Jefferson's

WELDING ENCYCLOPEDIA

Eighteenth Edition

Edited by
ROBERT L. O'BRIEN

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

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

© 1997 by the American Welding Society
All rights reserved. Published 1997

No part of this book may be reproduced in any form or by any means without permission in writing from the publisher.

Reasonable care was applied in the compilation and publication of Jefferson's Welding Encyclopedia to ensure authenticity of the contents. The American Welding Society assumes no responsibility for use of the information contained in this publication. An independent, substantiating investigation should be made prior to the reliance on or use of such information.

Printed in the United States of America.

Library of Congress Catalog Card Number: 97-070432
International Standard Book Number: 0-87171-506-6

© 1997 by American Welding Society
Originally published as *The Welding Encyclopedia*
© 1921, 1922, 1923, 1924 by L. B. MacKenzie
© 1926, 1928, 1930, 1932, 1938, 1941, 1943 by G. H. MacKenzie
© 1947 by The Welding Engineer Publishing Co., Division of McGraw-Hill Publishing Co. Inc.
© 1951 by McGraw-Hill Publishing Co., Inc.
© 1961 by Welding Engineer Publications, Inc.
© 1964, 1968, 1974 by Monticello Books, Inc.
Second printing 1976

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use only, or the internal, personal, or educational classroom use only of specific clients, is granted by the American Welding Society (AWS) provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: 508-750-8400; online: http// www.copyright.com

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

Dedicated to the Welders of America

A tribute to welders was expressed by Jeff Weber, Publisher of the *Welding Journal*, Miami, Florida, in the May, 1993 issue:

WHAT MAKES A WELDER?

A recent phone conversation with an old friend got me thinking about what it takes to be a welder. The person I was talking to has been welding for 25 years, but he said he is between jobs again, waiting for startup of a new project. The fact that he is not currently working troubled me, considering that this guy is truly an artist with a GTAW torch, a magician with a stick electrode. He can lay down a bead that looks like a machine made it, time after time. And when joint fitup isn't all it should be, he can improvise in ways a computer would never even think of.

As editor of this magazine, I run into lots of capable people in the welding industry, but the ones who impress me most are the ones who can express themselves through a welding gun. These highly skilled men and women are independent, savvy and capable, yet they have to face challenges and conditions that would prove daunting to most people. Here are a few ways one might describe a welder:

A welder is the guy you'll find working on a high plains pipeline in January at twenty below, or inside a boiler in the California desert at 105 degrees. He might be asked to backweld a joint in a section of pipe hot enough to melt a hard hat, or to do repairs at the top of a box section where elbow room and visibility are near zero. At a construction site, the welder is sometimes expected to weld joints that were easy to design on paper, but are nearly impossible to reach in a real life situation. On especially tricky jobs, he may have to weld in a tiny pocket, watching his progress with a hand mirror and trying to read his reflected movements backwards. Sometimes, high on a structure, the welder has to put up with gusting winds that threaten to blow away his gas shield while he attempts to block the drafts with his body. Despite all this, he has to weld the joint right the first time. There are no second chances and no opportunity to fix mistakes. Every job a welder does, every second of arc-on time, is permanently etched in steel and visible to everyone who passes by.

Unlike most workers, many welders must continually prove their ability, recertifying on every new job and every welding procedure they will use on that job. Since there is no guarantee that he will pass a certification test, the welder must keep practicing everything he knows, while learning new techniques every chance he gets. Welders on big projects must often wait by the phone for jobs, and when the call finally comes, they frequently have to travel long distances and live away from home for extended periods. If hired in the middle of a project, they must meet existing deadlines without complaint. And, while wages are sometimes good, pay increases are often out of the question because of the short-term nature of the work.

Yes, it's often a tough job, but we've got a devoted group of people who are willing and eager to do it. That's why I take my hat off to the welders of America. They possess levels of skill, resolve and professionalism that are rare today in any work force, anywhere. And that is what makes them absolutely essential to the well-being of our country.

Documents
Document Sharing Hub

Full document details: JWE-1997 scan



Photos by Renate Gaddis

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

Contents

Dedication iii
Foreword vi
Acknowledgments vi
Preface vii
Guide to Using the Encyclopedia viii
Alphabetical Entries 1
Appendixes 615
1. History of Welding and Cutting 615
2. Major Associations of the Welding Industry 631
3. Master Chart of Welding and Allied Processes 634
4. Welding Test Positions 635
5. Types of Weld Joints 638
6. Weld Joint Preparation 639
7. Welding Symbols 642
8. Weld Discontinuities 644
9. Types of Weld Cracks 645
10. Torch Nomenclature 646
11. Weld Sizes 648
12. Joint Penetration 650
13. Safety 651
14. Metric Conversions 662
15. Elements—Chemical Symbols and Atomic Numbers 666
16. Standards for Welding, Cutting, and Allied Processes 667
17. Filler Metal Specifications 683
18. Recommended Eye Protection 685
19. Automatic Welding Programs 687
Buyer's Guide 689

AVA Documents
Document Sharing Hub

Full document details: JWE-1997 scan

Foreword

Jefferson's
WELDING ENCYCLOPEDIA

The first four editions of The Welding Encyclopedia were published annually from 1921 through 1924 by L. B. MacKenzie. Mr. MacKenzie was given editorial assistance in this endeavor by H. S. Card. Both were on the staff of *The Welding Engineer*, a monthly publication of the Welding Engineer Publishing Company in Chicago, Illinois.

In his preface to the Fifth Edition in 1926, Mr. Card advised of the death of L. B. MacKenzie. The four editions from 1926 to 1932 were edited by Mr. Card, with Stuart Plumley succeeding him as editor for the 8th, 9th and 10th editions.

Ted Jefferson, by then a principal of the Welding Engineer Publishing Company, revised the Encyclopedia in 1943. He edited and published the 11th through 17th editions over a period of 33 years. Ted Jefferson died on July 6, 1988, at the age of eighty.

The American Welding Society has obtained publication rights for the Welding Encyclopedia. Because of Jefferson's long association with this book and his dedication to continuing its publication, we are changing the name of this book to *Jefferson's Welding Encyclopedia.*

The following is an excerpt from Ted Jefferson's Preface to the 17th Edition of the Welding Encyclopedia in 1976:

> *"In 1921 the coverage of welding involved a discussion of only three very basic processes used principally for maintenance or repair applications. Down through the years, the ever-changing and expanding field of welding has grown to include more than fifty welding processes, capable of joining a wide variety of materials."*

In 1997, more than ninety welding and allied processes are listed in the literature, and the number continues to grow.

Acknowledgments

The Editor is indebted to the following for their contributions to this book:

B. J. BASTIAN, P.E., Consultant, Benmar Associates; Royal Oak, MI
H. H. CAMPBELL III, Senior Staff Engineer, American Welding Society; Miami, FL
L. P. CONNOR, Director of Standards Activities, American Welding Society; Miami, FL
M. V. DAVIS, Ph.D., Consultant, Miami, FL
R. J. DYBAS, Consultant; Schenectady, NY
J. M. GERKEN, Ph.D., Consultant; Chagrin Falls, OH
R. A. HUBER, Consultant; Oak Ridge, TN
L. G. KVIDAHL, Ingalls Shipbuilding; Pascagoula, MS
A. LESNEWICH, Ph.D., Welding and Metallurgical Consulting Services, Severna Park, MD
A. F. MANZ, Consultant, A. F. Manz Associates; Union, NJ
R. W. MESSLER, Jr., Ph.D., Associate Professor, Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy, NY
E. P. NIPPES, Ph.D., Consultant; Vineyard Haven, MA

An associate in the production of this book was ANNETTE O'BRIEN, who prepared the text and served as copy editor. The Editor is grateful to L. G. KVIDAHL for his final review of the text.

ROBERT L. O'BRIEN
Editor

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

Preface

Eighteenth Edition

This edition represents a major revision of this encyclopedia, changing its orientation to the authoritative information base of the American Welding Society, and providing access to its resources.

Welding technology becomes more complex with every passing year, and has expanded to an extent that defies containment between the covers of a book. This encyclopedia presents as much information as is practical, but it is impossible to provide an exhaustive report on every welding process, variation, application, technique or material involved in the welding industry.

The Editor hopes Jefferson's Welding Encyclopedia will be a helpful resource to those who need authoritative welding information at their fingertips, and that it will be an effective starting point for those pursuing further scientific or engineering information. Following are some significant additions to the Eighteenth Edition:

Welding terms and definitions standardized by the American Welding Society are presented dictionary-style throughout the encyclopedia. They are identified by reference to Standard Welding Terms. Standard definitions are printed in italics.

Consensus standards, codes, specifications, recommended practices, classifications, methods, and guides for welding processes and applications documented by AWS are appropriately referenced. Standards of related organizations are referenced when applicable.

U.S. customary units are converted to the International System of Units (SI); conversion figures are appropriate to the application.

Nineteen appendixes have been included; most of these supply technical information from major American Welding Society documents. Appendix 1 contains historical notes of interest to the welding community.

A buyer's guide is provided; companies or organizations listed were exhibitors at the 1996 AWS International Welding and Fabricating Exposition in Chicago.

The primary editorial effort is directed to presenting new and updated material, although some of the basics of early welding processes are retained from previous editions, and much of the instructional material remains. An effort is made to meet the needs of persons associated with various areas of welding, and persons at many levels of expertise who are working with available equipment, old or new.

Most of the information available to the welding industry, and in this book, is the result of a continuous sharing of information involving every sector of the industry and spanning several generations. Contributors include research and development groups from manufacturers of welding equipment and consumables, universities, fabricators and job shops, as well as individual welders. All who are involved in the welding industry are grateful to those who have contributed and those who are continuing to develop and share technology. In that same spirit, we welcome comments, as well as contributions of further information.

ROBERT L. O'BRIEN
Editor

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

Guide to Using the Encyclopedia

The definition of an entry is presented in dictionary style. Terms and definitions standardized by the American Welding Society (AWS) are presented throughout the encyclopedia. Each AWS standard term is identified by reference to STANDARD WELDING TERMS. AWS standard definitions are printed in italics.

To find a specific consensus standard, code, specification, recommended practice, classification, method, or guide documented by AWS, refer to Appendix 16, Standards for Welding, Cutting, and Allied Processes. Refer also to the process, application, material or product involved. For example, to find standards or codes covering boilers, see BOILER CONSTRUCTION, as well as Appendix 16. To find AWS filler metal specifications, consult Appendix 17.

U.S. customary units are converted to the International System of Units (SI); conversion figures are appropriate to the application. For example, a postweld heat treat temperature of 1200°F converts exactly to 648.88°C, but the decimal figures are not meaningful. Therefore, the SI temperature is rounded off to 650°C. In critical cases, however, such as the melting point of an element or compound, the exact temperature in both scales is presented.

Appendixes 4 through 9, and Appendixes 11 and 12 have been designed to provide specific technical information about welds that is easy to find by consulting the appropriate appendix.

Welding and related processes are described in separate entries, for example, gas metal arc welding, laser beam welding, thermal spraying, or oxyfuel cutting. Refer also to the metal involved in a given project. Additional process information specific to the metal involved has been added to discussions under entries such as aluminum, cast iron, nickel, magnesium, and steel.

To use the Buyer's Guide, consult the product category, then refer to the alphabetical list of manufacturers and suppliers for a specific address, telephone or fax number. The Buyer's Guide is not all-inclusive; companies or organizations listed were exhibitors at the 1996 AWS International Welding and Fabricating Exposition in Chicago.

Documents
Document Sharing Hub

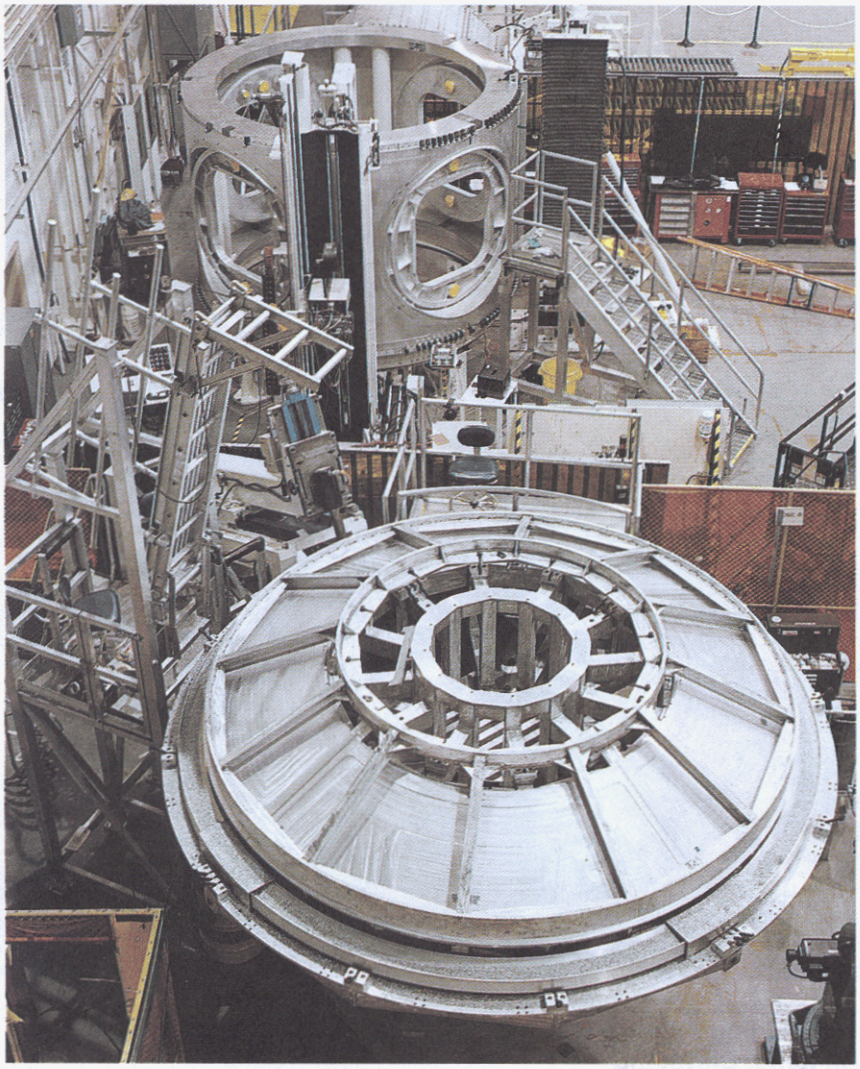
Full document details: JWE-1997 scan



Structural Steel Welding Application
BP America Building, Cleveland

AVA Documents
Document Sharing Hub

Full document details: JWE-1997 scan



Vertical welding on Node 1, the first United States element of the International Space Station, at NASA's Marshall Space Center, Huntsville, Alabama

Documents
Document Sharing Hub

Full document details: JWE-1997 scan

A

ABNORMAL GRAIN GROWTH

The formation of unusually large polycrystalline grains in a metal. This condition frequently occurs when a critical amount of strain (in the range of 2%) is present during heating to elevated temperatures.

ABRASION

A grinding action caused by abrasive solids sliding, rolling or rubbing against a surface; a scraped, ground, or worn area. Base plates are sometimes hardfaced to provide abrasion, or wear, resistance.

ABRASION SOLDERING

A soldering process variation during which the faying surface of the base metal is mechanically abraded. See STANDARD WELDING TERMS.

ABRASIVE

See GRINDING MATERIALS.

ABRASIVE BELT

A cloth or paper belt coated with abrasives used to rub, grind, or wear away by friction. The abrasive coating material may be sand or Carborundum, available in various grades and hardness factors.

ABRASIVE BELT GRINDER

A grinder which uses an abrasive belt for the removal of surplus material.

ABRASIVE BLASTING

A method of cleaning or surface roughening by a forcibly projected stream of abrasive particles. See STANDARD WELDING TERMS.

ABSORPTIONMETER

An instrument for measuring absorption of gases by liquids.

ABSORPTION BANDS

Dark bands in a spectrum produced by the selective absorption of light. The absorbing media are generally solids or liquids through which the light of the spectrum has been transmitted.

ABSORPTIVE LENS

A filter lens designed to attenuate the effects of glare and reflected and stray light. See STANDARD WELDING TERMS. *See also* FILTER PLATE.

AC or A-C

Abbreviation for alternating current. It is written *ac* when used as a noun and written as *a-c* when used as an adjective.

A-C ARC WELDING

An arc welding process using a power source that supplies an alternating current to the welding arc.

ACCELERATING POTENTIAL, Electron Beam Welding and Cutting

The potential that imparts velocity to electrons. See STANDARD WELDING TERMS.

ACCEPTABLE WELD

A weld that meets the applicable requirements. See STANDARD WELDING TERMS.

ACETONE

(C_3H_6O) A compound of carbon, hydrogen and oxygen; it is a volatile, flammable, liquid ketone used mainly as a solvent for such materials as resins, gums, oils, and cellulose.

Acetone is odorless and colorless; it evaporates rapidly. Acetone boils at 56°C (133°F). One liter of acetone weighs about 1 kg.

An important use for acetone is to stabilize acetylene gas. The safe, practical use of acetylene gas for welding and other applications would not be possible without acetone. Compressed acetylene itself is highly explosive; however, it can be safely compressed and stored in high-pressure cylinders if the cylinders are lined with absorbent material soaked with acetone. As a solvent agent for acetylene gas, acetone has an absorptive capacity of 25 volumes of acetylene per volume of acetone per atmosphere of pressure, or about 420 volumes of acetylene at 1724 kPa (250 psi) pressure.

