2 was 2 to 3 µm (7.9 x 10⁻⁵ in. to 1.2 x 10⁻⁴ in.) thick. The mean compositions and standard deviation in parentheses for the two layers are presented in Table 5.

The layer compositions were developed in a manner similar to that used for the Thermo-Span™ base metal. Sublayer No. 1 had the composition (Fe,Ni,Cu)₂(Ti,Cr,Nb,Mo). Sublayer No. 2 had the composition (Fe,Ni,Cu)_₂(Ti,Cr,Nb,Mo). It was observed silver was present in small quantities in both sublayers (<1% and 2%, respectively). The oxide layer present on the Inconel™ 718 surface probably provided some driving force for titanium segregation in the vicinity of the base metal/filler metal interface.

Four-Point Bending Strength: As-Fabricated Condition

The four-point bend strength data are shown in Fig. 8. The individual test values are included within the bar chart. Similar mean strength values were observed for brazed joints made with either Thermo-Span™ or Inconel™ 718 base metals; those strengths were 250±60 MPa (36±9 ksi) and 280±90 MPa (41±13 MPa), respectively. There was no deformation observed in either the Thermo-Span™ or Inconel™ 718 bend bars after testing to indicate the yield strengths of either base metal had been exceeded.

Shown in Fig. 9 are low- and high-magnification SEM photographs of the fracture surfaces of an as-fabricated, Thermo-Span™/Ag-Cu-Ti test specimen. The low-magnification images indicated the failure path progressed along the interface between the filler metal and the base metal. This hypothesis was substantiated by an energy dispersive X-ray analysis (EDXA) evaluation of the fracture surface, which revealed a relatively strong titanium presence. The Thermo-Span™ base metal contains titanium, but only at a level of 0.8%, which is too low to have accounted for the observed peak intensity. In addition, the earlier EDXA presented in Fig. 6 showed the accumulation of titanium at the base metal/filler metal interface, lending further evidence the fracture path was lo-
A similar fracture surface morphology and presence of titanium were observed with the tested Inconel™ 718/Ag-Cu-Ti specimens, indicating a crack path was along the base metal/filler metal interface.

Brazed Joint Microstructure: Post-Aging Condition

Optical microscopy of metallographic cross sections was used to identify aging-related changes to the microstructure of the Thermo-Span™/Ag-Cu-Ti brazed joints. Very little difference was observed in the interface microstructures between the different aging treatments. A representative EMPA trace of a Thermo-Span™ brazed joint aged at 575°C (1067°F) for 300 days is shown in Fig. 10. The EMPA trace from an as-fabricated sample is shown in Fig. 6B. The thickness of the total reaction layer after aging was approximately 8 µm (3 x 10⁻⁴ in.), indicating a decrease of 40% as compared to the as-fabricated case. The composition of the reaction layer was determined to be (Fe,Ni,Co,Cu)(Ti,Nb,Si,Cr), which was identical to the reaction layer compositions determined for the as-fabricated sublayers Nos. 1 and 2; however, unlike the as-fabricated sublayer No. 1, silver was not present to a significant degree (0.4±0.6%).

Electron microprobe analysis traces were made in the Thermo-Span™ base metal of the specimen aged at 150°C (302°F) for 200 days. Scans were made parallel to the filler metal/base metal interface, at distances of 10 µm (3.9 x 10⁻⁴ in.) and 25 µm (9.8 x 10⁻⁴ in.). In neither instance was there evidence that accelerated diffusion into, nor reaction of, the Thermo-Span™ base metal had occurred.

The aged Ag-Cu-Ti joints made with Inconel™ 718 base metal were similarly analyzed. Shown in Fig. 11 is a sequence of cross-section micrographs from specimens aged for 200 days at temperatures of 150°C (302°F), 350°C (662°F), and 575°C (1067°F). The interface reaction layers grew thicker by growing further into the base metal. Grain boundary diffusion/reaction artifacts, originally observed in the as-fabricated specimen, were retained. The formation of blocky particles located at the interface between the reaction layer and the filler metal increased with aging temperature. Finally, in the filler metal, the Cu-rich phase size was not significantly affected by the aging treatment.

Electron microprobe analysis was performed across the Inconel™ 718/Ag-Cu-
Ti interface of aged brazed joints. Representative EMPA traces are provided in Fig. 12 for the aging conditions of 150°C (302°F) for 100 days and 575°C (1067°F) for 300 days. Recall that the interface of the as-fabricated condition (Fig. 7B) was comprised of two sublayers, each approximately 2 to 3 μm (7.9 x 10⁻⁵ in. to 1.2 x 10⁻⁴ in.) thick and separated by a narrow band having a high concentration of iron. Aging at 150°C (302°F) for 100 days resulted in the following changes: There was a slight thickening of both sublayers to values of approximately 3 to 5 μm (1.2 to 2.0 x 10⁻⁴ in.). The intensity of the iron peak separating the two sublayers grew slightly. The midpoint composition of sublayer No. 1 (located next to the base metal) was unchanged when compared to the as-fabricated condition [(Fe,Ni,Cu)₃(Ti,Cr,Nb,Mo)₂]. The sub-layer No. 2 composition changed from (Fe,Ni,Cu)₂(Ti,Cr,Nb,Mo) to (Fe,Ni,Cu)₇(Ti,Cr,Nb,Mo)₃ after aging. The aged sublayer No. 2 also exhibited an increased level of titanium, as well as significant spatial fluctuations in the chromium, iron, and copper concentrations. In fact, for two of the five EMPA traces, the chromium and iron concentrations increased to an average of 14% and 22%, respectively, and the copper concentration dropped to approximately 3%, resulting in a composition of (Fe,Ni,Cu)₇(Ti,Cr,Nb,Mo)₃. Sublayer No. 2 exhibited locally higher concentrations of chromium (8-9%) and iron (25%) that were compensated by proportional decreases in the concentrations of other elements; the copper content remained the same for all five traces.

In summary, the effect of aging treatments on Thermo-Span™/Ag-Cu-Ti brazed joints was a slight decrease in the interface reaction zone thickness; there were no significant changes to the sublayer compositions. In the case of the Inconel™ 718/Ag-Cu-Ti specimens, aging treatments caused a noticeable increase in the thickness of the reaction layer. Aside from local chromium, iron, and copper fluctuations in the composition of the No. 2 sublayer, the sublayer compositions were similar to those recorded for the as-fabricated condition.

Four-Point Bending Strength: Post-Aging Condition

The four-point bend strength data from the aged Thermo-Span™/Ag-Cu-Ti and Inconel™ 718/Ag-Cu-Ti specimens appear in Fig. 13. The aging treatments did not appear to cause a significant change to the strength of the Thermo-Span™/Ag-Cu-Ti brazed joints — Fig. 13A. The possible exception was the single specimen aged at 350°C (662°F) for 100 days. The repeatability of this latter test was not confirmed.

The fracture surfaces of samples aged at 350°C (662°F) for 100 days and 575°C (1067°F) for 200 days were examined. At low magnification, the fracture surfaces appeared similar to those of the as-fabricated case (Fig. 9A) in which the fracture path was located near the filler metal/base metal interface. Shown in Fig. 14 are higher magnification SEM images of the fracture surfaces. The specimen aged at
350°C (662°F) for 100 days (Fig. 14A) had the same hillock features as did the fracture surface of the as-fabricated (Fig. 9B). Also, the aging treatment caused small peaks and valleys to appear on the fracture surface. The aging treatment at 575°C (1067°F) for 200 days caused the hillock structures to largely disappear; however, the fine peak and valley morphology remained on the fracture surfaces. Shown in Fig. 15 is the optical micrograph of the cross section of a tested bend bar that had been aged at 575°C (1067°F) for 200 days. The fracture path lay at the Thermo-Span™/Ag-Cu-Ti interface (as was similarly observed in the as-fabricated case). More specifically, however, the fracture path was observed to move between the reaction layer/Thermo-Span™ interface and the reaction layer/braze alloy interface. The scale of these fracture path jumps appeared to be commensurate with the fine scale peaks and valleys observed on the fracture surfaces.

The bend strength data aged Inconel™ 718/Ag-Cu-Ti specimens appear in Fig. 13B. As was the case with the Thermo-Span™/Ag-Cu-Ti couples, the aging treatments did not cause a significant change to the strength values. Similarly, the fracture paths were not changed from their base metal/filler metal interface.

In summary, the four-point bend strengths for both the Thermo-Span™ and Inconel™ 718 braze joints made with the Ag-Cu-Ti filler metal were not significantly affected by the aging treatments. The fracture paths remained located at the base metal/filler metal interface for as-fabricated as well as aged test specimens.

References
19. Thermo-Span™ is a registered trademark of Carpenter Technologies Corp., Reading, Pa.
20. Inconel™ is a registered trademark of Huntington Alloys, Huntington, WVa.
21. CuSil™ is a registered trademark of WESCO Products.
23. ibid. pp. 760, 916, and 942.
24. ibid. p. 971.
ABSTRACT. The mechanisms by which liq- uation is initiated in the partially melted zone of wrought, multicomponent alu- minum alloys during welding were studied using three representative liq- uation-susceptible alloys 2024, 6061, and 7075 as examples. Three different liq- uation mechanisms were identified. In Mechanism I, which is for alloys beyond the solid solu- bility limit, liq- uation-induced particles are always present and liq- uation can occur at any heating rate. In Mechanism II, for alloys within the limit but with the parti- cles, liq- uation requires high heating rates. In Mechanism III, for alloys within the limit and without the particles, liq- uation occurs when the matrix starts to melt. These three mechanisms cover most, if not all, wrought aluminum alloys since an alloy is either beyond or within the limit. Ternary phase diagrams were found to be a useful approach to checking if the alloys are within or beyond the limit. Alloy 7075, which contained liq- uation-inducing CuMgAl₂ particles and Cu₂FeAl₇ coatings on Fe-rich particles, was well within the limit and it liquated by Mechanism II. Alloy 6061 was also within the limit, but the mechanism depended on whether the solu- tion heat treatment of the heat was thorough enough to dissolve liq- uation-inducing Si-rich particles. If so, it liquated by Mechanism III; if not, by Mechanism II. Alloy 2024, which contained liq- uation-inducing CuAl₂ particles, was near the limit and it liquated by Mechanism I if the heat was beyond the limit and by Mechanism II if within. The liq- uation reactions caused by these particles or coatings were identified. Liq- uation-induced grain boundary segregation was severe, suggest- ing severe degradation of mechanical properties, as demonstrated in binary alloy 2219.

KEY WORDS
Aluminum Alloys
Grain Boundaries
Hot Cracking
Liq- uation
Solidification

BY C. HUANG AND S. KOU

Liq- uation Mechanisms in Multicomponent Aluminum Alloys during Welding

Three mechanisms cover most, if not all, wrought aluminum alloys and, for a given alloy and temper, the mechanism can vary from heat to heat.

Introduction

The partially melted zone (PMZ) is a region immediately outside the weld metal where liq- uation can occur during welding and lead to hot cracking and degradation of mechanical properties (Ref. 1). Since the 1950s, liq- uation and liq- uation-induced hot cracking in alu- minum alloys have been studied exten- sively, and alloys 2024, 6061, and 7075 are among the most frequently investigated materials (Refs. 2–12). Attention appears to have been focused much more on liq- uation-induced hot cracking than liq- uation itself. Optical micrographs of the PMZ showed dark-etching grain bound- aries (GBs) as evidence of GB liq- uation, but without further microstructural de- tails. Liq- uation mechanisms were often not discussed, the solidification of GB liq- uid was not studied, and the resultant GB segregation was not measured.

Recently, Huang and Kou (Refs. 13–15) studied PMZ liq- uation in GMA welds of alloy 2219. This was a binary alloy of about Al-6.3 wt-% Cu, with an Al-rich α matrix and δ (CuAl₂) particles. Large δ particles were present in the grain interior and sometimes at the GBs, and small δ particles were observed along the GB. To help discussion later in this report, the most significant results are briefly de- scribed below.

First, liq- uation was initiated at the eutectic temperature by the eutectic reaction between the α matrix and the δ particles to form the eutectic liquid. Unlike the constitutional liq- uation mechanism proposed by Pepe and Savage for maraging steels (Refs. 16, 17), rapid heating is not re- quired for liq- uation to occur. This is be- cause in alloy 2219, the δ particles are thermodynamically stable all the way to the eutectic temperature. The closer to the fusion boundary, the higher the peak temperature and the more adjacent α matrix dissolved in the eutectic liquid, and it turned it into a hypoeutectic liquid.

Second, GB liq- uid solidified with a planar mode and with severe solute segre- gation. Besides a dark-etching eutectic GB, a distinct light-etching α band, in fact, ex- isted along the GB. This microstructure clearly suggests the hypoeutectic GB liq- uid solidified with a planar solidification front, first as a soft and ductile solute-depleted α band and last as a hard, brittle solute-rich eutectic at the new GB. This was confirmed by both microsegregation measurements and microhardness testing after welding.

Third, solidification of GB liq- uid was directional — upward and toward the weld because of the high-temperature gra- dients in the PMZ.

Fourth, while the soft ductile α band yielded under tensile loading, the brittle GB eutectic fractured into pieces, thus ex- planing the dramatic strength and ductility losses of the PMZ in tensile testing after welding. The liq- uation of the large δ particles in the grain interior and the subse- quent solidification of the liquid re- sulted in large eutectic particles and an α ring surrounding each particle. While the ductile α rings yielded under tensile loading, the large brittle eutectic particles frac- tured into pieces just like the GB eutectic.

Work on the binary alloy 2219 has greatly improved fundamental under- standing of liq- uation and solidification in the PMZ of aluminum welds. However, most commercial aluminum alloys are...
multicomponent and it is essential the liquation mechanisms be understood. Unfortunately, this has not been done so far because multicomponent aluminum alloys are much more difficult to understand.

The purpose of the present study is to extend understanding of liquation in alloy 2219 to wrought multicomponent aluminum alloys. The three representative liquation-susceptible alloys, 2024, 6061, and 7075, are selected. To help understand the liquation mechanisms in these alloys, relevant heat treating literature is cited and ternary phase diagrams are used as an approximation. To identify the liquation-inducing particles and the liquation reactions involved, compositions of both particles in the base metal and particles and grain boundaries in the PMZ are determined. Liquation-induced grain boundary segregation is also determined.

**Experimental Procedure**

The three commercial aluminum alloys studied were alloys 2024-T351, 6061-T651, and 7075-T651. T3 stands for solution heat treating and cold working followed by natural aging. T6 stands for solution heat treating and then artificial aging. T51 stands for stress relieving by stretching (Ref. 18). Actual compositions of the alloys are listed in Table 1 with nominal compositions included for reference (Ref. 18).

Bead-on-plate welding was conducted by gas metal arc welding (GMAW) perpendicular to the rolling direction of the workpiece. The dimensions of the workpiece were 20 cm long, 10 cm wide, and 9.5 mm thick. It was welded in the length direction in the as-received condition.

The welding parameters were 7.41 mm/s (17.5 in./min) welding speed, 30 V arc voltage, 245 A average current, and Ar shielding. The filler metal was an alloy 4043 wire of 1.2-mm diameter. Its nominal composition is Al-5.2 wt-% Si. The wire feeding speed was 18.6 cm/s (440 in./min).

After welding, the base metal and the PMZ were examined. For optical microscopy, alloys 2024 and 7075 were etched by a solution of 0.5 vol-% HF in water, and alloy 6061 was etched by Keller’s reagent. Composition measurements were conducted both in the base metal and PMZ by energy dispersive spectroscopy (EDS) at 15 KV. In order to minimize the possible effect of etching on the accuracy of composition measurements, samples were lightly etched with 10 vol-% phosphoric acid for 15 s. However, light etching made the GBs in the base metal difficult to observe. One 6061 sample was etched with Keller’s reagent for 30 s to better reveal the PMZ microstructure in SEM images. All SEM images were taken with backscattered electrons at 15 KV and a 9-mm working distance.

**Results and Discussion**

**Liquation Mechanisms**

To help understand liquation in the PMZ, liquation mechanisms for wrought binary aluminum alloys will be discussed first. Three liquation mechanisms are proposed in Fig. 1. The binary phase diagram in Fig. 1A is similar to the Al-rich side of the binary Al-Cu phase diagram. The solid solubility limit refers to the maximum solubility of the solute B in the solid phase α. Alloys 1 and 2 are within and beyond the solid solubility limit, respectively. Alloy 2 is similar to wrought aluminum alloy 2219 (essentially Al-6.3 w-% Cu), which is beyond the maximum solid solubility of 5.65 wt-% Cu. In Alloy 2, AlB particles are stable up to the eutectic temperature Tf because the alloy is in the two-phase region of α + AlB. In Alloy 1, on the other hand, AlB particles are stable up to the solvus temperature only. Alloy 1 (an Al-4.5%Cu alloy, for instance) contains no such particles before welding if it is solution heat treated in the α-phase region and quenched (Ref. 19).

Liquation in Alloy 2 is initiated by Mechanism 1, as shown in Fig. 1B. The PMZ of Alloy 2 covers the area where the peak temperature during welding is between the liquidus temperature TL and the eutectic temperature Te. Upon heating to TL, liquation begins by the eutectic reaction AlB + α → L. Since AlB is thermodynamically stable up to TL, liquation occurs at TL regardless of the heating rate during welding.

Before proceeding further, it is worth mentioning the eutectic reaction at the eu-
tectic temperature here represents the initiation of liquation. Above the eutectic temperature, the eutectic liquid increases in volume and becomes hypoeutectic in composition as the adjacent α matrix dissolves into the liquid. The fraction of the liquid depends on the location in the PMZ. The closer to the fusion boundary, the higher the local peak temperature is and the greater the fraction liquid becomes, as dictated by the phase diagram. At the fusion boundary, the fraction of liquid becomes one. This is true regardless of the mechanism by which liquation is initiated.

Liquation is initiated in Alloy 1 by Mechanism II or III, as shown in Fig. 1C. It is by Mechanism II if Al₆B₃ particles are present and if the heating rate is high enough to keep AlB₃ from dissolving completely in α before reaching Tₚ. The residual AlB₃, if there is any at Tₚ, will initiate liquation at Tₚ by the eutectic reaction α + AlB₃ ≔ L. The resultant PMZ covers the area where the peak temperature during welding is between the liquidus temperature Tₑ and the eutectic temperature Tₑ. Mechanism II is the same as the constitutional liquation mechanism proposed by Pepe and Savage (Refs. 16, 17), which is well recognized in some steels and Ni-based superalloys but not aluminum alloys.

Liquation can also be initiated in Alloy 1 by Mechanism III if no Al₆B₃ particles are present at Tₚ to cause liquation. This happens when Alloy 1 is heated slowly during welding and Al₆B₃ particles dissolve in α before reaching Tₚ or when Alloy 1 is solutionized and quenched before welding (Ref. 19). Liquation occurs by melting of the α phase, α ≔ L, at the solidus temperature Tₛ, rather than by the eutectic reaction at Tₑ. Consequently, the resultant PMZ covers the area where the peak temperature during welding is between the liquidus temperature Tₑ and the solidus temperature Tₛ.