Another important feature of the acetone-acetylene solution is that the exothermic properties of the

AVA Documents
Document Sharing Hub
Full document details: JWE-1997 scan

acetone counteract the endothermic properties of the acetylene; consequently, the acetone-acetylene solution is, to a certain extent, immune from a complete dissociation in case an ignition or explosion is introduced into it. *See* ACETYLENE CYLINDERS.

ACETYLENE

Acetylene, a hydrocarbon (C_2H_2), is a colorless, flammable gas shipped dissolved in a solvent. It has a garlic-like odor. Acetylene is rated as a simple asphyxiant (ACGHI 1994–95). Users are cautioned not to discharge acetylene at pressures exceeding 103 kPa (15 psig), as noted by the red line on acetylene pressure gauges. Other specifications of acetylene are:

Molecular weight: 26.038

Specific Gravity (Air = 1): 0.91 at 0°C (32°F)

Specific Volume: 0.09 m^3/kg at 15.6°C (14.5 ft^3/lb at 60°F)

Critical Temperature: 35.2°C (95.3°F)

Critical Pressure: 6139.3 kPa (890.4 psia)

Acetylene is said to have an endothermic quality because it absorbs heat in formation and liberates it during combustion. In this respect, acetylene differs from most hydrocarbons: they are exothermic and give off heat during formation.

As a fuel gas, acetylene generates 1433 Btu per cu ft; 277 are derived from hydrogen combustion, 928 Btu result from the combustion of carbon into carbon dioxide, and 228 Btu result from its endothermic quality.

Chemical Characteristics

The chemical structure of acetylene is given in the formula C_2H_2, showing that two atoms of carbon (atomic weight 12) are combined with two atoms of hydrogen (atomic weight 1.008), which can be expressed as 92.3% carbon and 7.7% hydrogen. The nearest gaseous hydrocarbon is ethylene (C_2H_4), which consists of 85% carbon and 15% hydrogen.

Acetylene contains the highest percentage of carbon of all the gaseous hydrocarbons and is the only one of the unsaturated hydrocarbons with endothermic properties (viz: absorbs heat during its production, and liberates heat when it is decomposed). Because of these characteristics, the oxyacetylene flame creates intense heat. The theoretical maximum for the oxyacetylene flame is 4359°C (7878°F), although the working temperature is about 3316°C (6000°F). The temperature of the oxyacetylene flame cannot be approached by any other gas, and is only exceeded by the heat produced in the electric arc or electron beam and laser processes.

Metalworking with Acetylene

Acetylene is usually combined with oxygen to intensify the heat of the acetylene flame for welding. It can also be combined with air, but with a much lower flame temperature. The principal application for the air-acetylene mixture is in soldering operations.

Mixed in equal amounts and burned at the tip of a welding torch, oxygen and acetylene create the so-called neutral flame. This flame can be identified by the luminous, well-defined white cone at the torch tip, and by a fairly long, almost colorless outer envelope that is blue or orange at its leading edge. See Figure A-1. The neutral flame is the correct flame with which to weld many metals. *See* OXYACETYLENE FLAME.

If excess oxygen is fed into the torch, an oxidizing flame results. This flame is characterized by a short inner cone and a short outer envelope. The flame is hotter than a neutral flame, burning acetylene at the same rate.

When this situation is reversed and an excess of acetylene is used, the resulting flame is termed *carburizing*. This flame appears as a greenish feather-shaped form between the inner cone and outer envelope. There are white-hot carbon particles in this feather which are dissolved to some extent in molten metal during welding.

Applications

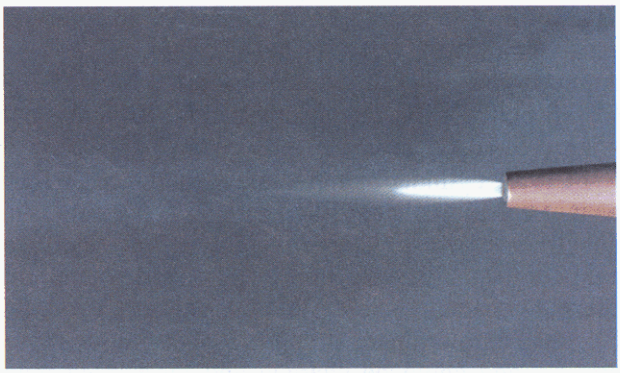
Because of its intense heat, and because it can be accurately controlled, the oxyacetylene flame can be applied to literally hundreds of welding and cutting operations, including hardfacing, brazing, beveling, gouging, and scarfing. The heating capability of acetylene is utilized extensively in bending, straightening, forming, hardening, softening, and strengthening many types of metals.

Historical Background

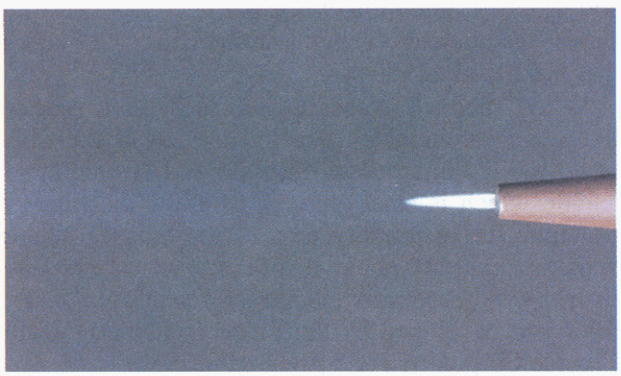
Acetylene gas was discovered by Edmund Davy in 1836, but it was not until 1862 when Woehler's discovery that acetylene gas could be produced from calcium carbide that the gas became well known. These developments were of little consequence, however, until 1892, when Thomas L. Wilson, of Spray, N. C., invented a process for producing calcium carbide and established facilities to produce it. He and James Morehead devised an economical commercial production method, and by 1895 acetylene gas was becoming recognized as a valuable gas for lighting.

AVA Documents Document Sharing Hub

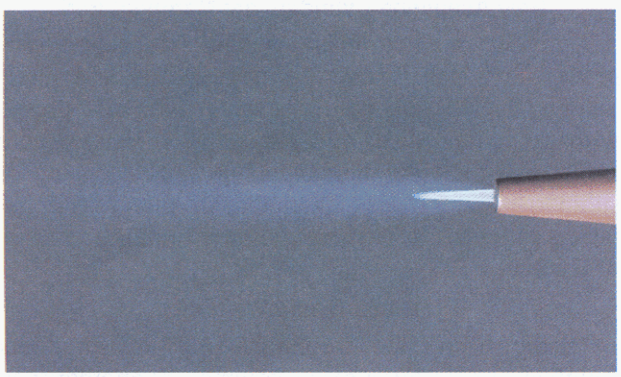
Full document details: JWE-1997 scan



(A) Carburizing



(B) Neutral



(C) Oxidizing

Figure A-1—Types of Oxyacetylene Flames

However, acetylene producers' hopes for widespread use of acetylene for illumination of streets and buildings were dashed by the growing use of incandescent lamps. Acetylene's potential in metalworking became apparent in World War I, when welding was adopted as the most effective and expedient method of constructing and repairing war ships and merchant vessels.

Producing Acetylene

Acetylene is produced either in generators, by the reaction of calcium carbide and water, or by the cracking of hydrocarbons in a chemical plant.

In the generator method, water is allowed to react with calcium carbide (CaC_2), a chemical compound produced by fusing lime and coke in an electric furnace. The reaction between water and carbide is instantaneous, and as a result, the carbon in the carbide combines with the hydrogen in the water, forming acetylene, while the calcium combines with the oxygen and water, forming slaked lime, or calcium hydrate.

There are two methods of generating acetylene: (1) carbide-to-water, and (2) water-to-carbide. The carbide-to-water method is generally used in the United States, while the water-to-carbide method is favored to a large extent in Europe.

A carbide-to-water generator operates on a "batch" basis, with a ratio of one gallon (8.3 lb) of water to one pound of carbide. This mixture is designed, in some generator models, to produce one cubic foot of acetylene per hour per pound of carbide hopper capacity. Some stationary generators are "double-rated" for capacities of 2 ft^3/hr per pound of carbide hopper capacity.

There are two further classifications for acetylene generators: low pressure and medium pressure. The low-pressure generator carries out the calcium carbide-to-water reaction process at pressures below 7 kPa (1 psi). A medium-pressure generator produces acetylene at between 7 and 103 kPa (1 and 15 psi).

Calcium carbide used for acetylene generation in the U. S. normally produces gas containing less than 0.4% impurities other than water vapor. Because of this favorable factor, there is no need for further purification of acetylene used for welding and cutting.

The welding supply distributor receives and resells acetylene in its most common form: dissolved in acetone and compressed in cylinders. These rugged acetylene cylinders have nominal capacities of 0.28, 1.1, 2.8, 6.4, or 8.5 m^3 (10, 40, 100, 225 or 300 cu ft) and hold the gas at a pressure of 1724 kPa (250 psi). See

Documents Document Sharing Hub

Full document details: JWE-1997 scan

ACETYLENE CYLINDERS, ACETYLENE CYLINDERS, Safe Handling, *and* ACETYLENE GENERATORS.

ACETYLENE CUTTING

See OXYFUEL GAS CUTTING.

ACETYLENE CYLINDERS

Because of the characteristics of acetylene gas, acetylene cylinders are constructed in an entirely different manner from those made to contain other gases.

Historical Background

Until 1904, no suitable acetylene container had been developed. The gas was used mainly for illumination and was generally piped directly from generators to the area to be served. In that year in Indiana, P. C. Avery displayed to two of his home state's most famous promoters, James Allison and Carl Fisher, a portable cylinder containing acetylene gas designed to power auto headlights. Then engaged in auto sales, Allison and Fisher were immediately interested, and with Avery, set up a small factory in Indianapolis to fabricate this "tank."

The shop was known as Concentrated Acetylene Company, until Avery withdrew in 1906. The company then became the Prest-O-Lite Company, the forerunner of the Linde Division of Union Carbide Corporation.

Allison and Fisher devoted much of their time relocating their plant into progressively larger quarters. Not until 1910 did they build one of sufficient size in what was then suburban Indianapolis, across the street from the site of the famed motor speedway they later constructed.

Carbide production continued to increase, and in 1913, a much improved acetylene cylinder similar to that used today was introduced. With these two major achievements, gas welding began replacing other metal joining methods.

Cylinder Stabilizing Fillers

The need for a porous substance in a cylinder to stabilize compressed acetylene was realized by the French scientist Fouche, one of the men responsible for the oxyacetylene mixture. The size of the filler, however, left very little room for gas in the cylinder. One filler was a magnesium oxychloride cement type; another was made of asbestos discs. The charcoal-cement filler was not developed until 1919, and in 1950 a sand-lime material became popular.

In 1897 a French team, Claude and Hess, demonstrated the value of acetone. This colorless, flammable liquid, when added to the porous material, is capable of absorbing 25 times its own volume of acetylene for each atmosphere 101 kPa (14.7 psi) of pressure applied. Thus, at full cylinder pressure of 1724 kPa (250 psi at 70°F), it can absorb over 400 times its own volume of acetylene.

In 1958, cylinder manufacturers announced a lightweight calcium-silicate filler with 92% porosity. This new filler lessened cylinder weight by 30%, increased cylinder capacity, and improved charging and discharging characteristics. Although only 8% solid, this filler had extraordinary strength, longer life, no deterioration, and could be charged and discharged much faster.

The calcium silicate filler, composed of sand, lime and asbestos, lined the cylinder and conformed to its shape. Its crushing strength, an indication of cylinder life, is 6205 kPa (900 psi).

When medical research indicated that asbestos fibers are carcinogenic due to the size of the fibers (less than 3.5 microns in diameter and 10 microns in length, which is small enough to allow the fibers to penetrate the respiratory tract of the lungs), cylinder manufacturers set about to produce an asbestos-free filler. A non-asbestos alkaline-resistant glass fiber filler was developed by the Linde Division of Union Carbide Corporation and patented in 1982.

A cut-away view of a modern acetylene cylinder is shown in Figure A-2.

How Acetylene Cylinders are Manufactured

Cylinder production and testing is a step-by-step procedure which insures ultimate quality and safety. Seamless shells are cold drawn in hydraulic presses with capacities up to 454 000 kg (500 tons). Center seams and footring attachments are welded using the submerged arc process. Cylinders are then normalized (stress relieved) to increase cylinder life and corrosion resistance.

Measure and Weight

In the filling area, cylinders are measured and weighed to determine exact volume. At another location, filler is mixed to correct proportions in hoppers, weighed, and mixed with water in agitators. Before each new batch of filler is used, a sample containing one cubic foot is weighed and examined to ensure correct mixture.

Cylinders are then filled automatically and weighed again. Factoring in the weight and volume of the cylinder confirms that it is accurately filled to specification. The cylinders are then oven-baked at 315°C (600°F) to

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

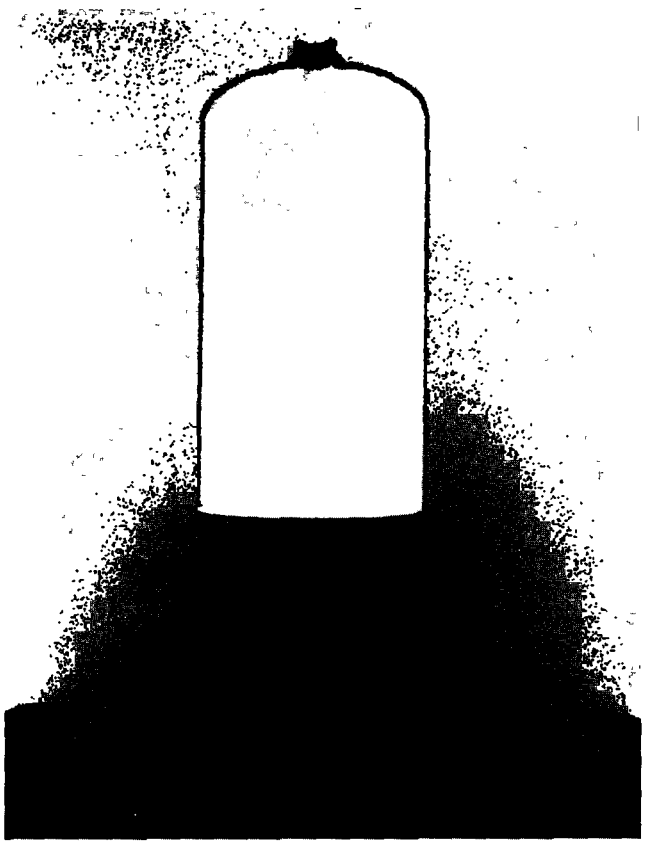


Figure A-2—Cross Section of an Acetylene Cylinder Showing the Filler Material

Photo courtesy of Norris Cylinder Company

eliminate the water. Baking time ranges from 40 to 120 hours, depending on cylinder size. After baking, another weight check is made to determine if any water remains. Since 1% moisture in the filler will affect ultimate performance, cylinders are baked again if only a slight moisture content is detected.

Fuse plugs and valves are installed, and cylinders are shot-blasted and painted. (Fuse plugs are small steel machine bolts with holes filled with a low-melting alloy designed to release gas in case of fire, and to lessen the acetylene pressure to reduce the possibility of an explosion).

Finally, strength proof tests at 4140 kPa (600 psi) are run. Pressure is then reduced to 2070 kPa (300 psi), and the cylinders are immersed in water to check for leaks. Drawn to a vacuum, they are charged with acetone and weighed again to determine if they are fully charged.

Cylinders are checked after each procedure during the manufacturing process. Those not meeting the rigid requirements of federal law and company rules are rejected regardless of the stage of manufacture. For example, a number of cylinders are selected from each completed lot, charged with acetylene, and tested to ensure proper discharge. If the cylinders do not meet specifications, the entire lot is rejected.

Basic Tests

A *bonfire test* is designed to check cylinder performance under conditions similar to a fire in a building. A fully charged cylinder is placed horizontally on racks, and specified sizes and amounts of wood strips are ignited around it. The cylinder passes the test if there is no appreciable shell bulge, no penetration of filler by decomposition, and no breakup of the filler.

The *flashback test* simulates torch flashback entering the cylinder, assumed to be at full pressure when the operator closes the valve immediately afterward. If the flash is immediately quenched in the cylinder with only a minimum of decomposition and without release of fusible plugs, the cylinder passes the test.

A *hot spot test* simulates negligent impinging of a torch flame against the cylinder. Flame is directed at the cylinder sidewall until a 3 to 20 mm (1/8 to 3/4 in.) bulge develops. If filler decomposition is limited to the area closely adjacent to the resulting cavity, performance is satisfactory.

The *bump test* determines the filler's resistance to mechanical shock received during normal service. The cylinder is mounted on a foundry mold-bumper and subjected to minimum 200 000 bumping cycles. At the conclusion of the test, satisfactory performance is indicated when there is no attrition, sagging, or cracking of the filler.

ACETYLENE CYLINDERS, Safe Handling

At ambient conditions, increased pressure and decreased temperature can liquefy acetylene. At extremely low temperatures, acetylene can solidify. The danger at the point of liquefaction or solidification (and the major reason why acetylene cannot be distributed in this form) is that the necessarily high pressures create a very unstable product. At the slightest provocation, compressed acetylene will dissociate into its chemical components, carbon and hydrogen. This dissociation is accompanied by drastic increases in both temperature and pressure, and results in an explosion.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

The acetylene distributor, as well as the user, must observe important precautions:

(1) Slings, hooks or magnets cannot be used to move cylinders. Cylinders of acetylene must be kept in an upright position. Cylinders cannot be dragged, and can never be used or stored in a horizontal position.

(2) A hand truck should be used when an acetylene cylinder must be moved, or the cylinder should be tilted slightly and rolled it on its bottom edge.

(3) A cylinder storage area should be chosen that is well removed from any heat sources, and the area should be posted with conspicuous signs forbidding smoking or the use of open flames or lights.

(4) If cylinders are stored outdoors, dirt, snow or ice should not be allowed to accumulate on valves or safety devices.

(5) The cylinders should be secured with chains or heavy rope so that they cannot be accidentally tipped over.

(6) A leaking cylinder must be handled with extreme care; it should be removed immediately from the storage area after checking to be sure that no sources of ignition are brought near it. The supplier should be notified immediately.

(7) One cylinder should not be recharged from another, or other gases mixed in an acetylene cylinder.

(8) Copper tubing should never be used to convey acetylene. Acetylene will react with the copper to form copper acetylide, an unstable compound which can explode spontaneously.

ACETYLENE FEATHER

The intense white, feathery-edged portion adjacent to the cone of a carburizing oxyacetylene flame. See STANDARD WELDING TERMS. *See also* Figure A-1.

ACETYLENE GENERATOR

In the United States, common practice has established a preference for the carbide-to-water machines, and they are almost universally used. There is another type of generator using calcium carbide molded into cakes, in which the water drops into the calcium carbide. This type of generator, while common in Europe, is almost unknown in the United States.

Insurance Regulations

The Underwriters' Laboratories is an organization maintained by the insurance companies of the United States which provides for the inspection and testing of all types of equipment which may be considered a fire or accident hazard, including welding and cutting equipment and acetylene generators. There are established sets of rules governing the design, construction, and installation of acetylene generators, including acetylene pipe lines.

Another insurance authority which publishes rules for acetylene generators is the Factory Mutual Engineering Organization, Norwood, Mass. Regulations of the American Insurance Service Group, New York, N.Y. and the National Fire Protection Association, Quincy, Mass. are also followed. See GAS SYSTEMS.

ACETYLENE WELDING

See OXYACETYLENE WELDING *and* OXYFUEL GAS WELDING.

ACID BRITTLENESS

Brittleness induced in steel, especially wire or sheet, by pickling in dilute acid for the purpose of removing scale. This brittleness is commonly attributed to the absorption of hydrogen.

ACID CORE SOLDER

A solder wire or bar containing acid flux as a core. See STANDARD WELDING TERMS.

ACID STEEL

See STEEL, ACID.

ACTIVATED ROSIN FLUX

A rosin base flux containing an additive that increases wetting by the solder. See STANDARD WELDING TERMS.

ACTIVE FLUX, Submerged Arc Welding

A flux from which the amount of elements deposited in the weld metal is dependent on the welding conditions, primarily on the arc voltage. See STANDARD WELDING TERMS. *See also* NEUTRAL FLUX.

ACTUAL THROAT

The shortest distance between the weld root and the face of a fillet weld. See STANDARD WELDING TERMS. See Appendix 11, Figure A, B. *See also* THROAT OF A FILLET WELD, EFFECTIVE THROAT, *and* THEORETICAL THROAT.

ADAMS, COMFORT A.

Founder and first president of the American Welding Society.

ADAPTER

A device for connecting two parts (i.e., of different diameters) of an apparatus, or for adapting apparatus

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

for uses not originally intended. An adapter is sometimes used to connect a regulator to a tank which has a valve threaded differently from the inlet connection of the regulator. **This practice is not recommended.**

ADAPTIVE CONTROL

Pertaining to process control that automatically determines changes in process conditions and directs the equipment to take appropriate action. See STANDARD WELDING TERMS. *See also* AUTOMATIC WELDING, MANUAL WELDING, MECHANIZED WELDING, ROBOTIC WELDING, *and* SEMIAUTOMATIC WELDING.

ADAPTIVE CONTROL BRAZING.

See STANDARD WELDING TERMS. *See also* ADAPTIVE CONTROL WELDING.

ADAPTIVE CONTROL SOLDERING

See STANDARD WELDING TERMS. *See also* ADAPTIVE CONTROL WELDING.

ADAPTIVE CONTROL THERMAL CUTTING

See STANDARD WELDING TERMS. *See also* ADAPTIVE CONTROL WELDING.

ADAPTIVE CONTROL THERMAL SPRAYING

See STANDARD WELDING TERMS. *See also* ADAPTIVE CONTROL WELDING.

ADAPTIVE CONTROL WELDING

Welding with a process control system that automatically determines changes in welding conditions and directs the equipment to take appropriate action. Variations of this term are adaptive control brazing, adaptive control soldering, adaptive control thermal cutting, and adaptive control thermal spraying. See STANDARD WELDING TERMS.

Adaptive (feedback) control systems are automatic welding systems which make corrections to welding variables based on information gathered during welding. The objective is to maintain weld quality at a constant level in the presence of changing welding conditions. Automatic adjustment of individual weld variables, such as arc current or arc length, is made by monitoring a weld characteristic, such as pool width. Other feedback control systems are available to provide electrode guidance and constant joint fill. *See also* AUTOMATIC WELDING, MANUAL WELDING, MECHANIZED WELDING, ROBOTIC WELDING, *and* SEMIAUTOMATIC WELDING.

ADDED METAL

A term sometimes used to describe the metal added to the base metal during arc, gas, or thermite welding.

ADHESIVE BONDING

Adhesive bonding is a materials joining process in which a nonmetallic adhesive material is placed between the faying surfaces of the parts or bodies, called *adherends*. The adhesive then solidifies or hardens by physical or chemical property changes to produce a bonded joint with useful strength between the adherends.

Adhesive is a general term that includes such materials as cement, glue, mucilage, and paste. (Terms relating to adhesives are defined in ANSI/ASTM D907.) Although natural organic and inorganic adhesives are available, synthetic organic polymers are usually used to join metal assemblies. Various descriptive adjectives are applied to the term adhesive to indicate certain characteristics, as follows:

(1) Physical form: liquid adhesive, tape adhesive

(2) Chemical type: silicate adhesive, epoxy adhesive, phenolic adhesive

(3) Materials bonded: paper adhesive, metal-plastic adhesive, can labeling adhesive

(4) Application method: hot-setting adhesive, sprayable adhesive.

Although adhesive bonding is used to join many nonmetallic materials, the following paragraphs refer only to the bonding of metals to themselves or to nonmetallic structural materials.

Adhesive bonding is similar to soldering and brazing of metals in some respects, but a metallurgical bond does not take place. The surfaces being joined are not melted, although they may be heated. An adhesive in the form of a liquid, paste, or tacky solid is placed between the faying surfaces of the joint. After the faying surfaces are mated with the adhesive in between, heat or pressure, or both, are applied to accomplish the bond.

An adhesive system must have the following characteristics:

(1) At the time the bond is formed, the adhesive must become fluid so that it wets and comes into close contact with the surface of the metal adherends.

(2) In general, the adhesive cures, cools, dries, or otherwise hardens during the time the bond is formed or soon thereafter.

(3) The adhesive must have good mutual attraction with the metal surfaces, and have adequate strength

AWS Documents Document Sharing Hub

Full document details: JWE-1997 scan

and toughness to resist failure along the adhesive-to-metal interface under service conditions.

(4) As the adhesive cures, cools, or dries, it must not shrink excessively. Otherwise, undesirable internal stresses may develop in the joint.

(5) To develop a strong bond, the metal surfaces must be clean and free of dust, loose oxides, oil, grease, or other foreign materials.

(6) Air, moisture, solvents, and other gases which may tend to be trapped at the interface between the adhesive and metal must have a way of escaping from the joint.

(7) The joint design and cured adhesive must be suitable to withstand the intended service.

A variety of adhesives can be used. Thermoplastic adhesives develop a bond through the evaporation of a solvent or the application of heat. The pressure-sensitive adhesives produce a bond when pressure is applied to the joint. Other adhesives, usually used for metals, react chemically with curing agents or catalysts. Some epoxy-based adhesives can produce joint strengths up to 70 MPa (10 000 psi) when cured at 175°C (350°F) for a few hours under pressures of about 1030 kPa (150 psi). The types of polymeric adhesives used to bond metal are listed in Table A-1.

Table A-1
Types of Polymeric Adhesives Used to Bond Metals

Solvent	Neoprene Nitrile Urethane (thermoplastic) Block copolymer Styrene-butadiene
Hot Melt	Ethylene vinyl acetate Block copolymer Polyester Polyamide
Pressure Sensitive	Block copolymer Acrylic
Chemically Reactive	Epoxy Phenolic Structural acrylic Anaerobic Cyanoacrylate Urethane

Advantages and Applications

Adhesive bonding has several advantages for joining metals when compared to resistance spot welding, brazing, soldering, or mechanical fasteners such as rivets or screws. Adhesive bonding is also capable of joining dissimilar materials, for example, metals to plastics; bonding very thin sections without distortion and very thin sections to thick sections; joining heat-sensitive alloys; and producing bonds with unbroken surface contours.

The adhesive that bonds the component may serve as a sealant or protective coating. Adhesives can provide thermal or electrical insulating layers between the two surfaces being joined, and different formulations of the adhesive can make the bonding agent electrically conductive. These properties are highly adaptable to mass-produced printed circuit boards, and to the electrical and electronic components industry.

Smooth, unbroken surfaces without protrusions, gaps, or holes can be achieved with adhesive bonding. Typical examples of applications are the vinyl-to-metal laminate used in the production of television cabinets and housings for electronic equipment. Other examples are automotive trim, hood and door panels, and roof stiffeners.

The ability of flexible adhesives to absorb shock and vibration gives the joint good fatigue life and sound-dampening properties. A specific example is the improved fatigue life of adhesive-bonded helicopter rotor blades.

A combination of adhesives and rivets for joints in very large aircraft structures has increased the fatigue life of joints from 2×10^5 cycles for rivets alone to 1.5×10^6 cycles for bonded and riveted joints. The large bonded area also dampens vibration and sound.

Adhesive bonding may be combined with resistance welding or mechanical fasteners to improve the load-carrying capacity of the joint. The adhesive is applied to the adherents first. Then the components are joined together with spot welds or mechanical fasteners to hold the joints rigid while the adhesive cures. Figure A-3 illustrates typical design combinations. These techniques significantly reduce or eliminate fixturing requirements and decrease assembly time when compared to conventional adhesive bonding methods.

Adhesive bonding may permit significant weight savings in the finished product by utilizing lightweight fabrications. Honeycomb panel assemblies, used extensively in the aircraft industry and the construction field are excellent examples of lightweight fabrications. Although weight reduction can be important in the function of the product, adhesive bonding of products may also provide considerable labor and cost savings in packing, shipping and installation.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

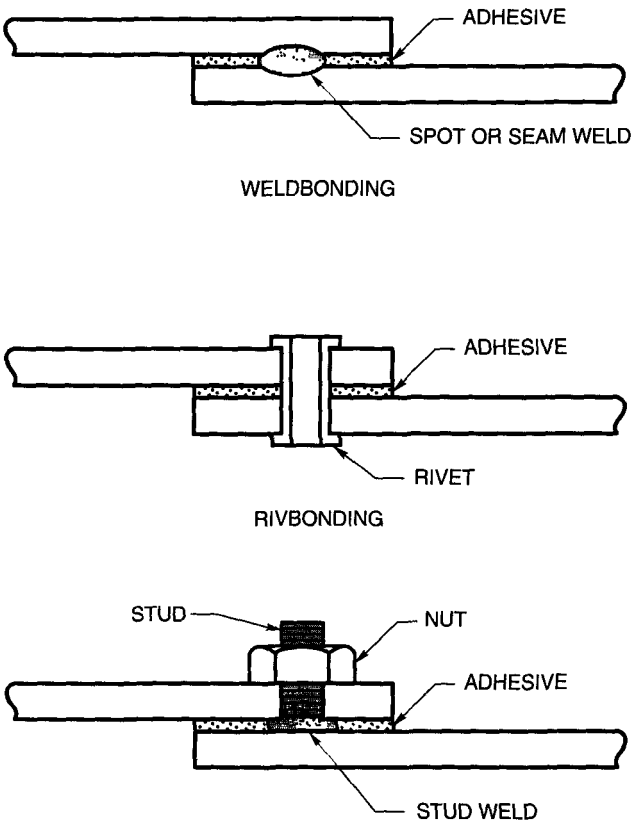


Figure A-3—Adhesive Bonding in Combination with Resistance Welds and Mechanical Fasteners

Limitations

Adhesive bonding has certain limitations which should be considered in its application. Joints made by adhesive bonding may not support shear or impact loads.These joints must have an adhesive layer less than 0.13 mm (0.005 in.) thick, and must be designed to develop a uniform load distribution in pure shear or tension. The joints cannot sustain operational temperatures exceeding 260°C (500°F).

Capital investment for autoclaves, presses, and other tooling is essential to achieve adequate bond strengths. Process control costs may be higher than those for other joining processes. In critical structural bonding applications, surface preparation can range from a simple solvent wipe to multi-step cleaning, etching, anodizing, rinsing and drying procedures; and joints must be fixtured and cured at temperature for some time to achieve full bond strength. Some adhesives must be used quickly after mixing. Nondestructive testing methods normally used for other joining methods are not generally applicable to evaluation of adhesive bonds. Both destructive and nondestructive testing must be used with process controls to establish the quality and reliability of bonded joints.

Service conditions may be restrictive. Many adhesive systems degrade rapidly when the joint is both highly stressed and exposed to a hot, humid environment.

Safe Practices

Corrosive materials, flammable liquids, and toxic substances are commonly used in adhesive bonding. Manufacturing operations should be carefully supervised to ensure that proper safety procedures, protective devices, and protective clothing are being used. All federal, state and local regulations should be complied with, including OSHA Regulation 29CRF 1900.1000, Air Contaminants. The material safety data sheet of the adhesive should be carefully examined before the adhesive is handled to ensure that the appropriate safety precautions are being followed.

References: American Welding Society. *Welding Handbook*, 8th Edition, Vol.1. Miami, Florida: American Welding Society, 1987; and American Welding Society. *Welding Handbook,* 8th Edition, Vol. 2. Miami, Florida: American Welding Society, 1991.

ADMIRALTY BRASS

An alloy which is 70% copper, 29% zinc and 1% tin, commonly used for condenser and heat exchanger tubing. *See* COPPER ALLOY WELDING.

AGE HARDENING

A term applied to a property exhibited by some of the light alloys, such as aluminum or magnesium, of hardening at ordinary temperatures after solution treatment or cold work. The controlling factors in age hardening are the composition of the material, degree of dispersion of the soluble phase, solution time and temperature, and aging time and temperature.

AGGLOMERATED FLUX, Submerged Arc Welding

A type of flux produced with a ceramic binding agent requiring a higher drying temperature that limits the addition of deoxidizers and alloying elements. This is followed by processing to produce the desired particle size. See STANDARD WELDING TERMS.

AGING

A term applied to metals and particular alloys which show changes in physical properties on exposure to ordinary or elevated temperatures.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

AGRICULTURAL WELDING

See FARM IMPLEMENT REPAIR.

AIR-ACETYLENE TORCH

A torch which produces a flame by burning a mixture of acetylene and air. The flame is as easily controlled and manipulated as the oxyacetylene flame, but has a lower temperature.

The air-acetylene torch operates on the same principle as the Bunsen burner, that is, the acetylene flowing under pressure through a Bunsen jet draws in the appropriate amount of air from the atmosphere to provide combustion. The flame is adjusted by controlling the amount of air admitted to the Bunsen jet. The mixer on the torch must be carefully adjusted to draw the correct volume of air to produce an efficient, clean flame. The air-acetylene flame ignites at 480°C (896°F) and produces a maximum temperature of 1875°C (3407°F).

The air-acetylene torch is used for brazing, soldering, and heating applications, but the flame temperature is not sufficient for welding, except for joining materials with a low melting point, like lead. It is widely used for soldering copper plumbing fittings up to 25 mm (10 in.) in diameter.

AIR ACETYLENE WELDING (AAW)

An oxyfuel gas welding process that uses an air-acetylene flame. The process is used without the application of pressure. This is an obsolete or seldom used process. See STANDARD WELDING TERMS.

AIR CAP

A nonstandard term for the nozzle of a flame spraying gun for wire or ceramic rod.

AIR CARBON ARC CUTTING (CAC-A)

A carbon arc cutting process variation that removes molten metal with a jet of air. See STANDARD WELDING TERMS.

The air carbon arc cutting process uses an arc to melt metal which is blown away by a high-velocity jet of compressed air. The electrodes are rods made from a mixture of graphite and carbon, and most are coated with a layer of copper to increase their current-carrying capacity. Standard welding power sources are used to provide the current. Air is supplied by conventional shop compressors, and most applications require about 550 kPa (80 psi) at between 560 to 840 liters/min (20 to 30 cubic feet per minute). Manual rod holders are very similar in appearance to shielded metal arc welding electrode holders, and supply both compressed air and current.

In gouging operations, the depth and contour of the groove are controlled by the electrode angle, travel speed, and current. Grooves up to 16 mm (5/8 in.) deep can be made in a single pass. In severing operations, the electrode is held at a steeper angle, and is directed at a point that will permit the tip of the electrode to pierce the metal being severed.

In manual work, the geometry of grooves is dependent on the cutting operator's skill. To provide uniform groove geometry, semiautomatic or fully automatic torches are used to cut "U" grooves in joints for welding. When removing weld defects or severing excess metal from castings, manual techniques are most suitable.