For wrought ternary aluminum alloys, the three liquation mechanisms shown in Fig. 2 are proposed. These mechanisms correspond to those for wrought binary alloys shown in Fig. 1. In a ternary phase diagram, the solid solubility limit is represented by a nonisothermal curve, while in a binary one, it is represented by a point of fixed composition and temperature (Fig. 1A). Again, Alloy 2 is beyond the solid solubility limit, and particles Al₆B₃ can react with the Al-rich phase α to initiate liquation by Mechanism I. Alloy 1 is within the limit, and liquation can be initiated by either Mechanism II or III, depending on whether the liquid-inducing particles Al₆B₃ are present at the reaction temperature or not.

According to Hatch (Ref. 20), both alloys 7075 and 6061 are within the solid solubility limit. Therefore, their liquation mechanisms can be expected to be either Mechanism II or III — Fig. 2. Also according to Hatch (Ref. 20), alloy 2024 is near the limit, and it can be either beyond or within the solid solubility limit, depending on the actual composition of the heat. If it is beyond the limit, the liquation mechanism can be expected to be Mechanism I. If it is within the limit, on the other hand, the liquation mechanism can be expected to be either Mechanism II or III.

Multicomponent phase diagrams, if they can be constructed, are rather complicated and difficult to understand. Therefore, it will be convenient if ternary phase diagrams can be used as an approximation to check if an alloy is within or beyond the limit. Figure 3 shows the solid solubility limits in the ternary phase diagrams of Al-Zn-Mg and Al-Si-Mg, and Al-Cu-Mg near the Al corner (Ref. 21). According to the workpiece compositions shown in Table 1, alloy 7075 is close to ternary AI-5.7Zn-2.6Mg by wt-%, which is well within the solid solubility limit as shown in Fig. 3A. Likewise, alloy 6061 is close to ternary Al-0.9Mg-0.6Si by wt-%, which is also within the solid solubility limit as shown in Fig. 3B. Alloy 2024 is close to AI-4.2Cu-1.3Mg by wt-%, which is near the solid solubility limit as shown in Fig. 3C. Therefore, it appears that ternary phase diagrams can be used as an approximation to determine the location of a multicomponent alloy with respect to the solid solubility limit.

Since an alloy is either within or beyond the solid solubility limit, Mechanisms 1, II, and III cover the liquation mechanisms in most, if not all, wrought aluminum alloys.

### Table 1 — Actual and Nominal (Ref. 18) Compositions (in wt-%) of the Workpiece

<table>
<thead>
<tr>
<th>Alloys 2024</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>0.15</td>
<td>4.18</td>
<td>0.63</td>
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<td>0.01</td>
<td>0.06</td>
<td>0.02</td>
<td>0.24</td>
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<td>Nominal</td>
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<td>4.4</td>
<td>0.6</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Alloys 7075</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>0.08</td>
<td>1.57</td>
<td>0.03</td>
<td>2.55</td>
<td>0.20</td>
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<td>0.28</td>
</tr>
<tr>
<td>Nominal</td>
<td></td>
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<td></td>
<td>2.5</td>
<td>0.23</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloys 6061</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>0.62</td>
<td>0.28</td>
<td>0.08</td>
<td>0.89</td>
<td>0.19</td>
<td>0.02</td>
<td>0.01</td>
<td>0.52</td>
</tr>
<tr>
<td>Nominal</td>
<td></td>
<td>0.6</td>
<td>0.28</td>
<td>1.0</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Liquation-Inducing Particles and Liquation Reactions

The compositions of the predominant particles in the base metal were determined to help understand the liquation re-

---

Fig. 3 — Solid solubility limits in ternary systems (Ref. 21). A — Al-Zn-Mg; B — Al-Si-Mg; C — Al-Cu-Mg. As indicated, the approximate locations of alloys 7075, 6061, and 2024 are consistent with the locations according to Hatch (Ref. 20).
Table 2 — Compositions (in at.-%) of Particles and a Grain Boundary in Alloy 2024

<table>
<thead>
<tr>
<th>Position</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Fe</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>al</td>
<td>0.04</td>
<td>33.52</td>
<td>0.00</td>
<td>0.32</td>
<td>0.17</td>
<td>0.39</td>
<td>0.33</td>
<td>65.22</td>
</tr>
<tr>
<td>a2</td>
<td>0.07</td>
<td>35.81</td>
<td>0.05</td>
<td>0.36</td>
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<td>0.12</td>
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<td>63.35</td>
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<tr>
<td>a3</td>
<td>0.06</td>
<td>34.30</td>
<td>0.02</td>
<td>0.54</td>
<td>0.10</td>
<td>0.05</td>
<td>0.09</td>
<td>64.85</td>
</tr>
<tr>
<td>b1</td>
<td>6.33</td>
<td>7.02</td>
<td>5.76</td>
<td>0.00</td>
<td>0.00</td>
<td>0.32</td>
<td>9.45</td>
<td>71.11</td>
</tr>
<tr>
<td>b2</td>
<td>6.19</td>
<td>8.66</td>
<td>6.01</td>
<td>0.07</td>
<td>0.01</td>
<td>0.00</td>
<td>10.31</td>
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<tr>
<td>b3</td>
<td>5.91</td>
<td>5.94</td>
<td>6.95</td>
<td>0.10</td>
<td>0.16</td>
<td>0.31</td>
<td>10.65</td>
<td>69.98</td>
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<tr>
<td>Partially Melted Zone (Fig. 8A)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pl</td>
<td>6.56</td>
<td>5.80</td>
<td>4.95</td>
<td>0.00</td>
<td>0.05</td>
<td>0.08</td>
<td>9.81</td>
<td>72.75</td>
</tr>
<tr>
<td>p2</td>
<td>6.74</td>
<td>2.77</td>
<td>6.48</td>
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<td>0.08</td>
<td>0.10</td>
<td>7.99</td>
<td>75.34</td>
</tr>
<tr>
<td>p3</td>
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<td>23.60</td>
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<td>0.02</td>
<td>0.00</td>
<td>0.12</td>
<td>67.20</td>
</tr>
<tr>
<td>gl</td>
<td>2.64</td>
<td>15.14</td>
<td>0.02</td>
<td>2.26</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>79.88</td>
</tr>
</tbody>
</table>

In the base metal of each alloy, iron (Fe) is an ever-present impurity in Al and particles form because the solubility of Fe in solid Al is very low. Compositions of similar particles at different locations were compared to check the consistency of EDS analyses. Iron-rich particles existed in the base metal of each alloy. Iron-rich particles appear to be CuAl2 (that is, Al-33Cu in at.-%). CuAl2 (and CuMgAl2) particles have been observed in alloys 2219, 2024, and 2014.

The EDS results for the particles in the base metal (and the PMZ) of alloy 2024 are listed in Table 2 in at.-%. Referring to Fig. 4, the compositions (in at.-%) of the particles in the base metal were essentially:

**Cu-rich particles**

- Al-34Cu at a1, Al-36Cu at a2, and Al-34Cu at a3

**Fe-rich particles**

- Al-9Fe-7Cu-6Si-6Mn at b1
- Al-10Fe-9Cu-6Si-6Mn at b2, and
- Al-11Fe-7Mn-6Si-6Cu at b3

The Cu-rich particles appeared to be CuAl2, and CuMgAl2 (liquation-causing) at a1. CuMgAl2 (liquation-causing) at a1

\[ \alpha + \text{CuMgAl}_2 \rightarrow L \downarrow \]

Fe-rich (nonliquation-causing): b1, b2, b3a, b4a

Cu2FeAl7 (liquation-causing): b3b, b4b

\[ \alpha + \text{Cu}_2\text{FeAl}_7 \rightarrow L + (\text{Cu,Fe})\text{Al}_6 \downarrow \]
CuAl₂ particles can cause liquation by the following eutectic reaction (Ref. 23):

$$\alpha + \text{CuAl}_2 \rightarrow L \text{ at } 548°C.$$ \hspace{1cm} (1)

Above the eutectic temperature the surrounding Al matrix melts into the eutectic liquid and dilutes it to a hypoeutectic liquid. Upon subsequent cooling, the hypoeutectic liquid solidified first as \(\alpha\) and last as eutectic \((\alpha + \text{CuAl}_2)\). Small CuAl₂ particles were present along the GBs in the base metal (though too small for composition analysis) and they can cause GB liquation, as observed in alloy 2219 (Ref. 13).

The presence of many large CuAl₂ particles in the base metal and a composition near the solid solubility limit together suggested the as-received alloy 2024 was either beyond the solid solubility limit or was within the limit but had not been solution heat-treated thoroughly to dissolve CuAl₂. In the former case, Mechanism I can occur regardless of the heating rate during welding. In the latter, however, Mechanism II (constitutional liquation) can occur under rapid heating. CuMgAl₂ particles, though not shown in Fig. 4, are likely to be present to cause similar liquation (Reaction 2).

The Fe-rich particles were similar to those insoluble by heat treating. Examples of such particles include \((\text{Fe,Cu,Mn})_3\text{Si}_2\), \((19 \text{ at.-% for Fe, Cu, and Mn together, and 6 at.-% for Si alone})\) or \((\text{Fe,Cu,Mn})_3\text{Si}_2\), \((15 \text{ at.-% for Fe, Cu, and Mn together, and 10 at.-% for Si alone})\) (Refs. 20, 22, 23). No liquation-causing reactions between Fe-rich particles and the Al matrix were found in the numerous reactions listed by Mondolfo (Ref. 23).

**Alloy 7075**

The EDS results for the particles in the base metal (and the PMZ) of alloy 7075 are listed in Table 3 in at.-%. Referring to Fig. 5, the compositions (in at.-%) of the particles in the base metal were:

- **Cu-rich particles**: \(\text{Al-26Cu-23Mg at } a1\)
- **Fe-rich particles**: 
  - \(\text{Al-14Fe-4Cu-2Zn at } b1, b2, b3\), and \(\text{Al-15Fe-4Cu-2Zn at } b3a, b4a\),
  - **Cu-rich coatings**: 
    - \(\text{Al-19Cu-9Fe at } b3\) and \(\text{Al-21Cu-10Fe at } b4b\).

**Table 3 — Compositions (in at.-%) of Particles and a Grain Boundary in Alloy 7075**

<table>
<thead>
<tr>
<th>Position</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Fe</th>
<th>Al</th>
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<tbody>
<tr>
<td><strong>Base Metal (Fig. 5)</strong></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>al</td>
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<td>26.08</td>
<td>0.00</td>
<td>22.99</td>
<td>0.07</td>
<td>1.86</td>
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<td>b1</td>
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<td>0.37</td>
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<td>0.47</td>
<td>1.97</td>
<td>13.68</td>
<td>79.30</td>
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<tr>
<td>b2</td>
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<td>3.78</td>
<td>0.40</td>
<td>0.28</td>
<td>0.25</td>
<td>2.19</td>
<td>13.16</td>
<td>79.16</td>
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<td>b3a</td>
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<td>0.24</td>
<td>0.19</td>
<td>0.25</td>
<td>2.27</td>
<td>14.58</td>
<td>78.19</td>
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<tr>
<td>b4a</td>
<td>0.71</td>
<td>3.96</td>
<td>0.47</td>
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<td>0.15</td>
<td>1.88</td>
<td>14.31</td>
<td>78.47</td>
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<td>b3b</td>
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<td>0.11</td>
<td>0.23</td>
<td>0.26</td>
<td>0.84</td>
<td>9.04</td>
<td>70.65</td>
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<td>b4b</td>
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<td>0.56</td>
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<td>1.77</td>
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<td>2.90</td>
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**Table 4 — Compositions (in at.-%) of Particles and a Grain Boundary in Alloy 6061**

<table>
<thead>
<tr>
<th>Position</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
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<th>Al</th>
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<tr>
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<td>1.70</td>
<td>0.00</td>
<td>15.53</td>
<td>72.74</td>
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<tr>
<td>h2</td>
<td>7.85</td>
<td>0.82</td>
<td>0.84</td>
<td>0.00</td>
<td>1.25</td>
<td>0.18</td>
<td>16.48</td>
<td>72.58</td>
</tr>
<tr>
<td>h3</td>
<td>8.60</td>
<td>0.38</td>
<td>1.04</td>
<td>0.01</td>
<td>2.49</td>
<td>0.02</td>
<td>14.77</td>
<td>72.50</td>
</tr>
<tr>
<td><strong>Partially Melted Zone (Fig. 8C)</strong></td>
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<td></td>
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</tr>
<tr>
<td>p1</td>
<td>8.21</td>
<td>1.39</td>
<td>0.79</td>
<td>0.09</td>
<td>1.97</td>
<td>0.00</td>
<td>15.70</td>
<td>71.85</td>
</tr>
<tr>
<td>p2</td>
<td>5.66</td>
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<td>1.82</td>
<td>0.00</td>
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<td>9.96</td>
<td>0.04</td>
<td>0.00</td>
<td>0.14</td>
<td>66.30</td>
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</table>
Fig. 7 -- Optical micrographs of the partially melted zone. A -- Alloy 2024; B -- alloy 7075; C -- alloy 6061.

Fig. 8 -- SEM images of the partially melted zone. A -- Alloy 2024; B -- alloy 7075; C -- alloy 6061 in Fig. 6. In alloy 6061, the thick grain boundary liquid and the little grain interior liquid suggest the liquid from the weld pool penetrated deep into the partially melted zone along the grain boundary.
A 6061 with liquation-causing Si-rich particles (Mechanism I)

Fig. 9 — SEM images of an alloy 6061 from a second supplier. A — Dark liquation-causing Si-rich particles in base metal; B — eutectic particles in PMZ; C — eutectic particle in PMZ enlarged.

Si-rich particles (dark, liquation-causing)

20 μm

Fig. 10 — PMZ optical micrograph of the alloy 6061 in Fig. 9 showing eutectic particles resulting from liquation caused by Si-rich particles.

PMZ of an alloy 6061 containing liquation-causing Si-rich particles (Mechanism II)

Fig. 11 — Grain boundary segregation in the partially melted zone.

The Cu-rich particles appeared to be CuMgAl (that is, Al-25Cu-25Mg in at.-%) (Refs. 20, 23). The presence of some CuMgAl₂ particles in the base metal suggested that the solution heat treatment of the as-received alloy 7075 was not thorough enough. CuMgAl₂ particles can cause liquation by the following eutectic reaction (Ref. 23):

$$\alpha + \text{CuMgAl}_2 \rightarrow L \text{ at } 518°C.$$ (2)

As shown in Fig. 3A, alloy 7075 is considered an Al-Zn-Mg ternary alloy just for determining the approximate location of the alloy relative to the solid solubility limit. This does not contradict the presence of Cu-rich particles or coatings in the alloy.

These Fe-rich particles (in Fig. 5) differed from those in the base metal of alloy 2024 (Fig. 4) because they had some Zn but little Si and Mn due to the composition of alloy 7075. Liquation-causing reactions between such Fe-rich particles and the Al matrix were not found (Ref. 23).

The Cu-rich coatings appeared to be CuFeAl (that is, Al-20Cu-10Fe in at.-%)
Grain Boundary Segregation in 2024 PMZ

Fig. 12 — Grain boundary segregation in the partially melted zone of alloy 2024. A — SEM image; B — Cu; C — Si; D — Mg. The overall composition of the workpiece (Table 1) is included for reference (from -2 to 0 μm).

Grain Boundary Segregation in 7075 PMZ

Fig. 13 — Grain boundary segregation in the partially melted zone of alloy 7075. A — SEM image; B — Zn; C — Cu; D — Mg.
Fe-rich particles are known to transform to Cu$_2$FeAl$_7$ during heat treatment of alloy 7075 ingots (Ref. 20). The following reaction is known to exist (Ref. 23):

$$\alpha + \text{Cu}_2\text{FeAl}_7 \rightarrow L + (\text{Cu,Fe})\text{Al}_6 \text{ at } 590°C.$$ (3)

Therefore, Cu$_2$FeAl$_7$ on the surface of Fe-rich particles was likely to cause liquidation by reacting with the surrounding Al matrix.

**Alloy 6061**

The EDS results for the particles in the base metal (and the PMZ) of alloy 6061 are listed in Table 4 in at.-%. Referring to Fig. 6, the compositions (in at.-%) of the particles in the base metal were essentially:

**Fe-rich particles**
- Al-16Fe-8Si-2Cr-1Mn at b1,
- Al-16Fe-8Si-1Cr-1Mn at b2, and
- Al-15Fe-9Si-2Cr-1Mn at b3.

The Fe-rich particles were often thin and, when oriented normal to the polishing surface, appear as short line segments. Liquidation-causing reactions between such Fe-rich particles and the Al matrix were not found (Ref. 23). No liquidation-causing particles were found in this alloy 6061. Since the Fe-rich particles did not cause liquation and there were no liquidation-causing particles present, liquation occurred by Mechanism III in this alloy 6061.

However, coarse Mg$_2$Si particles were reported to be present and cause liquation in alloy 6061 (Refs. 20, 22, 23). To resolve this discrepancy, an alloy 6061 from a different supplier was also welded, as will be discussed later.

**PMZ Microstructure**

The PMZ optical micrographs are shown in Fig. 7. As shown, the liquated and resolidified GB material consisted of a light etching α band that solidified first and a dark etching eutectic GB that solidified last. GB solidification was directional, that is, upward (indicated by the thick arrows) and toward the weld (Ref. 13). The latter was clearer in alloy 2024 because of more GBs facing the weld (to the upper right of the micrograph). The SEM images of the PMZ are shown in Figure 8. It is interesting to note the α band appeared as dark etching while the eutectic GB appeared as light etching.

**Alloy 2024**

The EDS results for the particles in the PMZ of alloy 2024 are listed in Table 2 in at.-%. Referring to Fig. 8A, the compositions (in at.-%) of the particles were essentially:

**Fe-rich particles**
- Al-10Fe-7Si-6Cu-5Mn at p1 and
- Al-8Fe-7Si-7Mn-3Cu at p2

**Cu-rich particle**
- Al-24Cu-8Mg-1Si at p3

The compositions of Fe-rich particles were close to those of the Fe-rich particles at b1 through b3 in the base metal — Fig. 4. As evident in SEM images of higher magnifications (not shown here because of space limitations), these Fe-rich particles looked similar in microstructure to the Fe-rich particles in the base metal.
Therefore, it appeared Fe-rich particles did not react with the Al matrix to cause liq uation. Otherwise, their composition and microstructure would have changed.

The Cu-rich particle at p3 had a composite-like structure of a normal eutectic and a particle-free α band surrounding it as shown in the inserted micrograph in Fig. 8A. It appeared a large CuAl2 particle reacted with the Al matrix and caused liq uation here, and the eutectic particle formed during subsequent solidification. Since the Al matrix contained Mg (Table 1), it brought Mg into the liquid hence the resul ting eutectic particle formed was Mg, Zn, and Cu and contents appeared lower than those of the particle at p2, possibly because of the background effect of this thin GB in the EDS composition analysis.