Voltage controlled automatic torches and control units are used for very precise gouging, with tolerances of less than 0.8 mm (1/32 in.), and are generally mounted on standard travel carriages.

Reference: American Welding Society. *Welding Handbook*, Vol. 2, 8th Edition. Miami, Florida: American Welding Society, 1991.

AIR CARBON ARC CUTTING TORCH

A device used to transfer current to a fixed cutting electrode, position the electrode, and direct the flow of air. See STANDARD WELDING TERMS.

AIRCRAFT WELDING

The character of welding changes in aircraft construction with each technological advancement that affects any aircraft component. Because the materials and joining techniques and processes utilized in the aircraft industry are constantly changing and improving, it is vital that the most recent standards and current literature on the subject be used for reference.

While airplanes were largely hand-made metallic structures in the past, only the lighter planes have the welded steel fuselage that was once popular. High-speed transports and military jets have a metallic skin to provide a monococque fuselage. Although rivets have been used to fasten the skin to the cell rings, spot welding also has an important role in the construction of this type of aircraft.

Welding is the method that has the versatility to meet the varying conditions of joining members of varying sizes and weights which make up aircraft structures. The aircraft structure, with its multiplicity of joints, must be light in weight and sufficiently strong to withstand severe conditions of service.

Documents Document Sharing Hub

Full document details: JWE-1997 scan

The welded joint offers rigidity, simplicity, low weight, approximately full-strength joints, low corrosion possibilities, and relatively low-cost production equipment. Because of these advantages, welding is used for building all classes of airplanes, from light two-place pleasure planes to giant supersonic jets.

Welded tubular structures form the framework for the landing gear and the engine mounts. Requirements of the jet engine have introduced many areas in which welding plays an important role.

Modern jet transports contain extremely high quality welds in the miles of duct work found in every jet plane. The welds are made by highly skilled gas tungsten arc welders in 5052 and 6061 aluminum, Inconel® 625 and 718 nickel-base alloys, and 6Al-4V titanium.

AIR CUSHION

A pneumatic pressure device, sometimes adjustable, incorporated in the air-operating mechanism of a resistance welding machine to provide a deceleration of a mechanical motion.

AIR FEED

A thermal spraying process variation in which an air stream carries the powdered surfacing material through the gun and into the heat source. See STANDARD WELDING TERMS.

ALIGNED DISCONTINUITIES

Three or more discontinuities aligned approximately parallel to the weld axis, spaced sufficiently close together to be considered a single intermittent discontinuity. See STANDARD WELDING TERMS.

ALIGNED POROSITY

A localized array of porosity oriented in a line. See STANDARD WELDING TERMS.

ALIGNMENT

Arrangement or position in line. To produce an accurate and serviceable weld when several parts are involved, an alignment jig is a necessity. *See* JIG, FIXTURE, *and* POSITIONER.

ALLOTROPY

The reversible phenomenon by which certain metals may exist with more than one crystal structure. For example, alpha, gamma and delta iron are three allotropic forms of iron with different crystal structures.

ALLOY

A substance with metallic properties and composed of two or more chemical elements of which at least one is a metal. See STANDARD WELDING TERMS.

The added element may be metallic or nonmetallic. *See also* STEEL, ALLOY; ALUMINUM ALLOYS; MONEL; COPPER ALLOY WELDING.

ALLOY POWDER

Powder prepared from a homogeneous molten alloy or from the solidification product of such an alloy. See STANDARD WELDING TERMS. *See also* POWDER BLEND.

ALLOY STEEL

See STEEL, ALLOY.

ALLOYING ELEMENTS

The chemical elements comprising an alloy. In steel it is usually limited to the metallic elements added to steel to modify its properties. For example, the addition of copper, nickel, or chromium individually or in combination produces alloys or special steels.

ALL-WELD-METAL TEST SPECIMEN

A test specimen in which the portion being tested is composed wholly of weld metal.

ALNICO ALLOYS

A series of alloys developed for use as permanent magnets. With the exception of Alnico III, all of these iron-base alloys contain aluminum, nickel, and cobalt as the principle alloying elements (as the name *Alnico* indicates). Most also contain 3% or 6% copper. Because these alloys are available only in the cast or sintered condition, they are difficult to fabricate by welding.

ALPHA BRASS

A copper-zinc alloy with a copper content greater than approximately 64%. "Yellow brass" is the name used in metallurgical literature.

ALPHA IRON

The body-centered cubic form of pure iron. *See* METALLURGY.

ALTERNATING CURRENT (ac or a-c)

(Abbreviation: ac, when used as a noun; a-c when used as an adjective). A current which reverses directions at regularly recurring intervals. Unless otherwise distinctly specified, the term alternating current refers

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

to a periodically varying current with successive half waves of the same shape and area.

ALTERNATING CURRENT ARC WELDING

An arc welding process in which the power supply provides alternating current to the arc.

ALUMINOTHERMIC PROCESS

A method of welding which makes use of the exothermic reaction which occurs when a mixture of aluminum and iron oxide powders is ignited. When ignited, this mixture produces superheated liquid steel and aluminum oxide slag at approximately 2760°C (5000°F). The liquid steel is sufficiently hot to melt and dissolve any metal with which it comes in contact and fuses with it to form a solid homogeneous mass when cooled. For this reason, this process is especially adapted to welding heavy steel and cast iron sections, such as those used in locomotive, marine, crankshaft and steel mill repairs, and is also used in pipe welding and rail welding. *See* THERMITE WELDING.

ALUMINUM

(Chemical symbol: Al). Aluminum is a silver-white, malleable, ductile, light, metallic element with good electrical and thermal conductivity, high reflectivity, and resistance to oxidation. Atomic weight, 26.97; melting point, 660°C (1220°F); specific gravity, 2.70 at 20°C (68°F).

Aluminum is one of the most abundant constituents of the earth's crust. It is found in most clays, soils and rocks, but the principal commercial source is the ore, bauxite, an impure hydrated oxide. The impurities are removed from bauxite by a chemical process leaving pure aluminum oxide, alumina. Pure metallic aluminum is obtained by electrolysis of the oxide.

Aluminum is third on the scale of malleability and fifth in ductility. It is only slightly magnetic and is strongly electro-positive, so that when in contact with most metals it corrodes rapidly. Aluminum will take a high polish, but it is likely to become "frosted" in appearance due to the formation of an oxide coating. Its electrical conductivity is about 60% that of copper.

Aluminum is used extensively as a deoxidizer in steel production, and as such it is an effective purifier. Aluminum lessens grain growth by forming dispersed oxides or nitrides.

ALUMINUM ALLOYS

Commercial aluminum alloys are grouped into two classifications: wrought alloys and cast alloys.

Wrought Alloys

Wrought alloys are those alloys which are designed for mill products for which final physical forms are obtained by mechanical working, such as rolling, forging, extruding and drawing. Wrought aluminum mill products include sheet, plate, wire, rod, bar, tube, pipe, forgings, angles, structural items, channels, and rolled and extruded shapes.

Cast Alloys

Cast alloys are those alloys which are shaped into final form by filling a mold with molten metal and allowing it to solidify in the mold.

Sand Casting. Sand casting utilizes a mold in sand made around a previously formed pattern to the exact shape desired in the final casting, but slightly larger in size to allow for shrinkage of the cast metal as it cools.

Permanent Mold Castings. Permanent mold castings are made by pouring molten metal into steel or iron molds.

Die Castings. Die castings are also made in steel molds, but the molten metal is forced under pressure into the die or mold cavities. Die casting yields a denser casting with a better surface finish, closer dimensional tolerances, and thinner sections when desired.

Clad Alloys

Clad alloys, which may be up to 5% of the total thickness on each side, yield a composite product which provides the high strength of the core alloy protected by the cladding.

Copper and zinc, when used as major alloying elements, reduce the overall resistance to corrosion of aluminum alloys. To gain the desired corrosion resistance in these alloys in sheet and plate form, they are clad with high purity aluminum, a low magnesium-silicon alloy, or an alloy of 1% zinc.

Wrought Alloy Designations

The Aluminum Association, an organization composed of manufacturers of aluminum and aluminum alloys, has devised a four-digit index system for designating wrought aluminum and wrought aluminum alloys. The first digit indicates the alloy group, i.e., the major alloying element, as shown in Table A-2. The second digit indicates a modification of the original alloy, or the impurity limit of unalloyed aluminum. The third and fourth digits identify the alloy or indicate the aluminum purity. *See* UNIFIED NUMBERING SYSTEM.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Table A-2
Aluminum Alloy Designations

Aluminum Alloy Group	Designation
Aluminum—99%	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium & Silicon	6xxx
Zinc	7xxx
Other Element	8xxx

Wrought Alloy Temper Designations

In this index system, the letter following the alloy designation and separated from it by a hyphen indicates the basic temper designation. The addition of a subsequent digit, when applicable, refers to the specific treatment used to attain this temper condition.

Alloys which are hardenable only by cold working are assigned "H" designations; alloys hardenable by heat treatment or by a combination of heat treatment and cold work are assigned "T" designations. Table A-3 shows the basic temper designations and resulting condition of the alloy.

Casting Alloy Designations

A system of four-digit numerical designations is used to identify aluminum casting alloys, as shown in Table A-4. The first digit indicates the alloy group, the second two digits identify the aluminum alloy within the group, and the last digit (which is separated from the first three by a period) indicates the product form. A modification of the original alloy or impurity limits is indicated by a letter before the numerical designation. The temper designation system for castings is the same as that for wrought product shown in Table A-3.

ALUMINUM BRAZING

In brazing, specific fluxes and filler materials with melting points lower than that of the parent metal are used for making a joint without melting the pieces to be joined. Brazing can be used to advantage when sections are too thin for welding, and for those assemblies having many parts which must be joined in an intricate manner. Brazing is generally lower in cost than gas or arc welding and is adaptable to mass production. Brazed joints have a smoother appearance, with well-rounded fillets which often require no finishing.

Brazed joints should be carefully designed to provide for full penetration of filler metal, because its flow depends largely on capillary action and gravity. Joints should be self-jigging for easy assembly prior to brazing. Lock seams, lap fillet, and T-joints are preferred because they have greater strength than butt or scarf joints.

Three commonly used aluminum brazing methods are furnace, molten flux dip, and torch.

Furnace Brazing

Furnace brazing consists of applying a flux and filler material to the workpieces, arranging them, then heating in a furnace to a temperature that causes the filler material to melt and flow into the joint without melting the parent metal. Filler material in various forms is added to the joint. In many cases, filler material in the form of a flat shim or wire ring can be fitted into the joint. Filler material is also supplied by using clad brazing sheet, shaped to fit the joint.

Standard types of furnace heating systems include forced air circulation, direct combustion, electrical resistance, controlled atmosphere, and radiant tube. The selection of furnace type is determined by the application requirements, as furnace operation and results vary. For example, temperature is most easily controlled in electrical resistance furnaces. Although combustion furnaces are least expensive, some assemblies cannot be exposed to the gases which are always present in this type. Radiant heat furnaces are sometimes difficult to regulate, but the type of heat produced is excellent for most brazing requirements. Aluminum-coated steel or firebrick linings are preferred for all types of heating units.

Rate of production is another consideration when selecting a heating unit. In batch furnaces, brazing is accomplished by placing a tray of assemblies inside, heating for the required time, then removing the batch. Though simpler, this furnace is slower than the furnace with a continuous conveying system in which the work moves through on a belt. The continuous furnace is more conservative of heat, and the gradual heating reduces danger of warping.

Temperature for individual batches will necessarily depend on such factors as the design of the parts, size of fillets, and alloy to be brazed. However, furnaces should have operating temperature ranges from 540 to 650°C (1000 to 1200°F), with control capability within ±3°C (5°F). Since regulation of temperature is critical, automatic control is the rule in production

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Table A-3
Basic Temper Designations Applicable to the Heat-Treatable Aluminum Alloys

Designation*	Description	Application
-0	Annealed	Applies to wrought products which are annealed to obtain the lowest strength temper, and to cast products which are annealed to improve ductility and dimensional stability. The 0 may be followed by a digit other than zero.
-F	As fabricated	Applies to products of shaping processes in which no special control over thermal conditions or strain hardening is employed. For wrought products, there are no mechanical property limits.
-W	Solution heat treated	An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat treatment. This designation is specific only when the period of natural aging is indicated; for example: W 1/2 hr.
-T1		Cooled from an elevated-temperature shaping process and naturally aged to a substantially stable condition. Applies to products which are not cold worked after cooling from an elevated-temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
-T2		Cooled from an elevated-temperature shaping process, cold worked, and naturally aged to a substantially stable condition. Applies to products which are cold worked to improve strength after cooling from an elevated-temperature shaping process, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
-T3		Solution heat treated, cold worked, and naturally aged to a substantially stable condition. Applies to products which are cold worked to improve strength after solution heat treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
-T4		Solution heat treated and naturally aged to a substantially stable condition. Applies to products which are not cold worked after solution heat treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
-T5		Cooled from an elevated-temperature shaping process and then artificially aged. Applies to products which are not cold worked after cooling from an elevated-temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
-T6		Solution heat treated and stabilized. Applies to products which are not cold worked after solution heat treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
-T7		Solution heat treated and stabilized. Applies to products which are stabilized after solution heat treatment to carry them beyond the point of maximum strength to provide control of some special characteristic.
-T8		Solution heat treated, cold worked, and then artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
-T9		Solution heat treated, artificially aged, and then cold worked. Applies to products which are cold worked to improve strength.
-T10		Cooled from an elevated-temperature shaping process, cold worked, and then artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

*Additional digits, the first of which shall not be zero, may be added to designation T1 through T10 to indicate a variation in treatment which significantly alters the characteristic of the product.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Table A-4
Designations for Cast Aluminum Alloy Groups

Alloy Group	Designation
Aluminum—99.00% minimum purity	1xx.x
Copper	2xx.x
Aluminum-silicon-copper or aluminum-silicon magnesium	3xx.x
Aluminum-silicon	4xx.x
Aluminum-magnesium	5xx.x
Aluminum-zinc	7xx.x
Aluminum-tin	8xx.x
Other alloy systems	9xx.x

jobs. If uniform rise of temperature does not occur naturally, forced circulation is essential.

Assemblies are generally placed in the furnace immediately after fluxing. When large areas have been fluxed, most of the moisture must be removed because the brazing process may be hindered if it is not removed. Preheating the parts for about 20 minutes at approximately 200°C (400°F) is usually sufficient.

Brazing time depends on the thickness of the parts. For instance, material 0.15 mm (0.006 in.) thick reaches temperature in a few minutes, while 13 mm (0.5 in.) thick material may take up to 45 minutes. After the filler material begins to melt, it takes approximately five minutes for the material to fill the joints.

Dip Brazing

Parts are assembled and dipped into a molten flux in dip brazing. This method has been very successful for the manufacture of elaborate assemblies, such as heat exchanger units. The flux application does not require a separate operation and the bath transmits heat to the interior of thin walled parts without overheating outside surfaces. Contamination is also held to a minimum.

Dip brazing is versatile. It is used in the manufacture of delicate specialty parts where tolerances up to ±0.05 mm (0.002 in.) are maintained in production, or in making large parts approaching 450 kg (1000 lb).

A separate furnace is necessary to preheat the assembly to prevent undue cooling of the flux bath. A furnace used for furnace brazing operated at 280 to 300°C (540 to 565°F) is satisfactory for preheating. It should be located near the dip pot so heat loss will be held to a minimum.

Size of the dip pot will depend on the size of the assemblies to be brazed, but should be large enough to prevent the parts from cooling the flux more than 5°C (10°F) below operating temperature when they are added.

Dehydration of the flux bath is accomplished by dipping 1100 or 3003 alloy sheet into it. As the sheet is attacked, the hydrogen evolved is ignited on the surface. Residue that forms on the bottom of the pot must be removed on a regular basis.

A modification of dip brazing is the application of a flux mixture to the assembly prior to immersion in a salt bath furnace. A typical example consists of making a paste of a mixture of a dry, powdered aluminum-silicon (548°C [1018°F] flow point) brazing alloy and flux, and water, and applying as much as required to fill the joints and make fillets. Next, the assembly is placed in an oven and heated to about 540°C (1000°F) to remove the water. This leaves the brazing alloy powder firmly cemented to the aluminum surfaces, the flux serving as the cement.

When the assembly is placed in the molten brazing salt, the alloy is held firmly in place by the flux cement while it is being heated and melted. The flux cement has a higher melting point than either the brazing alloy or the brazing salt, but it is soluble in the salt bath, so the brazing alloy is held in place, even while melting, until the cement has been dissolved by the molten salt. As the flux cement is dissolved away from the molten filler metal, the alloy runs into the joint capillary spaces and also forms smooth fillets.

Torch Brazing

This method of brazing can be accomplished by using a standard torch as a heat source. Correct torch tip can best be determined through trial, and often depends on the thickness of the piece to be brazed. Filler alloys with suitable melting ranges and efficient fluxes are available for all brazeable aluminum alloys. Most work can be torch brazed with 3 mm (1/8 in.) diameter wire.

A reducing flame with an inner cone about 25 mm (1 in.) in length and a larger exterior blue flame is preferred. Oxyhydrogen, oxyacetylene, oxynatural gas, or gasoline blow torches can be used. Ample clearance space must be allowed where the filler will flow, and a path for flux to escape must be allowed.

After painting with flux paste, the entire area of the joint is heated until the filler melts when it is touched against the heated parent metal. Too hot a flame, or allowing the joint to cool repeatedly, will cause

AA Documents Document Sharing Hub

Full document details: JWE-1997 scan

uneven results. Capillary flow tends to be toward the hottest spot, so it is important that the flow of the filler wire be controlled throughout. Heat should be applied just ahead of where flow is desired. Joints can be produced that have a final fillet that needs a minimum of finishing, if any.

All flux should be removed after brazing. If joints are accessible, a fiber brush with boiling water bath can be used. Scrubbing with hot water and rinsing with cold, then drying is often effective, as is blasting with a steam jet. When possible, a chemical treatment should be used to clean the joint.

Cleaning

Clean surfaces are essential if strong brazed joints are to result. All grease should be removed. Solvent or vapor cleaning will probably be sufficient for the non-heat-treatable alloys, but the for the heat-treatable alloys, the oxide film must be removed with a chemical or by abrasion with steel wool, or stainless steel brushes. All burrs should be removed, as flux will not flow around them.

In post-brazing cleaning, it is essential to remove all the flux. A solution of nitric acid (concentrated technical grade) in equal amounts of water is effective. When a large area is to be cleaned of residual flux, however, this method is not recommended because noxious fumes are generated. An exhaust system is advisable even for small production situations.

To achieve a uniform etch and remove flux in one operation, the work can be immersed in a nitric-hydrofluoric acid solution, using 2 L (0.5 gal) nitric acid, 1/8 L (1/4 pint) hydrofluoric acid, and 17 L (4.5 gal) of water. The major portion of flux should be removed first by immersing in boiling water, then immersing in the acid solution for 10 to 15 minutes, depending on the desired extent of etching. Parts are then drained and rinsed in cold running water, then in hot water. To avoid staining, the hot water bath should be limited to about 3 minutes.

Because of the reaction of a hydrofluoric acid solution with aluminum, in which hydrogen gas is generated, flux removal is efficiently accomplished by this method. The solution is compounded of 600 mL (1.25 pints) of acid, (technical concentrated grade) and 19 L (5 gal) of water. Though this solution is less contaminated by flux than those containing nitric acid, the hydrofluoric acid solution does dissolve aluminum. Therefore, immersion time should be limited to 10 minutes or less. Discoloration can be removed by a quick dip in nitric acid.

When maximum corrosion resistance is important, or when parts are thin, parts can be dipped in a solution of 2 L (2.25 qts.) of nitric acid (technical concentrated grade), 1.8 kg (4 lb.) of sodium dichromate, and 17 L (4.5 gal) of water. The usual procedure is to immerse the parts in hot water, then in the dip solution at 65°C (150°F) for 7 to 10 minutes, followed with rinsing in hot water.

ALUMINUM BRONZE (9% Aluminum Bronze)

A copper-aluminum alloy commonly used for the fabrication of corrosion resistant parts and marine hardware.

ALUMINUM CASTINGS, Welding

Both the gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) processes are used for welding aluminum castings. In general, welding aluminum alloy castings requires a technique similar to that used on aluminum sheet and other wrought products. However, many castings are susceptible to thermal strains and cracks because of intricate design and varying section thicknesses. In highly stressed structures, castings depend on heat treatment for strength. Welding tends to destroy the effect of the initial heat treatment. In these cases, welding is not recommended unless it is possible for the casting or assembly to be heat-treated again after welding, when the loss in strength can largely be restored.

Preparation for Welding

Before welding, castings should be cleaned carefully with a wire brush and an appropriate solvent to remove every trace of oil, grease and dirt. When welds are to be made in sections heavier than approximately 5 mm (3/16 in.), the edges should be beveled at an angle of about 45°. When preparing defective areas for welding, any unsoundness or dross must be completely melted or cut away before proceeding with the weld. When two or more pieces are to be assembled, or if a broken piece is to be welded, the parts should be held by a fixture and clamped in the correct position for preheating and welding. The clamps should be attached in a way that will permit free expansion of the casting during heating, otherwise stresses may develop which will result in excessive distortion or cracks.

Preheating

Prior to welding a casting that is large or intricate in design, it should be preheated slowly and uniformly in a furnace to avoid thermal stresses and facilitate development of the required temperature for welding. A temperature of 370 to 42[illegible]°C (700 to 800°F) is gener-

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

ally sufficient for preheating. If the casting is small, or if the weld is near the edge and in a thin walled section, an experienced welder can often do the necessary preheating with an oxyfuel gas torch applied in the region of the weld. After welding, the casting should be cooled slowly and uniformly to room temperature to reduce the danger of excessive stresses and possible cracks.

Welding Precautions

Surface defects and small holes in aluminum castings can be repaired by welding after the part is correctly prepared and preheated. However, when working with assemblies or broken castings, there are several points to consider during welding. The individual parts should first be tack-welded into place, and actual welding should begin at the center and proceed toward the end. When any difference exists in the thickness of the sections being joined, the GTAW welder must carefully distribute the heat from the torch in order to avoid melting the lighter section while bringing the heavier section up to welding temperature. A similar precaution must be taken with sheet and casting assemblies, and welders may require a little experience to develop the proper technique.

Choice of Welding Rod

When welding castings of the non-heat-treatable aluminum alloys or assemblies involving such castings, consisting of welding rod Al-5%Si or Al-4%Cu, 3%Si is generally used. However, in the case of castings requiring subsequent heat treatment, a welding rod of the same alloy as the casting should be used. The size of the rod best suited for the job will, of course, depend to some extent on the thickness of the metal being welded, but in general, a rod 1.6 to 2.4 mm (1/16 in. to 3/32 in.) diameter will be satisfactory.

ALUMINUM, Oxyfuel Gas Welding

Satisfactory butt, lap, and fillet welds can be made with an oxyfuel gas torch on sections of aluminum ranging up to 25 mm (1 in.) in thickness. The oxyfuel gas welding process would only be used where a source of electric power is not available for arc welding. Oxyhydrogen or oxyacetylene flames produce the heat necessary to offset the high thermal conductivity of the aluminum. Generally, the other oxygen-gas combinations do not provide sufficient heat for welding, but may be used for preheating, which is often needed when joining thick sections.

Overlap joints are not recommended for gas welding because there is danger of flux entrapment in the overlap. When possible, the joint should be designed as a butt weld. If an overlap joint is made, it should be completely welded around the edges to seal the overlapped area.

Preheating is essential in gas welding to allow proper fusion. Sections thicker than 6 mm (1/4 in.) should be preheated to 310 to 370°C (600 to 700°F). Preheating above 425°C (800°F) is not recommended because there is danger of melting some of the alloying constituents. Heat should be applied uniformly to both parts being joined. *See* OXYFUEL GAS WELDING.

ALUMINUM, Gas-Shielded Arc Welding

One of several advantages of gas shielded arc welding of aluminum alloys over other methods of fusion welding is that the need for flux is eliminated, thus removing a potential source of corrosion. Other advantages are that welding can be accomplished in all positions; there is better visibility and greater speed. Sound, pressure-tight joints with high strength and low distortion can be produced. Because of these advantages, the inert-gas-shielded processes are the predominant methods of fusion welding aluminum alloys.

Relatively easy to perform, gas tungsten arc welding (GTAW) uses non-consumable tungsten electrodes, alternating current, and argon or helium shielding gas. When filler material is needed, it can be fed automatically or manually. Aluminum as thin as 0.6 mm (0.025 in.) can be welded, but production welding is more easily controlled when thickness is 1.0 mm (0.040 in.) or greater.

Gas metal arc welding (GMAW), employs aluminum wire as both electrode and filler metal, uses direct current, and a shielding gas of argon or helium, or a mixture of these. The filler wire is fed automatically into the welding zone at a speed compatible with the arc length and welding current, resulting in higher welding speeds than possible with the gas tungsten arc method. Because the heat zone on each side of the weld is narrower, GMAW produces welds of superior strength. A further advantage is that metal of considerable thickness can often be welded without preheating because of high current densities and the concentrated heat of the arc.

ALUMINUM, Pressure Welding

Pressure welding or solid phase bonding of aluminum is accomplished by applying high pressure on the surfaces to be joined, either with or without heat, in the complete absence of melting.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Pressure can be applied by aligning two punches or tapered rolls. Another method uses a shoulder punch on one side of the material and a flat plate or anvil on the other. A third method uses a single tapered roll and a flat surfaced roll. In some instances, punches with shoulders are employed to control the amount of punch penetration and flatten the deformation at the point of entry simultaneously.

Wire brushing is the most satisfactory method of surface preparation.

Pressure Gas Welding

Metal flow between clean interfaces is essential to a cold pressure weld. Simple pressure is not enough. Once started, metal flow must be vigorous and continuous, although speed seems to have little bearing on quality of weld. Pressure must be applied over a comparatively narrow strip, so that the metal can flow away from the weld at both sides. When continuous welds are to be used, the indentor should be of waved design, rather than straight, for maximum strength. Strip and sheet can also be butt welded, but as the width increases, the gripping problem for the dies also increases.

There are two basic methods of pressure gas welding: closed joint and open joint. Coalescence is produced simultaneously over the entire area of abutting surfaces by heating with oxyacetylene flames and then applying pressure. No filler metal is used.

In closed joint welding (also called solid phase and closed butt welding), weld faces are in contact during the complete welding cycle. Ends are carefully cleaned, butted, and heated to a high temperature, but not to the melting stage. Pressure is applied, thereby upsetting the weld zone in a plastic deformation. Various refinements are used in this method, particularly in pressure. Often a low initial pressure is applied, and the pressure is increased as the metal attains its plastic state. Maximum pressure can be applied throughout the welding process, or different pressures may be applied at regular or varying intervals.

In open joint welding, parts are spaced a short distance apart, and heated to the melting temperature. When melting temperature is reached, the parts are brought together rapidly, causing an upset, or partial fusion, weld. Most of the melted material is squeezed from the interface by the impact, and the resulting weld resembles a resistance flash weld.

ALUMINUM, Resistance Welding

Resistance welding is a process in which the welding heat is generated in the parts to be joined by resistance of the parts to the flow of an electric current. Spot welding, seam welding and flash welding are forms of resistance welding.

All the aluminum alloys can be resistance welded. Because the physical characteristics of aluminum are different from those of steel, somewhat different equipment may be required, although modified equipment is often adapted with excellent results. More electrical capacity is usually required for aluminum than for steel.

Advantages of resistance welding are low cost, high production speed, and automatic operation. The major disadvantage is the high initial cost of the equipment. Consequently, resistance welding is generally confined to mass production items where the low cost per weld will offset the high cost of the equipment.

Spot and Seam Welding

Three types of resistance welding equipment are used for spot and seam welding aluminum alloys. These are classified on the basis of the electrical system supplying welding current as follows: standard alternating current (ac), energy storage, electromagnetic, and energy storage, electrostatic. Electrostatic welding may be either magnetic or condenser energy storage. The comparative current and pressure cycles for these systems are shown in Figure A-4.

Alternating-Current Welding

Since aluminum and its alloys have comparatively high thermal and electrical conductivities, high welding currents and relatively short welding times are required in spot welding.

In the widely used alternating-current method for spot welding, the high welding current required is obtained from the secondary coil of a welding transformer having a turns ratio from 20:1 to 100:1. The primary coil is usually connected to either 230 or 460-volt, 60 Hz power supply. An electronic control is used to time the application of welding current ranging from 1 to 30 cycles.

Current Regulation. The secondary current required varies with the thickness of the material to be welded, as shown in Table A-5. To obtain the correct current, an electronic control adjusts the current in steps of approximately 1000 amperes. Taps either on the primary of the welding transformer, or on a separate auto-transformer may be used. Where necessary, a series-parallel switch is provided on the welding transformer primary to permit adjustment of the current down to 25% of the maximum, which is usually sufficient to cover the normal range of material thickness.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

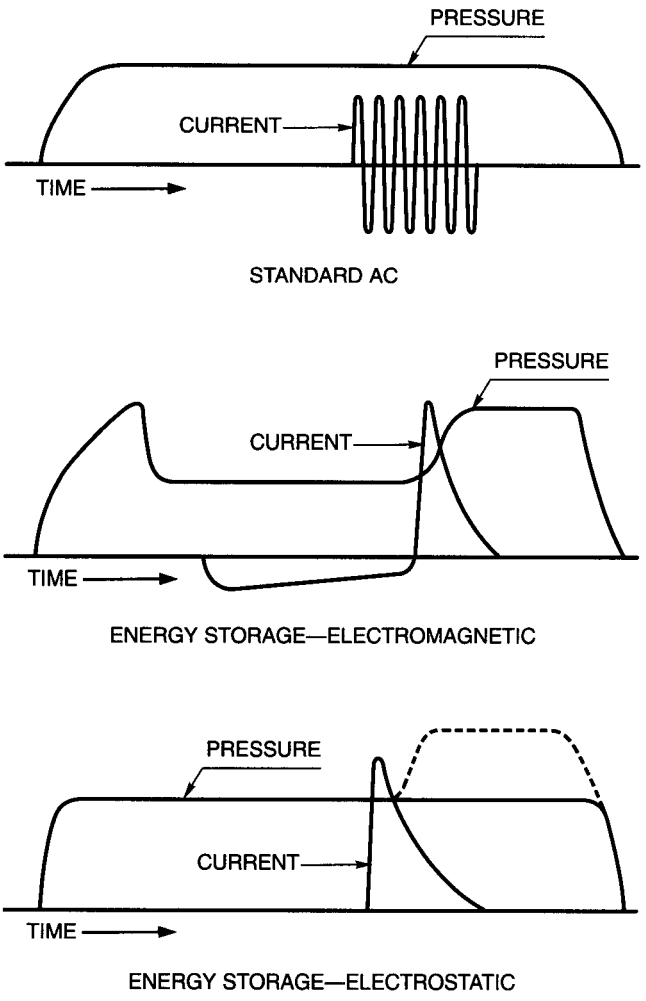


Figure A-4—Comparative Pressure and Current Cycle for A-C and Energy-Storage Resistance Welding Systems

Pressure Regulation. The welding pressure is applied either by a cam and spring mechanism, a pneumatic cylinder or a hydraulic cylinder. Pneumatic operation is preferred, since most manufacturing plants have compressed-air systems and the welding pressure may be adjusted to the desired value. The pressure required on alternating-current welding machines is given in Table A-5.

Timing. The welding time is controlled by means of a switch in the supply line to the welding transformer primary. Both mechanically operated and magnetically operated welding contactors have been used for this purpose, but modern machines use solid state switches. Such devices should control the welding time to the values listed in Table A-5, with an accuracy of plus or minus one cycle. Improved welds result when the controls are adjusted to close the circuit at a uniform point in the voltage wave, and to open the circuit when the welding current passes through zero. However, some variation from this ideal condition is permissible for welding most of the aluminum alloys.

Table A-5
Machine Settings for A-C Spot Welding Aluminum Alloys

Thickness, in.	Time, cycles	Current, amperes	Tip pressure, lb.	
			Min.	Max.
0.016	4	14 000	200	400
0.020	6	16 000	300	500
0.025	6	17 000	300	500
0.032	8	18 000	400	600
0.040	8	20 000	400	600
0.051	10	22 000	500	700
0.064	10	24 000	500	700
0.081	12	28 000	600	800
0.102	12	32 000	800	1000
0.128	15	35 000	800	1200

Electronic equipment for controlling the duration of welding current is widely used with alternating-current welding machines. When these machines are provided with means to start the flow of current in synchronism with the supply voltage, the consistency of weld strength and the appearance of the welds are improved over that obtained when less precise timing equipment is used. Electronic timing equipment for controlling the magnitude as well as the duration of welding current provides a smooth adjustment of the welding heat.

Current Demand. One of the chief objections to alternating-current spot-welding machines is that the high currents required for aluminum welding place a very high electrical demand on the system supplying the machines. This current demand is of intermittent nature, single-phase, and of very low power factor, and may cause disturbances in electric lights and other electric equipment. This condition can be alleviated to a large extent by installing static condensers in series with the primary of the welding transformer. The manufacturer of the welding equipment should be con-

Documents Document Sharing Hub
Full document details: JWE-1997 scan

sulted to determine the size and number of condensers required.

Magnetic-Energy Storage Welding

The electrical current demand for spot welding aluminum can be reduced even further by using magnetic-energy storage equipment, which stores the welding energy in an inductor transformer by establishing a direct current of 100 to 400 amperes in the primary winding of this transformer. On interruption of the current by a contactor, a high value of current is established in the secondary circuit and through the work being welded. This current decays to a low value in 0.01 to 0.05 second.

Equipment for this process also has an electrode pressure system which permits the welding pressure to be varied during the welding operation. The combination of a short duration welding current impulse and a varying pressure results in welds of very sound structure and good appearance.

The maximum power demand for magnetic energy storage equipment is about one-tenth that required for alternating-current equipment, but this system can weld the same thickness of material because the energy is obtained by drawing a lower power for a longer time.

Condenser-Energy Storage Welding

The condenser-energy storage equipment utilizes static condensers to store the energy used for welding. Three-phase primary power is stepped up in voltage and rectified to charge the condensers to a voltage from 1000 to 3000 volts. When this bank of charged condensers is connected to the primary of the welding transformer, an impulse of welding current rises rapidly to its maximum value and decays to zero at a somewhat slower rate. When welding with this equipment, a constant high value of welding pressure is generally used. In some cases a higher pressure is used at the end of the weld to provide a forging action on the solidified weld metal.