Consider the particle at position, p3, which was labeled at two positions, p3a and p3b (shown later in Fig. 13A at a higher magnification). It was interesting to note the liq uated material at p3 (its lower left corner) penetrated into the GB. It was also interesting to note the particle at position p3 was on the average brighter on the outside and somewhat darker inside. This particle is discussed further as follows.

As mentioned previously, the base metal contained Fe-rich particles with CuFeAl2 on the surface. One possibility was CuFeAl2 liq uated but the Fe-rich portion did not dissolve in the liquid produced by the liq uation process. However, the material at position p3b was essentially Al-15Mg-13Zn-9Cu by at.-% and contained little Fe. This suggested it did not come from the liq uation of CuFeAl2. Furthermore, the material at position p3a was essentially Al-12Fe-4Cu-3Zn-2Cr-2Mg by at.-% and had more Cr and less Fe than those at positions b3a and b4a in Fig. 5. This suggested it did not come from the undissolved Fe-rich portion of a particle like b3 and b4 in the base metal.

The other possibility was that CuFeAl2 liq uated, for instance, through Reaction 3 and formed (Cu,Fe)Al2. As the temperature rose further, the volume of liquid increased by melting the surrounding Al matrix and (Cu,Fe)Al2. During subsequent solidification of the resultant liquid, the Fe-rich portion of the particle at p3 formed first and then the Cu-containing portion. It was interesting to note the composition of the material at p3b was close to that of the normal eutectic at position p2. It is possible the Fe-rich solid precipitated from the liquid and grew and became the Fe-rich portion and, upon further cooling, the eutectic nucleated heterogeneously on the Fe-rich portion and formed the Cu-containing portion.

Alloy 6061

The EDS results for the particles in the PMZ of alloy 6061 are listed in Table 4 in at.-%. Referring to Fig. 8C, the compositions of the particles (in at.-%) and grain boundary were essentially:

Fe-rich particles

Al-16Fe-8Si-2Cr-1Mn-1Cu at p1,
Al-17Fe-6Si-2Cr-1Mn-1Cu at p2

Grain boundary

Al-20Si-10Mg-4Cu at gl.

The sample in Fig. 8C was etched with Keller’s regent for 30 s to reveal the PMZ microstructure more clearly in the SEM image. Otherwise, only Fe-rich particles would have been visible (Fig. 6). As shown previously, the base metal of alloy 6061 contained angular Fe-rich particles (Fig. 6) but no liq uation-causing reactions between these Fe-rich particles and the Al matrix were found (Ref. 23). Figure 8C is further discussed as follows.

The composition of the particle at p1 was similar to the compositions of the Fe-rich particles in the base metal (b1 through b3 in Fig. 6). Its microstructure was also similar to that of the Fe-rich particles, that is, without a composite-like eutectic. The groove around the particle was caused by etching. These similarities suggested Fe-rich particles do not cause liq uation in alloy 6061. The small particle at p2 was a similar Fe-rich particle that happened to be close to the GB, and was caught in the GB liq uid.

The GB at gl had a composite-like structure of a normal eutectic and a particle-free α band below it, typical of a liq uated GB.

It was interesting to note in Fig. 8 that the amount of liq uid along one GB was much greater in alloy 6061 than in alloy 6024 or 7075, even though alloy 6061 was much less alloyed and thus could be expected to liq uate less. It was not likely liq uation alone could produce so much GB liq uid in alloy 6061, especially when there was little liq uation in the grain interior. Therefore, most of the GB liquid could have come from the weld pool.

As mentioned previously, coarse Mg2Si particles were reported to be present in alloy 6061 (Refs. 20, 22, 23), and Al-Mg-Si eutectic particles were reported to be present in the PMZ of such an alloy 6061 (Ref. 22). However, no coarse Mg2Si particles were observed in the 6061 base metal in Fig. 6, and no Al-Mg-Si eutectic particles were observed in the 6061 PMZ in Fig. 8C, either.

To resolve the discrepancy between the present study and previous studies regarding the presence of coarse Mg2Si particles in alloy 6061, additional welding experiments were conducted on similar 6061 plates from a supplier different from that of the alloy 6061 shown in Fig. 6. Figure 9A shows the SEM image of the base metal of a 6061-T651 plate from one such supplier. Unlike the alloy 6061 shown in Fig. 6, many dark particles were present in the base metal. One such particle was enlarged for closer examination. The sample was not etched at all in order not to dis-
solve the dark particles, which disappeared quickly even just briefly etched. Results of EDS analysis showed these particles had different compositions. Examples of the compositions (in at.-%) included Al-47Si-1Cu (the dark particle shown in the enlarged SEM image in Fig. 9A), Al-41Si-1Fe, Al-34Si, Al-49Si-20Mg-3Cu, Al-41Si-14Mg-5Cu-3Zn, Al-36Si-22Zn-1Mg, and Al-29Si-19Zn-1Cu. As such, these dark particles in the base metal were Si-rich with various concentrations of Mg, Cu, and Zn. These particles may have come from the eutectic particles formed during the terminal stage of casting. However, since alloy 6061 is within the solid solubility limit, the presence of the Si-rich particles in the base metal suggests the solution heat treatment was not thorough enough to dissolve these particles completely. Most of these particles looked similar to that shown in the enlarged SEM image in Fig. 9A. They did not look like composites but had some light Fe/Cu-rich particles embedded in them. Apparently, these dark, Si-rich particles were much more complicated in composition and had less Mg than the previously reported Mg-Si particles (Refs. 20, 22, 23). No composition analysis was shown to back up the claim of Mg-Si. As shown in Fig. 9A, there appeared to be some light angular Fe-rich particles scattered in the base metal as well.

In the PMZ these dark, Si-rich particles caused liquation by reacting with the surrounding Al matrix and formed eutectic particles, such as those shown in Figs. 9B and 9C. Results of EDS analysis showed that the dark areas in the eutectic were mostly Si-rich with various concentrations (in at.-%) of Mg, Cu, Zn, and Fe, for instance, Al-38Si-10Mg-5Cu, Al-9Si-1Fe, Al-30Si-10Zn-1Cu. In the case of alloy 2219 (Al-6.3 wt-% Cu) segregated Mg-Si particles (Ref. 14). For the aluminum alloys, the segregated Mg-Si particles (Ref. 14) and Mg2Si particles (Refs. 20, 22, 23). As shown in Fig. 12A through D, the light etching cz phase was surrounded by coarse CuAl2 particles (Refs. 13-15). The cz phase is light in optical micrographs, but not the SEM images.

According to the compositions of the dark, Si-rich particles in the matrix, they can cause liquation by the following and other eutectic reactions (Ref. 23):

\[
\begin{align*}
\alpha + Si &\rightarrow L at 577^\circ C \\
\alpha + Mg, Si + Si &\rightarrow L at 555^\circ C
\end{align*}
\]

Grain Boundary Segregation

Figure 11 provides a mechanism for the GB segregation that develops during solidification of the GB liquid in the PMZ. Allowing Cc to be the concentration of a given alloying element in the base metal, theoretically, the concentration of the GB eutectic, Cg, is the composition of the eutectic if the GB eutectic is normal, and of Al2Cu, if the GB eutectic is divorced. In practice, the value of Cc can be affected by the GB thickness if it is not significantly greater than the interaction volume of electrons in the EDS analysis. In the absence of solute back diffusion into the solidified material, the concentration of the element at the starting edge of the α band should be kCo, where k is the equilibrium partition ratio of the element. The dash line shows the resultant GB segregation of the element. However, if back diffusion is significant, the concentration of the element at the starting edge of the α band will be greater than kCo, as the solid line indicates.

In the case of alloy 2219 (Al-6.3 wt-% Cu with k = 0.17), back diffusion was evident. The Cu concentration at the starting edge of the α strip was essentially 3 wt-%, which was significantly higher than the 1.07 wt-% Cu based on kCo (= 0.17 x 6.3 wt-%) (Ref. 14). For the aluminum alloys studied here, back diffusion of alloying elements is expected to be significant. However, this cannot be verified because k is not readily available in multicomponent alloys.

The SEM micrograph in Fig. 12A shows an α band in the PMZ of alloy 224 and path XY along which solute segregation (in wt-%) across the α band was measured. As shown in Fig. 12B through D, Cu, Si, and Mg segregated to the GB and the α band became depleted in these elements. For reference, the workpiece composition taken from Table 1 was superimposed on the segregation curve from 2 to 0 µm. As compared to the GB at g in Fig. 8A, this GB had much more Cu and a different microstructure. It should be pointed out that in the PMZ, the GB composition can vary from GB to GB or even within one GB. It can be affected by a large particle nearby (such a Cu-rich particle) if the particle liquates and joins the local GB liquid.

Figure 13 shows GB segregation in the PMZ of alloy 7075. As shown, Zn, Cu, and Mg all segregated heavily to the GB, leaving the α band solute depleted. GB segregation in the PMZ of alloy 6061 is shown in Fig. 6. It is shown in Fig. 14. Segregation of Si and Mg to the GB was clear. Like all other liquated GBs in alloy 6061, this GB was connected to the fusion boundary. The location of the segregation measurement is 205 µm from the fusion boundary. It is interesting to note that along the same GB but at 568 µm away from the fusion boundary, the measured segregation shows Si rose from below 1 wt-% in the α band to 25 wt-% at the GB, and Mg rose from below 1 to 16 wt-%. As such, much more Si than Mg was present here, even though alloy 6061 had more Mg than Si (Table 1). Based on the diffusion distance 
\[d = 568 \mu m, a typical diffusion coefficient of D = 5 \times 10^{-5} \text{ cm}^2/\text{s}, and the approximation of } d^2 = Dt, the required time for Si to diffuse from the fusion boundary to this location was t = 65 s. This long diffusion time suggests the high Si content here is not likely to be caused by Si diffusion from the weld pool. Therefore, it appeared the Si-rich liquid from the weld pool backfilled the GB. The liquid was enriched in Si because of the 4043 filler metal (Al-5.2 wt-% Si).