Welds produced on this type equipment are excellent in appearance and the structure is very sound. Another advantage is that the maximum demand on the power system is about one-tenth of that required for a-c welding equipment to join the same thickness of material.

Electrodes

The correct selection of electrode shape and the maintenance of this shape in production is essential to achieving consistent spot welds on aluminum. Welding electrodes serve three functions: (1) They conduct the welding current into the parts being welded. (2) They exert sufficient pressure on the material to hold it in place. (3) They conduct the heat out of the parts welded to prevent the weld zone from reaching the outside surfaces of the material.

At least one of the electrodes must be shaped so that current will be highly concentrated in the weld. This electrode may be dome-shaped with a 25 to 50 mm (1 to 2 in.) radius, or it may be conical with a 158° to 166° included cone angle. Another tip shape often used with the energy-storage welding processes consists of a truncated cone with a 160° to 130° cone angle and a flat spot with a diameter equal to twice the thickness of the weld material, plus 3 mm (1/8 in.). The same shape electrode can be used on the other side of the work, or a flat electrode can be used on one side of the work to obtain a surface with the minimum of electrode marking. These flat electrodes may be from 16 to 30 mm (5/8 in. to 1-1/4 in.) in diameter. A further increase in diameter does not improve the appearance of the weld.

The electrodes must be of sufficient diameter to carry the required welding currents without undue heating. A 16 mm (5/8 in.) diameter electrode is suitable for currents up to 35 000 amp. and a welding time of 15 cycles, when the rate of welding is not more than 40 welds per minute. When higher welding currents or greater welding speeds are used, electrodes of 22 to 30 mm (7/8 to 1-1/4 in.) diameter should be used. For welding currents less than 20 000 amps and welding times less than 8 cycles, 12 mm (1/2 in.) diameter electrodes are satisfactory.

A coating of aluminum alloy gradually forms over the face of the electrode. This alloy "pickup" is of low electrical conductivity, and eventually causes the electrodes to stick to the work and to melt the surface of the base material. The pickup can be removed from the electrodes with No. 160 or No. 240 abrasive cloth, but in removing pickup from dome-shaped electrodes, it is important to maintain the original electrode shape.

On alternating-current welding machines using dome or cone shaped electrodes, pickup must be removed from the tips after 15 to 80 welds, depending on the material welded. On energy-storage equipment using the truncated cone electrodes, less pickup is formed, and from 60 to 300 welds may be made before the electrodes require cleaning. The tip cleaning operation requires from 2 to 3 seconds.

Seam Welding

Equipment for seam welding aluminum is similar to a-c spot-welding equipment except that the electrodes

Documents Document Loading Hub

Full document details: JWE-1997 scan

are replaced by roller electrodes from 10 to 16 mm (3/8 to 5/8 in.) thick and from 15 to 22 cm (6 to 9 in.) diameter. One or both of these wheels are trimmed to an included "V" angle of 158° to 166°, or a 25 to 50 mm (1 to 2 in.) radius to concentrate the current in the weld. The wheels and the work are cooled by a water flow of 8 to 12 L/min (2 to 3 gal/min), directed against the periphery of the wheel near the weld. Usually one of the wheels is driven at an adjustable constant speed from 30 to 150 cm/min (12 to 60 in./min). It is essential in seam welding that the electronic timing control initiate and close off the weld current in synchronism with the supply voltage.

Flash Welding

Aluminum alloys in the form of sheet, tubing, extrusions, and rolled bar can be butt- or miter-flash welded to form joints of equal or greater strength than those produced by fusion welding. In flash welding, the parts to be joined are securely clamped in dies on the welding machine, and an electric arc is established between the ends of the parts to be welded. This arc is maintained by placing the parts together as the aluminum material is consumed in the arc. When the ends of the parts are sufficiently heated by this arcing process, the weld is made by rapidly driving the heated ends together with sufficient pressure to hold the material in intimate contact until the weld metal has cooled.

Equipment. So that no arcing occurs when welding aluminum, the flash-welding machine must have sufficient transformer capacity to supply a current density of 15 500 amp/cm^2 (100 000 amp/in^2.) within the section welded, when the parts are in firm contact. The secondary voltage of the flash-welding transformer can be from 2 to 20 volts. The machine must be equipped with appropriate dies and die-clamping devices to securely hold the parts being welded to prevent slipping during the upsetting action which takes place when the weld is formed. One of the clamping dies must be driven toward the other with an accelerated motion to establish and maintain the flashing, and to obtain a very rapid upset motion at the end of the flashing period. The mechanism for driving the movable die must be sufficiently rigid and strong to upset the largest area of section to be welded.

Clamping Dies. Dies are made from hard-drawn copper or copper alloys. Water cooling is not required except on very high production machines. The clamping dies should securely contact at least 80% of the outside circumference of the part to be joined. The length of the dies is usually from 25 to 50 mm (1 to 2 in.) and is limited only by the possibility of crushing the material if too small a die length is used. In addition to holding the parts, the die blocks serve as a means of conducting electric current into the parts being welded and of conducting heat out of the parts during the welding process. A secure electrical connection between one of the dies contacting at least 40% of the circumference of the part must be made.

Flashing. The duration of the flashing motion must be sufficient to permit adequate coverage by the arc of the entire section welded. Considerable variation can be tolerated in both the amount of material flashed off and the time of flashing, providing a uniform, steady flash is maintained. Total material flashed off both pieces varies from 6 mm (1/4 in.) for small diameter wires to 18 mm (3/4 in.) for large diameter rod. Flashing times from one-half to one second are used, although the flashing time can be reduced to as low as 1/20 second, if sufficient current is available to maintain flashing.

Welding Current. Welding current is adjusted by varying the secondary voltage applied to the dies. It is usually done with taps on the primary of the welding transformer. An adjustment which provides an upset current of about 15 500 amp/cm^2 (100 000 amp. per in.^{2}) is used. The current obtained during flashing is from 1/5 to 1/3 of the current which flows after the parts have come into good contact during the upset.

Welding Time. The transformer is energized before the parts to be welded have come into contact and is de-energized by opening a contactor (or by other means) in the primary supply to the welding transformer. The time relation between the beginning of the upset motion and the cutoff of power from the welding transformer is the most critical adjustment in the flash welding of aluminum. The current is removed after 1 to 5 cycles following the initiation of the upset cycle. The time delay of mechanical current interruptions is critical. If the current is shut off too early, oxide inclusions occur in the welds; if it is shut off too late, overheating of the weld and low weld strength are the result.

Costs. The economics of constructing special dies to hold the parts, and the time and material necessary to adjust the machine for production are such that from 500 to 1000 joints are usually required to justify the cost of setting up the flash-welding process. Production rates from 60 to 200 welds per hour can be

AA Documents Document Sharing Hub

Full document details: JWE-1997 scan

obtained, depending on methods used in clamping the parts. The actual welding operation lasts only one second.

Finishing the Welds. Chipping or grinding methods are used to remove the excess upset material to finish the weld. Welds finished and treated by the anodizing process exhibit only a narrow line of slight discoloration at the weld.

ALUMINUM SOLDERING

Soldering is an economical and practical means of joining aluminum on a production basis. With careful attention to such details as surface preparation, solder composition, temperature, and application of heat, a variety of joints can be soldered.

Although less heat is required to raise the temperature of a piece of aluminum sheet of a given thickness than is required for a sheet of copper or steel of the same thickness, aluminum must be heated from 55 to 110°C (100 to 200°F) higher than either of these metals when it is to be soldered. The higher temperature is specified to produce joints with good resistance to corrosion, and is one of the key factors in producing successful soldered joints in aluminum.

Preparing the Surface

As a first step, it is necessary to remove the oxide film on aluminum so that the filler metal can contact and bond with the parent metal. This is accomplished by one of the following methods:

(1) Mechanical abrasion
(2) Application of ultrasonic energy
(3) Electroplating
(4) Use of either chemical or reaction-type fluxes

Mechanical Abrasion

Scraping is the simplest way to remove oxide. Due to the rapid rate at which the film re-forms on aluminum, scraping is impractical unless it is accomplished in the presence of molten solder. The solder then wets and bonds with the parent metal and results in a precoated or "tinned" surface.

Although there are many variations of the process, one example is as follows: Two sheets of aluminum are heated to the melting temperature of the solder. A small amount of solder is then melted on the sheets and rubbed with an abrasion tool until the solder wets the surface. The two precoated sheets are then placed together and held in contact until the solder solidifies. A strong joint results.

A fibrous glass brush is one of the most satisfactory abrasion tools, since no corrosion hazard is created and the close-packed strands remove the oxide without damage to the parent metal.

Some solder rods, called "abrasion solders," have melting characteristics which permit them to perform the dual role of solder source and abrasion tool. However, only a precoated or "tinned" surface is produced, and a second operation is generally required to complete the joining.

Ultrasonic Cleaning and Soldering

Cleaning. Ultrasonic energy can be used to remove oxide film on aluminum. An electronic power oscillator is used to generate electrical impulses (currents) at frequencies from 15 to 50 kHz; these electrical impulses are converted to mechanical motion by a device known as a *magnetostrictive transducer.* Commercial transducers used in soldering tools consist of a nickel core and a coil around the core that is connected to the oscillator. When the nickel core (a laminated nickel core is generally used to reduce eddy currents) is subjected to an electromagnetic impulse resulting from electric current flowing through the coil, it constricts a maximum of 30/1 000 000 (30×10^{-6}) of its length. If the end of the vibrating core is brought into contact with molten solder, the vibrating core will produce numerous holes, or voids, within the liquid. When aluminum is immersed in the liquid solder, the collapse of the voids creates an abrasive effect known as *cavitation erosion* on the surface of the metal. This erosive action removes the oxide film.

Soldering. In ultrasonic aluminum soldering, the area to be precoated, or "tinned," is cleaned, heated to soldering temperature, about 190°C (375°F), and the solder, usually a 90-10 tin-zinc combination, is applied. A quantity of solder is melted on the surface to form a molten puddle, and the end of the transducer is swept over this surface. The ultrasonic energy removes the oxide from the aluminum, allowing a firm solder bond.

The ultrasonic method can also be applied in dip soldering, or, with modifications, in brazing and welding.

The primary advantages of the ultrasonic process are that no flux is required, and joint quality is equal to that of joints soldered by any other process using the same solder and parent metal. The disadvantages are high cost of equipment, small capacity of the units, and the limitation that direct soldering of lap or crimp joints is not practical.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Plated Surfaces for Soldering

It is possible to prepare the aluminum surface to be soldered by electrolytically plating it with a metal, such as copper. Before deposition of the copper, the aluminum surface is treated by immersing the aluminum in a solution of alkaline sodium zincate. The zincated surface is then electrolytically plated with copper to produce a surface that can be easily soldered with the conventional solders and fluxes used to solder copper.

Fluxes for Soldering Aluminum

Chemical and reaction fluxes are the types generally used for soldering aluminum. Chemical fluxes are usually recommended when the joint temperature is less than 275°C (525°F). However, in some applications, the maximum temperature limit can be successfully raised to 325°C (620°F). At temperatures exceeding 275°C (525°F), the chemical fluxes decompose; at temperatures above 325°C (620°F), this decomposition becomes so rapid that it is impractical to use this type of flux.

In general, chemical fluxes are used with the tin-lead-cadmium-zinc solders. For best results, the magnesium content of the aluminum alloy being soldered should not exceed 1%, and the silicon content should not exceed 5%.

All of the common commercial reaction fluxes deposit zinc or tin, or both, on the aluminum surfaces. These metals alloy with the aluminum, and a thin alloy layer is formed in the area near the original surface of the material.

Solders for Aluminum

There are four groups of commercial solders for aluminum: zinc base, zinc-cadmium base, tin-zinc base, and the tin-lead base. All these may contain appreciable quantities of other metals. Table A-6 shows the composition of typical solders for aluminum.

The zinc-base solders produce joints with shear strengths of 103 MPa (15 000 psi) and higher, with good corrosion resistance. These solders require soldering temperatures ranging from 370 to 435°C (700 to 820°F).

The zinc-cadmium base solders develop joints with shear strengths in excess of 70 MPa (10 000 psi), with intermediate corrosion resistance. They require soldering temperatures of 265 to 400°C (510 to 750°F).

The tin-zinc base solders develop joints with shear strengths in excess of 48 MPa (7000 psi), with intermediate corrosion resistance. They require soldering temperatures of 290°C (550°F) or higher.

The tin-lead solders containing cadmium or zinc produce joints with shear strength in excess of 34 MPa (5000 psi), with corrosion resistance adequate for interior applications only. These solders are applied at soldering temperatures of 230°C (450°F) or higher.

Solders high in zinc content are applied to aluminum for a soldered system that is very resistant to corrosive attack. Hot dip tinned surfaces are used in special applications to produce readily solderable surfaces, since tin quickly wets an aluminum surface from which the oxide has been removed. Thus, pretinned aluminum soldering materials and techniques cannot be used. However, molten tin penetrates aluminum-magnesium alloys along the grain boundaries, and alloys containing more than 0.5% magnesium can be seriously damaged by this penetration. Cadmium is only slightly soluble in solid aluminum and forms a very limited diffusion zone in aluminum soldered joints. Cadmium is not usually used as a solder by itself, but is used effectively to improve the properties of zinc- and tin-base solders. Lead is practically insoluble in solid aluminum and is not normally used as a solder by itself. In combination with tin, zinc and cadmium, lead forms an important class of solders for aluminum.

Joint Design

The joint designs used for soldering aluminum are similar to those used with other metals. The most common designs are lap, crimped, and T joints. Capillary spacing varies with method, alloy, solder, joint, and flux. Generally, joint spacings from 0.25 to 0.60 mm (0.010 to 0.025 in.) are maintained when a chemical flux is used, and from 0.05 to 0.25 mm (0.002 to 0.010 in.) with reaction fluxes.

Torch Soldering

Air-fuel gas or oxyfuel gas torches are used effectively to solder aluminum assemblies. The flame temperature (gas mixtures) and heat output (torch size) can be independently adjusted to provide optimum conditions for specific applications. The flux is usually painted on the joint, and the solder is either pre-placed or manually fed into the joint using solder wire. The best torch soldering technique involves heating the assembly initially on both sides of the joint area until solder flow can be initiated in the joint area. The flame can then be moved to a position directly over the joint and slightly behind the front of the solder flow. In this way the flame does not come into direct contact with

Documents Document Sharing Hub

Full document details: JWE-1997 scan

Table A-6
Composition of Typical Solders for Use with Aluminum

Solder Type	Sn	Zn	Al	Cd	Pb	Cu	Approximate Melting Range* °C	Approximate Melting Range* °F
Zn Base	—	94	4	—	—	2	382–393	720–740
Zn Base	—	95	5	—	—	—	380	710
Zn Base	—	79.6	10	0.4	3	5	216–400	420–750
Zn-Cd Base	—	90	—	10	—	—	265–404	509–760
Zn-Cd Base	—	17.5	—	82.5	—	—	265	509
Sn-Zn	20	15	0.8	64.2	—	—	110–120	230–250
Sn-Zn	30	70	—	—	—	—	200–380	390–710
Sn-Zn	60	39.4	—	—	0.1	0.5	200–340	390–645
Sn-Zn	69.3	28	0.7	—	2.0	—	195–335	385–635
Sn-Zn	80	20	—	—	—	—	200–275	390–530
Sn-Pb	36.9	—	—	3.8	58.3	—	145–230	290–450
Sn-Pb	31.6	9	—	8	51	0.4	140–250	282–485
Sn-Pb	40	15	0.8	—	44.2	—	170–360	335–675
Sn-Pb	20	15	0.8	64.2	—	—	110–275	230–530

*Solid-Liquid Range

the flux before it has performed its function, and the speed and ease of soldering is at a maximum.

Furnace Soldering

Furnace soldering is a highly productive, efficient method for fabricating aluminum assemblies. In this process, the entire assembly is raised to temperature, thus minimizing distortion. The solder is usually preplaced in the joint, using wires, shims, or washers of filler material. Flux is applied by spraying, painting, or immersing the part in the flux by flowing a liquid flux over the assembly. The assembly is then placed in a furnace and brought to temperature. The flux must be carefully protected against charring or volatilization before it has performed its function. Joint design and furnace characteristics should be such that all sections of the joint are brought to temperature at the same time in order to prevent excessive alloying and penetration by liquid solder.

Dip Soldering

Dip soldering is an efficient process for joining assemblies at a high production rate. It is a versatile process because the same techniques used for other metals can often be utilized for soldering aluminum by merely changing solder and flux. Any of the solders listed in Table A-6 can be used for dip soldering. Solder selection should be based on service and operating characteristics required, and cost of the solder.

In dip soldering, the flux tends to insulate the part to be soldered from the solder, thus a heavy coat of flux will reduce the rate at which the part is brought to soldering temperature. Since the rate of heating will be greatest if a small amount of flux is used, and because solder will prevent the surface from being reoxidized, a dilute liquid flux is recommended for dip soldering. Also, the flux should be selected to operate at the optimum temperature of the solder to minimize drossing, dissolution, and liquid metal penetration, and to provide the best operating characteristics possible.

Soldering Aluminum Alloys

While aluminum and all the aluminum alloys can be satisfactorily joined by soldering, the alloying elements influence the ease with which they are soldered. Alloys commonly used in commercial applications are 1100, 1145, 3003, 5005, and 6061.

Commercially pure aluminum (1100), aluminum of higher purity (1145), and aluminum-manganese (3003) alloys can be readily joined using all soldering techniques. Aside from ensuring that the surface is reasonably free of extraneous dirt or corrosive prod-

AVA Documents Sharing Hub

Full document details: JWE-1997 scan

ucts, no special surface preparation is needed for soldering these alloys. They are also resistant to intergranular penetration by liquid solder.