Summary and Conclusions

In summary, since liquation can cause hot cracking and/or severe loss of strength and ductility and since most aluminum alloys are multicomponent, a fundamental study was conducted on the mechanisms by which liquation is initiated in the PMZ of wrought multicomponent aluminum alloys during welding. Three representative liquidation-susceptible alloys 2024, 6061, and 7075 were studied. Three liquation mechanisms were identified. The compositions and morphologies of the particles in the base metal were examined in order to help identify the liquation-inducing particles and the corresponding liquation reactions. The compositions and morphologies of both the particles and grain boundary phases in the PMZ were also examined to help further understand the liquation mechanisms. Liquation-induced grain boundary segregation was determined.

Conclusions are as follows:

1) Three different liquation mechanisms have been identified, and they cover most, if not all, of the wrought multicomponent aluminum alloys. For alloys...
T351, the liquation mechanism can vary for alloys within the limit but with such particles, liquation requires high heating rates (Mechanism III). However, alloys within the limit and without such particles, liquation occurs when the aluminum matrix starts to melt (Mechanism III).  

2) For a given alloy and temper, for instance, alloy 6061-T651 and alloy 2024-T351, the liquation mechanism can vary from heat to heat, depending on the exact alloy composition and the heat treatment history.  

3) Alloy 2024 contains Cu and likely CuMgA1, particles and is near the solid solubility limit. Therefore, the liquation mechanism depends on the composition of the heat welded. An alloy 2024 can liquate by Mechanism I if it is beyond the solid solubility limit and by Mechanism II if within the limit. In either case, liquation can occur by the following reactions:

\[ \alpha + \text{CuAl} \rightarrow L + \text{CuMgAl} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

4) Alloy 7075 contains both CuMgA1 and Fe-rich particles coated with Cu,FeAl, It is well within the solid solubility limit and thus liquates by Mechanism II. Liquation can occur by the following reactions:

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

\[ \alpha + \text{CuMgAl} \rightarrow L + \text{CuMg} \]  

5) Alloy 6061 is also within the solid solubility limit. Depending on how thorough the solution heat treatment, it may or may not contain Si-rich particles. Liquation is initiated by Mechanism III when Fe-rich particles alone are present, and by Mechanism II when Si-rich particles are also present. Si-rich particles can cause liquation through, for example, the following reactions:

\[ \alpha + \text{Si} \rightarrow L + \text{Si} \]  

\[ \alpha + \text{Si} \rightarrow L + \text{Si} \]  

\[ \alpha + \text{Si} \rightarrow L + \text{Si} \]  

\[ \alpha + \text{Si} \rightarrow L + \text{Si} \]  

\[ \alpha + \text{Si} \rightarrow L + \text{Si} \]  

6) Ternary phase diagrams can be a useful approximation for determining the location of a multicomponent alloy with respect to the solid solubility limit, at least in the cases of alloys 2024, 6061, and 7075.  

7) The liquation-causing particles in alloy 6061, at least in the one studied here, are not MgSi particles as suggested in the literature but Si-rich particles with varying Mg, Cu, and Zn contents. The eutectic particles in the PMZ are not the Al-Mg-Si eutectic particles as suggested in the literature either, but cutectic particles consisting of Si-rich and Fe-rich phases.  

8) Numerous Fe-rich particles are present in wrought aluminum alloys, but they do not appear to cause liquation.  

9) GB segregation can be rather severe in the PMZ of multicomponent aluminum alloys. Scavenging GB segregation can dramatically degrade the PMZ mechanical properties, as demonstrated in binary alloy 2219.

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References


An experiment in which a high-power CO$_2$ laser beam was split into two equal-power beams that were then used as a welding heat source indicated the dual-beam laser could significantly improve weld quality.

By J. Xie

Abstract. In recent years, laser beam welding using two laser beams, or dual-beam laser welding, has become an emerging welding technique. Previous studies demonstrated use of dual-beam laser processing can delay humping onset to higher speeds and slow down cooling rates. In this study, a detailed investigation was performed to quantify the benefits of dual-beam laser processing and to understand the mechanism for improving weld quality. A 6-kW CO$_2$ laser beam was split into two equal-power beams and the dual beams were located in tandem (one beam follows another) during welding. Experimental results indicated the dual-beam laser could significantly improve weld quality. For steel, surface quality was improved with fewer surface defects such as undercut, surface roughness, spatter, and underfill. Weld hardness and centerline cracking susceptibility were also reduced. In aluminum, quality improvements were in the form of smooth weld surfaces and fewer weld defects such as porosity, surface holes, and undercut. A high-speed camera investigation of welding vapor plumes above a workpiece showed plume height and size changed dramatically in conventional single-beam laser welding and the average fluctuation frequency was 1.2 kHz for steel. As the plume fluctuation was associated with keyhole instability, unstable vapor plume indicated the process was unstable and would result in poor welds. The vapor plumes in dual-beam laser welding were found to fluctuate at a certain frequency range, but the plume size changed only slightly during welding. The stabilized process contributed to improved weld quality in dual-beam laser welding.

Introduction

Laser welding has been widely used in the automotive, aerospace, electronic, and heavy manufacturing industries to join a variety of materials. In the automotive industry, high-power lasers are used to weld many components such as transmissions, mufflers, catalytic converters, exhaust systems, and tailor-welded blanks. It was reported about 70 million tailor-welded blanks were produced in 2000, a number predicted to be 95 million in 2001 (Ref. 1).

However, a number of defects, such as porosity, surface holes, irregular heads, undercuts, humping, and solidification cracking, are often found in laser welds. Industrial laser users are always looking for economical methods to improve weld quality and relax the strict fitup requirement for workpieces. A welding technique that combines two high-energy beam sources (either electron beams or laser beams), called “dual-beam welding,” has been investigated in recent years. Initial experimental studies showed the dual-beam process offered several advantages over the conventional single-beam process. An early electron beam (EB) welding experiment performed by Arata et al., who used dual electron beams during welding, demonstrated a trailing beam impinging on a molten pool could increase the welding speed at which humping occurred up to 50% (Ref. 2). In dual-beam laser processing, the dual beams can be arranged either side by side (Fig. 1A) or in tandem — Fig. 1B. Conrad Banas (Ref. 3) used a bendable mirror to split a laser beam into two beams that were then arranged side by side during welding to increase the fitup tolerance of workpieces — Fig. 1A. A study on using side-by-side laser beams for improved fitup tolerance has been reported in welding tailored blanks (Ref. 4). The rule of thumb is that the air gap between two workpieces should be less than 10% of the sheet thickness for butt joints and 25% for lap joints in conventional single-beam laser welding. Use of the side-by-side dual-beam lasers could substantially increase the fitup tolerance in welding tailored blanks (Ref. 4).

Dual laser beams arranged in tandem (Fig. 1B) have been reported to provide benefits over conventional single-beam laser welding such as improved weld quality (Refs. 5–11). The current study focused on the tandem dual-beam laser welding process and its impact on weld quality. In this paper, unless specified, dual-beam laser welding means two laser beams are arranged in tandem, as shown in Fig. 1B.

One of the possible benefits of using the dual-beam laser was to decrease cooling rates in laser welding of high-carbon steel (Refs. 5, 6). It was said cooling time between 800 and 500°C could be extended from 3.8 up to 7 s by enlarging the distance between the two beams (interbeam spacing), where two 5-kW CO$_2$ lasers were combined (Ref. 5). A dual-beam laser welding experiment on AISI 4140 steels was performed by Liu and Kannatey-Asibu in which the leading laser beam was focused on the surface of a workpiece and the trailing beam was defocused on the weld bead at an interbeam space of 10 mm (Ref. 6). The dual-beam process resulted in lower cooling rates, reduced hardness,

Key Words

Laser Welding
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Defect
Steel
Aluminum
Vapor Plume
Fluctuation
Keyhole Instability
and a smaller volume percentage of martensite in the 4140 steel welds when compared to single-beam laser welds. Similar results were obtained in welding thin, high-carbon steel sheet (0.85% carbon content) using two combined pulsed Nd:YAG lasers (Ref. 7). Several mathematical models on the cooling rates in dual-beam laser welding were developed by Kannatey-Asibu et al. (Refs. 8, 9). These theoretical analyses showed the cooling rates at the weld centerline were reduced from 1004°C/s in the single-beam process to 570°C/s in the dual-beam process while the laser power and inter-beam spaces were 1.8 kW and 10 mm, respectively (Ref. 9).

Dual-beam laser processing was also reported to help reduce porosity and prevent cracking in laser welding of aluminum alloys. Porosity in weld metal could be significantly reduced when the leading laser beam was focused at the workpiece surface and the trailing beam was defocused at 2 mm above the workpiece (Ref. 5). In this experiment, two 5-kW CO₂ lasers were combined with an angle of 30 deg between two beams and an interbeam space of 3 mm. Using a dual-beam laser system that combined a continuous wave Nd:YAG (200 W) and a pulsed Nd:YAG (410 W), microcracking could be prevented in welding 1-mm-thick AS5052 aluminum sheets (Ref. 10). A similar experiment using two pulsed Nd:YAG lasers indicated porosity and cracking were reduced when welding 0.8-mm AS5005 aluminum plates (Ref. 11). In this experiment, the leading beam was focused on the surface at an incline angle of 10 deg and the trailing beam focused down at an angle of 45 deg. It was found porosity- and crack-free weds could be produced at interbeam spaces of 0.2 and 0.4 mm only, while other processing parameters were 10-Hz pulse frequency, 3-ms pulse width, 140-mm/min travel speed, 18-J pulse energy for the leading beam, and 9 J for the trailing beam. As interbeam spacing was increased to greater than 0.6 mm, the effects of reducing porosity and cracking no longer existed in the experiments (Ref. 11).