Use of molten tin solders results in intergranular penetration in alloys containing 0.5% or more magnesium. Zinc solders will also cause intergranular penetration of aluminum-magnesium alloys, but the extent of penetration is usually not significant until the magnesium content of the parent alloy exceeds 0.7%.

Aluminum alloys containing more than 5% silicon are not usually soldered by procedures requiring the use of a flux.

The addition of zinc or copper to aluminum does not materially reduce the solderability. However, these metals are used in combination with other elements to form high-strength, heat-treatable alloys. Films formed on the surface during heat treatment reduce the solderability, so a chemical surface pre-treatment is usually recommended. In some instances, alloys such as 2024 and 7075 have been satisfactorily soldered using reaction fluxes without using chemical pretreatment. If chemical fluxes are used, a chemical pretreatment is usually required.

Additions of small amounts of magnesium and silicon to aluminum produce an alloy system commonly referred to as the aluminum-magnesium-silicate alloys. These alloys, 6061 and 6063, are easily soldered and are not as susceptible to intergranular penetration by liquid solder as the binary aluminum-magnesium alloys of a similar magnesium content.

Excellent Solderability. Binary aluminum-magnesium alloys, in sheet and other forms, provide excellent solderability, and include 1030, 1050, 1060, 1070, 1075, 1080, 1085, 1090, 1095, 1099, 1100, 1130, 1145, 1160, 1171, 1180, 1187, 1197, and 3003. Chemical or reaction fluxes may be used.

Good Solderability. Alloys considered "good" for soldering are 3004, 5005, 5357, 6053, 6061, 6062, 6063, 6151, 6253, 6951, 7072, and 8112. With the exception of the first two, reaction type flux is recommended.

Fair Solderability. Fair solderability is accorded alloys 2011, 2014, 2017, 2018, 2024, 2025, 2117, 2214, 2218, 2225, and 5050.

Poor Solderability. The alloys rated as poor for soldering are 5052, 5652, 7075, 7178, 7277, 4032, 4043, 4045, 4343, 5055, 5056, 5083, 5086, 5154, 5254, and 5356.

ALUMINUM, Ultrasonic Welding

Ultrasonic welding is a metal joining process in which high-intensity vibratory energy, usually at a frequency above audibility, or in excess of 15 kHz, is introduced into the area to be welded as the workpieces are held together under pressure. This process depends on the conversion of high-frequency alternating current to mechanical vibration. Ultrasonic welding involves complex relationships between the static clamping force, the oscillating shear forces, and a moderate temperature rise in the weld zone, creating conditions which result in atomic diffusion across the interface. The metal recrystallizes to a very fine grained structure having the properties of moderately cold-worked metal. The magnitude of the factors required to produce a weld are functions of the thickness, surface condition, and the mechanical properties of the workpieces. *See* ULTRASONIC WELDING.

Pieces to be joined are clamped at low pressure (4 to 160 kg [10 to 350 lb.]) between two welding members or sonotrodes, and the vibratory energy is introduced for a brief interval. The heart of the equipment is a magnetostrictive transducer, a rectangular stack built up of "A" nickel laminations wrapped with insulated wire. Nickel laminations are used for the transducer because of the transducer's substantial change in length when magnetized. The equipment develops power at supersonic frequency to drive the transducer stack which, in turn, converts electrical current to mechanical vibrations, then transmits them to the upper sonotrode. The high frequency vibratory energy produced by the transducer passes from the welding head through the two pieces to be welded, where it disrupts the oxide film at the interface and eliminates the need for any further preparation.

All combinations of aluminum alloys form a weldable pair. They may be joined in any available form: cast, extruded, rolled, forged, or heat-treated. Soft aluminum cladding on the surface of these alloys facilitates welding. Aluminum can be welded to most other metals, including germanium and silicon, the primary semiconductor materials.

Applications include electronic components, electrical connections, foil and sheet splicing, encapsulation and packaging, and structural welding.

ALUMINUM WROUGHT ALLOYS, Welding

Wrought aluminum alloys can be joined by most fusion and solid state processes, as well as by brazing and soldering (See ALUMINUM BRAZING *and* ALUMINUM SOLDERING).

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

The relative weldability of the wrought non-heat-treatable alloys is shown in Table A-7. Similar information for the wrought heat-treatable alloys is shown in Table A-8. In addition to the processes listed in the tables, wrought aluminum alloys are welded by electron beam and plasma arc welding, and such solid state processes as friction welding, diffusion welding, explosion welding, high frequency welding and cold welding. Submerged arc welding is one of the few processes not commercially used on wrought aluminum alloys.

The selection of a process for welding wrought aluminum alloys depends on many factors, such as the application and service environment, the physical dimensions of the parts being welded, the number of parts involved, the joint design required for the application, and the welding equipment available to do the job.

The selection of filler metals for welding wrought aluminum alloys depends on the particular alloy, but also may be influenced by the process selected and the service requirements of the product. Some additional considerations are joint design, dilution, cracking tendencies, strength and ductility requirements, corrosive environment, and appearance. Table A-9 shows a filler metal selection chart for welding aluminum alloys.

AMERICAN WIRE GAUGE

The gauge used to designate the sizes of solid copper wires used in the United States. Formerly called Brown and Sharpe gauge.

AMMETER

An instrument that measures and indicates in amperes the rate of flow of electricity through a circuit.

AMMETER SHUNT

A special low resistance conductor connected to the terminals of an ammeter to carry nearly all the current, allowing only a very small current to flow through the ammeter.

Table A-7
Weldability[1,2] of Nonheat-Treatable Wrought Aluminum Alloys

Aluminum Alloy	Gas	Arc with Flux	Arc with Inert Gas	Resistance	Pressure	Brazing	Soldering with Flux
1060	A	A	A	B	A	A	A
1100	A	A	A	A	A	A	A
1350	A	A	A	B	A	A	A
3003	A	A	A	A	A	A	A
3004	B	A	A	A	B	B	B
5005	A	A	A	A	A	B	B
5050	A	A	A	A	A	B	B
5052, 5652	A	A	A	A	B	C	C
5083	C	C	A	A	C	X	X
5086	C	C	A	A	B	X	X
5154, 5254	B	B	A	A	B	X	X
5454	B	B	A	A	B	X	X
5456	C	C	A	A	C	X	X

1. Weldability ratings are based on the most weldable temper:
   A. Readily weldable.
   B. Weldable in most applications; may require special technique or preliminary trials to establish welding procedures, performance, or both.
   C. Limited weldability.
   X. Particular joining method is not recommended.
2. All alloys can be adhesive bonded, ultrasonically welded, or mechanically fastened.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Table A-8
Weldability[1,2] of Heat-Treatable Wrought Aluminum Alloys

Aluminum Alloy	Gas	Arc with Flux	Arc with Inert Gas	Resistance	Pressure	Brazing	Soldering with Flux
2014	X	C	C	B	C	X	C
2017	X	C	C	B	C	X	C
2024	X	C	C	B	C	X	C
2036	X	C	B	B	C	X	C
2090	X	X	B	B	C	X	C
2218	X	C	C	B	C	X	C
2219	X	C	A	B	C	X	C
2519	X	C	B	B	C	X	C
2618	X	C	C	B	C	X	C
6005	A	A	A	A	B	A	B
6009	C	C	B	B	B	X	C
6010	C	C	B	B	B	X	C
6013	C	C	B	A	B	X	C
6061	A	A	A	A	B	A	B
6063	A	A	A	A	B	A	B
6070	C	C	B	B	B	X	C
6101	A	A	A	A	A	A	A
6262	C	C	B	A	B	B	B
6351	A	A	A	A	B	A	B
6951	A	A	A	A	A	A	A
7004	X	X	A	A	B	B	B
7005	X	X	A	A	B	B	B
7039	X	X	A	A	B	C	B
7075	X	X	C	B	C	X	C
7079	X	X	C	B	C	X	C
7178	X	X	C	B	C	X	C

1. Weldability ratings are based on the most weldable temper:
   A. Readily weldable.
   B. Weldable in most applications; may require special technique or preliminary trials to establish welding procedures, performance, or both.
   C. Limited weldability.
   X. Particular joining method is not recommended.
2. All alloys can be adhesive bonded, ultrasonically welded, or mechanically fastened.

AVA Documents
Document Sharing Hub
Full document details: JWE-1997 scan

Table A-9
Guide to the Selection of Filler Metal for Aluminum Welding[a,b,c]

Base Metal	201.0 206.0 224.0	319.0, 333.0, 354.0, 355.0, C355.0	356.0, A356.0, 357.0, A357.0, 413.0, 443.0, A444.0	511.0, 512.0, 513.0, 514.0, 535.0	7004, 7005, 7039, 701.0, 712.0	6009 6010 6070	6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	5456	5454
1016, 1070, 1080, 1350	ER4145	ER4145	ER4043[d,e]	ER5356[e,f,g]	ER5356[e,f,g]	ER4045[d,e]	ER4043[e]	ER5356[g]	ER4043[e,g]
1100, 3003, Alc. 3003	ER4145	ER4145	ER4043[d,e]	ER5356[e,f,g]	ER5356[e,f,g]	ER4043[d,e]	ER4043[e]	ER5356[g]	ER4043[e,g]
2014, 2036	ER4145[h]	ER4145[h]	ER4145	—	—	ER4145	ER4145	—	—
2219	ER2319[d]	ER4145[h]	ER4145[e,f]	ER4043[e]	ER4043[e]	ER4043[d,e]	ER4043[d,e]	—	ER4043[e]
3004, Alc. 3004	—	ER4043[e]	ER4043[e]	ER5356[i]	ER5356[i]	ER4043[e]	ER4043[e,i]	ER5356[g]	ER5356[i]
5005, 5050	—	ER4043[e]	ER4043[e]	ER5356[i]	ER5356[i]	ER4043[e]	ER4043[e,i]	ER5356[g]	ER5356[i]
5052, 5652[l]	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[i]	ER4043[e]	ER5356[f,i]	ER5356[i]	ER5356[i]
5083	—	—	ER5356[e,f,g]	ER5356[g]	ER5183[g]	—	ER5356[g]	ER5183[g]	ER5356[g]
5086	—	—	ER5356[e,f,g]	ER5356[g]	ER5356[g]	—	ER5356[g]	ER5356[g]	ER5356[g]
5154, 5254[l]	—	—	ER4043[e,i]	ER5356[i]	ER5356[i]	—	ER5356[i]	ER5356[i]	ER5356[i]
5454	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[i]	ER4043[e]	ER5356[f,i]	ER5356[i]	ER5554[h,i]
5456	—	—	ER5356[e,f,g]	ER5356[g]	ER5356[g]	—	ER5356[g]	ER5556[g]	—
6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	ER4145	ER4145[e,f]	ER4043[e,i,j]	ER5356[i]	ER5356[e,f,i]	ER4043[d,e,j]	ER4043[e,i,j]	—	—
6009, 6010, 6070	ER4145	ER4145[e,f]	ER4043[d,e,j]	ER4043[e]	ER4043[e]	ER4043[e,i,j]	—	—	—
7004, 7005, 7039 710.0, 712.0	—	ER4043[e]	ER4043[e,i]	ER5356[i]	ER5356[g]	—	—	—	—
511.0, 512.0, 513.0, 514.0, 535.0	—	—	ER4043[e,i]	ER5356[i]	—	—	—	—	—
356.0, A356.0, 357.0, A357.0, 413.0 443.0, A444.0	ER4145	ER4145[e,f]	ER4043[e,k]	—	—	—	—	—	—
319.0, 333.0, 354.0, 355.0, C355.0	ER4145[h]	ER4145[e,f,k]	—	—	—	—	—	—	—
201.0, 206.0, 224.0	ER2319[d,k]	—	—	—	—	—	—	—	—

a. Service conditions such as immersion in fresh or salt water, exposure to specific chemicals, or a sustained high temperature [over 66°C (150°F)] may limit the choice of filler metals. Filler metals ER5183, ER5356, ER5556, and ER5654 are not recommended for sustained elevated-temperature service.
b. Recommendations in this table apply to gas shielded arc welding processes. For oxyfuel gas welding, only ER1188, ER1100, ER4043, ER4047, and ER4145 filler metals are ordinarily used.
c. Where no filler metal is listed, the base metal combination is not recommended for welding.
d. ER4145 may be used for some applications.
e. ER4047 may be used for some applications.
f. ER4043 may be used for some applications
g. ER5183, ER5356, or ER5556 may be used.
h.–m. See table footnotes on next page.

AVA Documents
Document Sharing Hub
Full document details: JWE-1997 scan

Table A-9 (Continued)
Guide to the Selection of Filler Metal for Aluminum Welding

Base Metal	5154 5254[l]	5086	5083	5052 5652[i]	5005 5050	3004 Alc. 3004	2219	2014 2036	1100 3003 Alc. 3003	1060, 1070 1080 1350
1060, 1070, 1080, 1350	ER5356[e,f,g]	ER5356[g]	ER5356[g]	ER4043[e,g]	ER1100[e,f]	ER4043[e,g]	ER4145[e,f]	ER4145	ER1100[e,f]	ER1188[e,f,k,m]
1100, 3003, Alc. 3003	ER5356[e,f,g]	ER5356[g]	ER5356[g]	ER4043[e,g]	ER1100[e,f]	ER4043[e,g]	ER4145[e,f]	ER4145	ER1100[e,f]	—
2014, 2036	—	—	—	—	ER4145	ER4145	ER4145[h]	ER4145[h]	—	—
2219	ER4043[e]	—	—	ER4043[e,g]	ER4043[d,e]	ER4043[d,e]	ER2319[d]	—	—	—
3004, Alc. 3004	ER5356[i]	ER5356[g]	ER5356[g]	ER5356[e,f,i]	ER5356[f,i]	ER5356[f,i]	—	—	—	—
5005, 5050	ER5356[i]	ER5356[g]	ER5356[g]	ER5356[e,f,g]	ER5356[f,i]	—	—	—	—	—
5052, 5652[l]	ER5356[i]	ER5356[g]	ER5356[g]	ER5654[f,i,l]	—	—	—	—	—	—
5083	ER5356[g]	ER5356[g]	ER5183[g]	—	—	—	—	—	—	—
5086	ER5356[g]	ER5356[g]	—	—	—	—	—	—	—	—
5154, 5254[l]	ER5654[i,l]	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—

a–g. See table footnotes on preceding page.
h. ER2319 may be used for some applications. It can supply high strength when the weldment is postweld solution heat-treated and aged.
i. ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. In some cases, they provide: (1) improved color match after anodizing treatment, (2) highest weld ductility, and (3) higher weld strength. ER5554 is suitable for sustained elevated-temperature service.
j ER4643 will provide high strength in 12.7 mm (1/2 in.) and thicker groove welds in 6XXX alloys when postweld solution heat treated and aged.
k Filler metal with the same analysis as the base metal is sometimes used. Filler alloys (ER4009 or R4009, ER4010 or R4010, and R4011 meet the chemical composition limits of R-C355.0, R-A356.0 and R-A357.0 alloys, respectively.
l. Base metal alloys 5254 and 5652 are useful for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for low-temperature service [66°C (150°F) and below].
m. ER1100 may be used for some applications.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

AMORPHOUS STRUCTURE

A non-crystalline structure.

AMPERE

A unit of electrical current used to state the rate of flow of electricity through a circuit. One ampere is equivalent to the steady current produced by one volt applied across a resistance of one ohm. *See* ELECTRICAL UNITS.

ANGLE

The figure formed between two intersecting lines or projecting surfaces. Angles are measured in degrees; one degree (1°) is 1/360 of a complete circle. For specific angles used in beveling workpieces to be welded and methods of forming angles, *see* BEVELING.

ANGLE OF BEVEL

See STANDARD WELDING TERMS. *See also* BEVEL ANGLE.

ANNEALING

A treatment process in which a material in the solid state is heated, then cooled at a slow rate. *See* HEAT TREATMENT.

The annealing temperature and the rate of cooling depend on the material and the purpose of the treatment. Annealing is used to effect any of the following changes in metal:

(a) Relieve stresses
(b) Induce softness
(c) Alter ductility, toughness, electrical, magnetic, or other physical properties
(d) Refine the crystalline structure
(e) Remove gases
(f) Produce a definite microstructure

Annealing is a comprehensive term. Some specific annealing heat treatments are:

Full Annealing. Heating iron-base alloys above the critical temperature range, holding above that range for a specified period of time, followed with slow cooling to below that range.

The annealing temperature is generally about 55°C (100°F) above the upper limit of the critical temperature range, and the holding time is usually not less than one hour for each inch of section of the workpiece being treated. The workpiece is then allowed to cool slowly in the furnace. In some applications, the workpiece is removed from the furnace and placed in a medium which will cool the material at a slower rate than unrestricted cooling at room temperature.

Process Annealing. Heating iron-base alloys to a temperature below or close to the lower limit of the critical temperature, followed with cooling as specified.

Spheroidizing. Any process of heating and cooling steel that induces a rounded or globular form of carbide. The spheroidizing methods generally used are:

(1) Prolonged heating at a temperature just below the lower critical temperature, usually followed by relatively slow cooling.

(2) For small parts made of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.

(3) Tool steel is generally spheroidized by heating to a temperature in the range of 750 to 800°C (1380 to 1480°F) for carbon steels (higher for many alloy tool steels), holding at heat from 1 to 4 hours, and cooling slowly in the furnace.