Changes in weld depth in dual-beam laser welding were investigated in some studies (Refs. 5, 12). An experiment studying the influence of interbeam spacing and power ratio of dual laser beams on weld depth and width was reported by Glumann et al. (Ref. 5). In the experiment, the angle between the two CO₂ laser beams was 30 deg and the laser power combinations were 400/3500, 3500/1700, and 3500/900 W, respectively. The experimental results showed changes in weld depth and width were small at spaces of 1, 10, and 20 mm (Ref. 5). Further investigation indicated weld depths produced by both single- and dual-beam lasers were almost the same if the dual beams were focused on a common spot (Ref. 5). Another welding experiment, in which a 1-kW pulsed and a 2-kW CW Nd:YAG laser beams impinging at the same spot on a 304 stainless steel plate, showed weld depth.
basically be divided into two types, angled and parallel. Most of the reported dual-beam systems, many were the combination of two Nd:YAG lasers because of easy manipulation by using two focus heads with fiber optics (Refs. 10-12). It was possible to combine CO2 lasers by using a special optic device as well (Ref. 5). The combined dual-beam laser systems were more flexible in changing interbeam spacing and the power ratio of dual laser beams. However, the split dual laser beams were almost parallel and had the same planes of polarization (coherent) as many lasers produced polarized beams. Based on the arrangements of the two laser beams, the dual-beam process can basically be divided into two types, angled and parallel. Most of the reported dual-beam systems were angled and a small interbeam spacing could easily be achieved.

In these systems. In the parallel dual-beam systems, spacing was usually large and they were often used for reducing cooling rates (Refs. 6, 7). In such systems with a large interbeam spacing, two Nd:YAG laser heads could simply be put together by a common holding fixture (Refs. 7, 11, 12), or a transmissive beam splitter was inserted in a CO2 laser beam path if the laser power was not high (<2 kW) (Ref. 6). The welding mechanisms and impact on laser welds are believed to be slightly different between the angled and parallel dual-beam processes and, also, the welding mechanism changed with variations in interbeam spacing in both the angled and parallel beam systems.

Generally, there might be three types of welding mechanisms in parallel dual-beam laser welding, depending on interbeam spacing, as shown in Fig. 2. The first type is the dual-beam process with large interbeam spacing in which one of the two beams creates a keyhole and the other acts as a heat source for heat treating the laser weld beam. The second is the two laser beams generate two keyholes in a common weld pool and the mass flow pattern of the molten metal is changed. In Type 3 of the parallel dual-beam process, interbeam spacing is small and the two beams interact with materials in a common keyhole. In the angled dual-beam process, the mechanism is also believed to be changed at various interbeam spacings similar to the parallel dual-beam process.

When interbeam spacing in the parallel dual-beam process is large (Type 1), the leading beam usually acts as a welding heat source to create a keyhole on the workpiece, and the trailing beam is usually defocused or has a lower laser power to do heat treating on the laser weld. In this case, the cooling rate is reduced and this feature can benefit some crack-sensitive materials such as high-carbon or alloyed steels. Additionally, the amount of the hartenitic structure is increased in the weld metal and heat-affected zone (HAZ), and improved toughness is expected for the welds. This benefit has been verified by a number of experiments and was well analyzed by mathematical modeling (Refs. 5-9).

As interbeam spacing is reduced to a certain degree, the welding mechanism switches to Type 2, in which two laser beams interact in a common weld pool but the dual laser beams create two separate keyholes, as shown in Fig. 2. In an early work on dual EB welding (Refs. 2, 16), the influence of interbeam spacing on mass flow of liquid metal in a weld pool and the formation of humping and undercut were discussed; the tested interbeam spaces were 4, 7, and 16 mm, respectively. It was found humping and regular welds could only be prevented at the 7-mm space because of the change in the flow direction of molten metal in the weld pool. However, humping and some surface defects were present at the 4- and 16-mm spaces. In the experiment, two separate keyholes were generated by two electron beams in a common weld pool (Ref. 2). When interbeam spacing is reduced further to the Type 3 mechanism, the two laser beams are close enough to create one common keyhole in the weld pool. Few welding experiments have been reported for such a parallel dual-beam process with small spaces.

In angled dual-beam laser welding, the welding mechanism could be slightly different from that in parallel dual-beam laser welding. It was reported a funnel-shaped keyhole was produced by combining two high-power CO2 lasers at a 30-deg angle and 1- to 2-mm spaces (Refs. 5, 15). The keyhole created by angled dual beams was enlarged; thereby, the keyhole might not be easy to collapse. Therefore, the angled dual beams enhanced the keyhole stability and weld quality was improved (Refs. 13, 15). In this dual-beam CO2 laser system, a special optical device was designed to combine the two high-power CO2 lasers (Ref. 5).

Although dual-beam laser processing...
Weld characteristics such as surface quality, weld morphology, cracking susceptibility, weld hardness, and defects were analyzed and the dynamic behavior of vapor plumes was investigated using a high-speed camera.

Experiments

In this study, a 6-kW, parallel dual-beam CO₂ laser system with a small interbeam space was investigated. A flat mirror ahead of the focusing mirror was replaced with a wedge mirror to split the incoming laser beam into two equal-powered and parallel beams, as shown in Fig. 3. The power density distribution of the split laser beams measured by a Primes beam analyzer is shown in Fig. 4. Dimensions of the laser beams, interbeam spacing, and power density could accordingly be obtained from the test results. The diameter of the dual laser beams and the interbeam spaces were found to be 0.4 and 1.2 mm, respectively, at the focal length of 200 mm. Interbeam spacing was determined by both the wedge mirror and focal length. In the study, a fixed interbeam space was used for all welding experiments, and the current setup (6-kW laser power and 1.2-mm space) should create a common keyhole in most welding conditions that were defined as the Type 3 mechanism in Fig. 2. Conventional single-beam laser welding was performed as well using the 6-kW CO₂ laser.

The welding experiments included bead-on-plate and butt-joint welding of steel and aluminum plates. In the bead-on-plate experiments, 6.25-mm-thick AISI 1045 steels and 6.0-mm-thick 5052 aluminum alloys (2.2–2.8% Mg) were used. Laser power was kept at 6 kW and travel speeds varied from 0.625 to 7.62 m/min. The laser beams were focused on the surface of the workpieces using a 200-mm parabolic focusing mirror. Helium was used as the shielding gas delivered to the welding area by a side jet at a flow rate of 20 L/min.

In complete-penetration butt-joint welding, 6.25-mm-thick 1045 steel plates and 3-mm-thick 5083 aluminum alloy sheets were used. These sheets were shear cut and no machining was prepared for the edges to be welded. The laser power and travel speed for welding 1045 steel plates were 6 kW and 1.25 m/min, respectively. In the butt-joint welding of 3-mm 5083 aluminum sheets, laser powers were 3 kW in the single-beam process and 4.5 kW in the dual-beam process while travel speed was kept at 3.81 m/min. Back shielding with helium gas was used in laser butt-joint welding of aluminum plates.

Welds produced by the single- and dual-beam CO₂ laser were visually inspected and the welded plates were
checked using X-ray radiography to detect cracking and porosity in the welds. Hardness distributions in the base metal, HAZ, and fusion zone were measured.

To understand the laser/material interaction mechanism in dual-beam laser welding, a high-speed camera was used to investigate the dynamic behavior of the vapor plumes above the workpiece by performing bead-on-plate welding on 6.35-mm-thick 1045 steel plates. The experimental setup is shown in Fig. 5. The camera used was a high-speed motion analyzer Model 4540 made by Eastman Kodak Co. and run at a speed of 9000 frames/s.

Results and Discussion

Laser Welds

Complete-penetration butt-joint welds of 1045 steel produced by both single and dual laser beams are shown in Fig. 6. The weld made by the dual-beam process was smooth but the single-beam laser was rough and irregular. The bead-on-plate welding results on 1045 steel plates in which travel speed was varied from 1.25 to 7.62 m/min and laser power was kept constant at 6.0 kW are shown in Fig. 7. Among the single-beam laser welds, appearance of the shallow beads produced at high speeds was acceptable, but the deep welds made at low speeds presented some surface defects and the welds were irregular. However, the dual-beam laser welds were always smooth and no defects were found for the welds made with the same welding parameters. This implies dual-beam laser welding is a stable process and good welds were achieved over the range of process parameters investigated.

Aluminum alloys are well known to be difficult to laser weld because of their high reflectivity, high thermal conductivity, and volatilization of low boiling point constituents. Weld defects such as surface holes, undercut, porosity, and irregular beads are often observed. A complete penetration weld was made using the single-beam CO2 laser and the weld surface was quite smooth; the single-beam laser weld was irregular with some spatter — Fig. 8. Partial-penetration, bead-on-plate aluminum welds produced by the single- and dual-beam lasers are shown in Fig. 9. As expected, dual-beam laser welds had much fewer defects than the single-beam laser welds. Generally, Nd:YAG lasers, instead of CO2 lasers, have to be used to make acceptable aluminum welds due to the short wavelength (1.06 mm for Nd:YAG vs. 10.6 mm for CO2 lasers) that improves laser energy absorption for aluminum workpieces. The current experiment implies it is possible to use CO2 lasers to produce acceptable aluminum welds by using dual-beam laser processing.

Centerline Cracking and Hardness

Centerline cracking was found in both the single- and dual-beam laser welds of 1045 steel plates, as shown in Fig. 10. A typical centerline crack found in the 1045 steel welds is also shown in Fig. 11. Since 1045 steel is a medium-carbon steel with a carbon content of 0.45%, the material is sensitive to solidification cracking in welding. Centerline cracking is a type of solidification crack usually found in medium/high-carbon steel, some alloyed steels, and aluminum alloys. While cracking was found in some of the dual-beam laser welds, it was found in almost every single-beam laser weld for the process conditions investigated. Centerline cracking susceptibility, which was defined as the ratio of the accumulated crack length over total weld length, was plotted against the travel speeds for both processes in Fig. 12. Centerline cracking was present in a wide speed range in single-beam laser processing and it was detected only over a small range in dual-beam laser welding. This result implies dual-beam laser welding may have less cracking susceptibility than conventional laser welding.

Weld hardness was tested at the location 1.5 mm below the weld surfaces as shown in Fig. 13. Average hardness of the single- and dual-beam laser welds was Hv 640 and Hv 590, respectively. This result indicates dual-beam laser welds might have better toughness than single-beam laser welds due to lower hardness.

Since the materials/welding parameters used in the single- and dual-beam processes were exactly the same, the differences in cracking susceptibility and weld hardness should be contributed by the change in heat flows during welding. In the dual-beam process, the keyhole
shape would be elongated along the welding direction due to the interbeam spacing. As a result, the temperature distribution around the weld pool was changed, which may have resulted in the change in mechanical restraint around the pool and the cooling rate of molten metal. In dual-beam laser welding, the mechanical restraint might be reduced somewhat, thereby reducing cracking susceptibility. The temperature gradient in the transverse direction could be flattened because of heat conduction loss along the transverse direction. The cooling rate of molten metal was therefore reduced, leading to lower hardness. A detailed analysis of heat flow and its impact on welds in dual-beam laser welding will be addressed in another paper.

Fluctuation of Vapor Plumes

Welding experiments indicated weld quality could be substantially improved using dual-beam laser welding technology. It was interesting to understand how the dual beams interact with materials and why weld quality was improved in dual-beam laser welding. The laser/material interaction in dual-beam laser welding with a small space was studied by investigating the dynamic behavior of vapor plumes (or plasma plumes in some literature) using a high-speed camera, as shown in Fig. 5.

The vapor plume was found to fluctuate in height under the high-speed camera in single-beam laser welding of steel. The typical cycles of the vapor plume fluctuation are shown in Fig. 14. The plume grew to a maximum height, then decreased with respect to time. When the plume was small enough, it grew up again to start another fluctuation cycle. Occasionally, the vapor plume completely disappeared, as shown in the picture at t = 1.10 ms in Fig. 14. In the single-beam laser welding of steel experiment, the plume fluctuated in the frequency range from 0.9 to 1.5 kHz, and the average fluctuation frequency was 1.2 kHz at the travel speed of 1.25 m/min. In other words, cycle time of each plume fluctuation was in the range of 0.66 to 1.1 ms and the average cycle time was 0.83 ms in CO2 laser welding of steel.

When welding speed was increased from 1.25 to 7.62 m/min with the laser power kept at 6 kW, keyhole depth decreased accordingly. The plume fluctuation was still observed, but the change in plume height was less and the phenomena of complete disappearance of the plume (t = 1.10 ms in Fig. 14) was no longer observed. In other words, the plumes were more stable at high speeds due to shallow keyholes, and the stabilized plumes represented acceptable welds with fewer defects. The average fluctuation frequency at 7.62 m/min was almost the same as that at 1.25 m/min, which was 1.2 kHz. The frequency of plume fluctuation in laser welding might be related to material properties and laser wavelength instead of welding parameters.

Plume fluctuation in high-power laser welding is typically related to the keyhole instability experimentally observed in both laser and electron beam (EB) welding using X-ray transmission techniques (Refs. 17, 18). The keyhole instability was strongly affected by the irregular mass flow of molten metal in a keyhole (Ref. 17). A detailed discussion on plume fluctuation, irregular mass flow, and keyhole instability could be found in Ref. 19.

In single-beam laser welding, the surface of a workpiece is heated up to the boiling point in a short time (an order of milliseconds) by high-power laser beams (Refs. 20, 21). The material is vaporized to create a keyhole in the workpiece and then portions of the metal vapor and shielding gas are ionized by the laser beam, forming a hot and high-pressure plume in the keyhole. The plumes are called “vapor plumes” or “plasma plumes” in some of the literature. When the keyhole is completely open, the vapor plume can easily escape from the keyhole and a portion of the escaped plume can be observed above the workpiece. Since the keyhole is usually unstable during welding due to irregular mass flow of molten metal (Refs. 17, 18), the keyhole opening contracts at a certain frequency range. The keyhole is occasionally closed or collapsed. When the keyhole opening decreases in size or contracts, it limits the escape of the plume from the keyhole and, therefore, the plume above the workpiece becomes smaller. Meanwhile, plume pressure increases in the key-hole and, therefore, the plume above the workpiece becomes smaller.
Welding Direction

![Graph](image)

Fig. 14 — Size of vapor plumes dramatically changed in single-beam laser welding (1045 steel, bead on plate, CO2 laser, 6 kW, 1.25 m/min, helium).

![Graph](image)

Fig. 15 — Vapor plume size varied slightly in dual-beam laser welding (1045 steel, bead on plate, 1045 steel, CO2 laser, 6 kW, 1.25 m/min, helium).

hole by continuous irradiation of the laser beam. When the plume pressure in the keyhole is high enough, the plume erupts out of the keyhole and the plume size is thereby increased. The plume eruption brings some liquid metal out of the keyhole in the form of spatter (Ref. 19) and results in a cavity in the bead. If insufficient liquid metal fills back to the cavity, the weld appearance will be rough and irregular. In laser welding of aluminum, this situation becomes worse because the high thermal conductivity gives a very short solidification time for liquid metal to refill the cavity. This could be the reason weld defects such as surface holes, undercut, porosity, and irregular beads are often found in aluminum welds. As a result, the eruption of vapor plumes during welding might be responsible for the spatter and some weld defects in single-beam laser welding.

In dual-beam laser welding, plume fluctuation was observed, but the variation in plume size was much smaller, as shown in Fig. 15. Under certain conditions, the plume was completely stable and the plume size changed very little. The stable vapor plume might indicate the keyhole was always open during dual-beam laser welding and plumes could continuously come out of the keyhole. The stabilized and open keyhole, which was elongated by two close laser beams (dual beams), allowed the metal vapor and plasma inside to continuously escape and the pressure of the plume inside the keyhole was kept at a low level. Thus, big plume eruptions could be suppressed by the stable and open keyhole. Little plume eruption could lead to smooth welds and little spatter, as shown in Figs. 6-9. In addition, the plumes in dual-beam laser welding appeared larger and the maximum height was smaller when compared to conventional single-beam laser welding, because the dual beam kept the elongated keyhole open most times and suppressed vapor plume eruption.

Fluctuation frequency of vapor plumes in single- and dual-beam laser welding of steel is summarized in Fig. 16. Average fluctuation frequency was found to be 1.4 kHz in dual-beam laser welding, which was slightly higher than the 1.2 kHz of single-beam laser welding. The increased fluctuation frequency of the vapor plume meant smaller amounts of plume escaped per eruption.

However, it was occasionally found there were two vapor plumes at a high welding speed of 7.62 m/min, as shown in Fig. 17. This implies two keyholes might be created at a high speed with the current dual-beam setup and one plume was found only at speeds lower than 7.62 m/min. In other words, it was the Type 3 welding mechanism (one keyhole in one weld pool) at speeds less than 7.62 m/min and then it switched to the Type 2 mechanism (two keyholes in one pool) at a higher speed. Generally, the welding mechanism would change to Type 2 in Fig. 2 if interbeam spacing and welding speed increased or laser power decreased. Some industrial applications of the dual-beam laser welding technique were discussed in Refs. 22 and 23. It was found use of dual-beam Nd:YAG lasers could make high-quality aluminum welds (Ref. 22).

**Conclusions**

A 6-kW CO2 laser beam was split into two equal-power beams with small spacing by a wedge mirror and then the split laser beams or dual beams were used to weld steel and aluminum plates. Welding results were analyzed and the dual-beam laser process was investigated using a high-speed camera to better understand the impact of dual laser beams on weld quality. The following conclusions were obtained:

1) Weld surface quality was significantly improved for both steel and aluminum using the dual-beam laser welding technique. Weld spatter, weld hardness, and centerline cracking susceptibility were reduced in steel welds. Porosity, irregular beads, and spatter were substantially decreased in aluminum welds. Using the dual-beam technique, it is possible to use CO2 lasers to achieve acceptable aluminum welds.
2) Using a high-speed camera, the vapor plumes above the workpiece were found to be unstable and the height and volume of the plumes fluctuated dramatically in single-beam laser welding of steel. The average fluctuation frequency was 1.2 kHz. Unstable plumes might result in weld defects such as surface holes, irregular beads, and spatter.

3) Vapor plume fluctuation was found to be suppressed in dual-beam laser welding. Fluctuation was still found, but the height and volume of the plumes varied slightly. The stabilized vapor plume implies the dual laser beams could keep the elongated keyhole open, which suppresses eruption of plumes during welding. The increased process stability would result in improved weld quality.

4) In the current experimental setup with two parallel laser beams with a small interbeam spacing, one common keyhole in a weld pool was created in most welding conditions. The welding mechanism may switch to two keyholes in a weld pool with an increase in interbeam spacing and welding speed or a decrease in laser power.

References

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