Malleablizing. An annealing operation performed on white cast iron partially or wholly to transform the combined carbon to temper carbon, and in some cases wholly to remove the carbon from the iron by decarbonization. Temper carbon is free graphite carbon in the form of rounded nodules composed of an aggregate of minute crystals.

Graphitizing. Graphitizing is a type of annealing for gray cast iron in which some or all of the combined carbon is transferred to free graphitic carbon.

ANNEALING, ELECTRIC

Annealing of small parts can be accomplished by placing them between the terminals of an electric resistance welding machine, and turning on the current in the usual manner. Sufficient heat will quickly be generated to soften the metal.

Annealing with electric heating apparatus, correctly termed *stress relieving*, has been applied very successfully to welded carbon-molybdenum steel piping systems. These steels harden during the welding process and residual stresses are likely to be set up in the joint. Stress relieving after welding will adjust these stresses. *See* ANNEALING, FURNACES, HEAT TREATMENT, METALLURGY, *and* INDUCTION HEATING.

ANODE

An electrode with a positive charge; the electron-collecting electrode of an electron tube in an electric circuit. The anode is the terminal on which oxygen gas collects in an electrolytic oxygen-hydrogen generator.

Documents Document Sharing Hub

Full document details: JWE-1997 scan

It is the terminal of a primary cell, or of a storage battery when it is delivering current.

ANODE DROP

See VOLTAGE DROP.

ANODIZING

Coating a metal with a protective film by electrolytic action.

Anodizing refers to the surface treatment of aluminum to prevent oxidation. It is a "deplating" process, since the work itself becomes the anode in the plating bath and metal is thrown off rather than put on. Nascent oxygen is released at the anode. This immediately attacks the metal surface and forms an extremely hard oxide film. The anodizing treatment is widely used in the aircraft industry, and to treat aluminum automobile pistons.

APPARENT EFFICIENCY

In alternating current apparatus, apparent efficiency is the ratio of net power output to the volt-ampere input.

ARC

See STANDARD WELDING TERMS. *See also* WELDING ARC.

An electric arc is formed when two conductors of an electric circuit are brought together forming electrical contact, then separated, with sufficient voltage available to maintain the current of electricity through the intervening gaseous medium.

In a continuous current arc, the conductor from which the current flows is called the *positive electrode*, or *anode*. The conductor to which the current flows is called the *negative electrode,* or *cathode*. The heated gases are sometimes called the arc flame, or the arc plasma.

ARC BLOW

The deflection of an arc from its normal path because of magnetic forces. See STANDARD WELDING TERMS.

Arc blow, when it occurs, is encountered principally with direct-current welding of magnetic materials (iron and nickel). It can be encountered with alternating current under some conditions, but these cases are rare, and the intensity of the arc blow is always much less severe. Direct current flowing through the electrode and base metal sets up magnetic fields around the electrode which tend to deflect the arc to the side at times, but usually the arc is deflected either forward or backward along the joint.

Back blow is encountered when welding toward the workpiece connection near the end of the joint or into a corner. Forward blow is encountered when welding away from the lead at the start of the joint. In general, arc blow is the result of two basic conditions:

(1) The change of direction of the current flow as it enters the work and is conducted toward the work lead.

(2) The asymmetric arrangement of magnetic material around the arc, a condition that normally exists when welding is done near the end of ferromagnetic materials.

Although arc blow cannot always be eliminated, it can be controlled or reduced to an acceptable level through a knowledge of the above two conditions.

Except in cases where arc blow is unusually severe, certain corrective steps may be taken to eliminate it or at least to reduce its severity. Some or all of the following steps may be necessary:

(1) Place the workpiece lead connections as far as possible from the joints to be welded.

(2) If back blow is the problem, place the workpiece connection at the start of welding, and weld toward a heavy tack weld.

(3) If forward blow causes the trouble, place the workpiece connection at the end of the joint to be welded.

(4) Position the electrode so that the arc force counteracts the arc blow.

(5) Use the shortest possible arc consistent with good welding practice. This helps the arc force to counteract the arc blow.

(6) Reduce the welding current.

(7) Weld toward a heavy tack or runoff tab.

(8) Use the backstep sequence of welding.

(9) Change to ac, which may require a change in the electrode classification.

(10) Wrap the workpiece lead around the workpiece in the direction that sets up a magnetic field which will counteract the magnetic field causing the arc blow.

ARC BRAZING

An electric brazing process in which the heat is obtained from an electric arc formed between the base metal and an electrode, or between two electrodes. See STANDARD WELDING TERMS.

ARC CHAMBER

A nonstandard term for PLENUM CHAMBER.

Documents Document Sharing Hub

Full document details: JWE-1997 scan

ARC CONTROL

Arc control in d-c welding machines is accomplished primarily by a rheostat in the welding circuit. On a-c machines, controlling the output current is of prime importance and can be accomplished by using one of the following: movable shunt control, movable coil control, tapped reactor coil control and electronic control. The method is usually dictated by process requirements, economics of manufacturing, and the necessity for remote control capabilities.

ARC CUTTER

See STANDARD WELDING TERMS. *See also* THERMAL CUTTER.

ARC CUTTING (AC)

A group of thermal cutting processes that severs or removes metal by melting with the heat of an arc between the electrode and workpiece. See STANDARD WELDING TERMS.

This definition covers a number of processes that are or have been used for cutting or gouging metals, including the following:

(1) Plasma Arc Cutting (PAC)
(2) Air Carbon Arc Cutting (CAC-A)
(3) Shielded Metal Arc Cutting (SMAC)
(4) Gas Metal Arc Cutting (GMAC)
(5) Oxygen Arc Cutting (AOC)
(6) Gas Tungsten Arc Cutting (GTAC)
(7) Carbon Arc Cutting (CAC)

Thermal gouging is a thermal cutting process variation that removes metal by melting or burning the entire removed portion, to form a bevel or groove.

ARC CUTTING GUN

A device used to transfer current to a continuously fed cutting electrode, guide the electrode, and direct the shielding gas. See STANDARD WELDING TERMS.

ARC CUTTING OPERATOR

See THERMAL CUTTING OPERATOR.

ARC CUTTING ELECTRODE, OXYGENLESS

All metals can be cut using the shielded metal arc welding (SMAW) process and oxygenless arc cutting electrodes. The electrode coating is formulated to react exothermically, concentrating the heat and force of the arc at the point of cut. They are designed to have a slow burn-off rate, so that maximum length of cut can be achieved with each electrode. They are capable of withstanding a higher range of cutting amperages. Oxygenless arc cutting is not limited to ferrous metals, since it does not depend on the heat generated by the oxidation of the iron to propagate the process.

Application technique is a factor to be considered when specifying electric arc cutting. Welding personnel proficient in the use of conventional electrodes are also able to use the specially designed oxygenless arc cutting electrodes.

ARC CUTTING TORCH

See STANDARD WELDING TERMS. *See also* AIR CARBON ARC CUTTING TORCH, GAS TUNGSTEN ARC CUTTING TORCH, *and* PLASMA ARC CUTTING TORCH.

ARC FORCE

The axial force developed by an arc plasma. See STANDARD WELDING TERMS.

ARC FURNACE

An electric furnace in which the heat is produced by an arc between two electrodes. *See* FURNACE.

ARC GAP

A nonstandard term when used for ARC LENGTH.

ARC GAS

A nonstandard term when used for ORIFICE GAS.

ARC GOUGING

Thermal gouging that uses an arc cutting process variation to form a bevel or groove. See STANDARD WELDING TERMS. *See also* ARC CUTTING.

When the compressed-air carbon arc process is used, the metal to be gouged or cut is melted with an electric arc and blown away with a high-velocity jet of compressed air parallel to the electrode. A special torch directs a stream of air along the electrode and external to it. The torch is connected to an arc welding machine and any compressed-air line which delivers approximately 690 kPa (100 psi) of compressed air. Since this pressure is not critical, a regulator may not be necessary.

The electrode is a special composition of carbon and graphite and is usually copper clad to increase its operating life.

ARC LENGTH

The distance from the tip of the welding electrode to the adjacent surface of the weld pool. See STANDARD WELDING TERMS.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

Arc length is the distance through the center of the arc from the end of the electrode to the point where the arc makes contact with the surface of the work.

The length of the arc for a coated electrode (SMAW) is usually greater than that of the bare electrode (GMAW) because with the latter, the greater heat intensity of the arc assures penetration and fusion, while the gas shield protects the molten metal from atmospheric contamination.

The arc length of the coated electrode is usually longer than the portion that may be apparent to the eye, because the end of the electrode core wire burns away more rapidly than the coating and allows the coating to come closer to the molten pool than the actual end of the core of the electrode.

ARC OXYGEN CUTTING

A nonstandard term for OXYGEN ARC CUTTING.

ARC PLASMA

A gas that has been heated by an arc to at least a partly ionized condition, enabling it to conduct an electric current. See STANDARD WELDING TERMS.

ARC SEAM WELD

A seam weld made by an arc welding process. See STANDARD WELDING TERMS. *See* Figure A-5. *See also* ARC WELDING.

ARC SEAM WELD SIZE

See STANDARD WELDING TERMS. *See also* SEAM WELD SIZE.

ARC SPOT WELD

A spot weld made by an arc welding process. See STANDARD WELDING TERMS. *See* Figure A-6. *See also* ARC WELDING.

ARC SPOT WELD SIZE

See STANDARD WELDING TERMS. *See also* SPOT WELD SIZE.

ARC SPRAYER

See STANDARD WELDING TERMS. *See also* THERMAL SPRAYER.

ARC SPRAYING (ASP)

A thermal spraying process using an arc between two consumable electrodes of surfacing materials as a heat source and a compressed gas to atomize and propel the surfacing material to the substrate. See STANDARD WELDING TERMS. *See also* THERMAL SPRAYING.

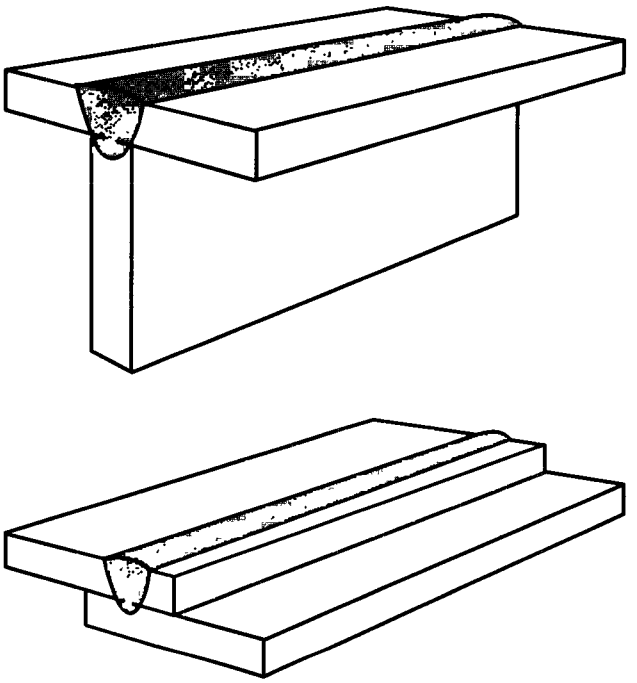


Figure A-5—Arc Seam Welds

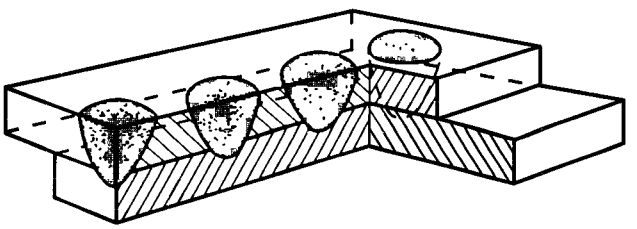


Figure A-6—Arc Spot Welds

The arc spray process is used to apply coatings of various materials which enhance, protect, or seal the workpiece. The process uses an arc between two wires (feedstock), and is sometimes referred to as *wire arc spraying*. The wires are kept insulated from each other and automatically advance to meet at a point within an atomizing gas stream. A potential difference of 18 to 40 volts applied across the wires initiates an arc as they converge, melting the tips of both wires. An atomizing gas, usually compressed air, is directed across the arc zone, shearing off molten droplets which form the atomized spray, and ejecting them from the arc at the rate of several thousand particles

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

per second. The velocity of the gas through the atomizing nozzle can be regulated to control deposit characteristics.

In comparison with wire flame spraying, the quantity of metal oxides is better controlled and spray rates are higher in wire arc spraying, so this process is often more economical.

Equipment. The wire arc spray system can be operated from a control console or from the gun. The control console will have the switches and regulators necessary for controlling and monitoring the operating circuits that power the gun and control the spray procedure, as follows:

(1) A solid-state direct current power source, usually the constant voltage type

(2) A dual wire feeding system

(3) A compressed gas supply with regulators and flowmeter built into the control assembly

(4) Arc spray gun and appropriate console switching

The wire control unit consists of two reel (or coil) holders, which are insulated from each other, and connected to the spray gun with flexible insulated wire guide tubes. Wire sizes range from 1.6 to 3.2 mm (1/16 to 1/8 in.). The wire arc spray process can deposit as little as 0.45 kg/hr (1 lb/hr). Factors controlling the rate of application are the current rating of the power source and the permissible wire feed rate to carry the available power.

Direct current constant potential power sources providing a voltage of 18 to 40 volts are normally used in this process. This permits operation over a wide range of metals and alloys. The arc gap and spray particle size increase with a rise in voltage. The voltage should be kept at the lowest possible level, consistent with good arc stability, to provide the smoothest coatings and maximum coating density.

Advantages and Limitations. Compared to flame spraying, energy and labor costs are lower for arc spraying because of its higher deposition rate, lower maintenance, low gas costs, and higher deposition efficiencies.

One adverse effect of the high energy state of the atomized particles is their tendency to change composition through oxidation or vaporization, or both. These effects can be minimized by judicious wire selection.

The arc spray method is less versatile than flame or plasma methods, because powders and nonconductive materials cannot be used.

A technique called *bond coat mode* can be used in this process to achieve higher strength bonds with some materials; when the conditions of this mode are carried out, the following are ensured: (1) fine spray particle size, (2) minimum loss of alloy constituents, (3) concentrated spray pattern, and (4) high melting rate.

Arc Spraying Applications

Arc spray deposits can provide protection against many types of corrosive attack on iron and steel. Zinc, aluminum, and stainless steels can be used as surfacing materials. A thick layer of zinc or aluminum can protect steel against oxidation and provide a strong bond for an organic coating.

Safety

Local, state, and federal safety regulations should be investigated, and procedures must comply with them. The potential hazards involved in arc spraying operations are electrical shock, fire, gases, dust and fumes, arc radiation and noise. These potentials are not unique to thermal spraying; the general requirements for the protection of thermal spray operators are the same as for welders, set forth in ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes;* ANSI Z87.1, *Practices for Occupational and Educational Eye and Face Protection*; ANSI Z88.2, *Practices for Respiratory Protection;* ANSI Z89.1, *Safety Requirements for Industrial Head Protection.* Also, CGA P-1, *Safe Handling of Compressed Gases.*

ARC SPRAYING OPERATOR

See STANDARD WELDING TERMS. *See also* THERMAL SPRAYING OPERATOR.

ARC STRIKE

A discontinuity resulting from an arc, consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any metal object. See STANDARD WELDING TERMS.

ARC STUD WELDING (SW)

An arc welding process that uses an arc between a metal stud, or similar part, and the other workpiece. The process is used without filler metal, with or without shielding gas or flux, with or without partial shielding from a ceramic or graphite ferrule surrounding the stud, and with the application of pressure after the faying surfaces are sufficiently heated. See STANDARD WELDING TERMS.

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

In arc stud welding, the base end of the stud is joined to the other work part by heating the stud and the work with an arc drawn between the two. When the surfaces to be joined are properly heated, they are brought together under low pressure. Stud welding guns are used to hold the studs and move them in proper sequence during welding. There are two basic power supplies used to create the arc for welding studs. One type uses d-c power sources similar to those used for shielded metal arc welding (SMAW). The other type uses a capacitor storage bank to supply the arc power. The stud arc welding processes using these two types of power sources are known as *arc stud welding* and *capacitor discharge stud welding*, respectively.

Arc stud welding, the more widely used of the two major stud welding processes, is similar in many respects to manual SMAW. The heat necessary for welding of studs is developed by a d-c arc between the stud (electrode) and the plate (work) to which the stud is to be welded. Welding time and the plunging of the stud into the molten weld pool to complete the weld are controlled automatically. The stud, which is held in a stud welding gun, is positioned by the operator, who then actuates the unit by pressing a switch. The weld is completed quickly, usually in less than a second. This process generally uses a ceramic arc shield, called a *ferrule*. It surrounds the stud to contain the molten metal and shield the arc.

Capacitor discharge stud welding derives its heat from an arc produced by the rapid discharge of electrical energy stored in a bank of capacitors. During or immediately following the electrical discharge, pressure is applied to the stud, plunging its base into the molten pool of the workpiece. The arc may be established either by rapid resistance heating, and vaporization of a projection on the stud weld base (arc time: 3–6 milliseconds), or by drawing an arc as the stud is lifted away from the workpiece (arc time: 6–15 milliseconds). The capacitor discharge process does not require a shielding ceramic ferrule because of the short arc duration and small amount of molten metal expelled from the joint. It is suited for applications requiring small to medium studs.

For either process, a wide range of stud styles is available. They include such types as threaded fasteners, plain or slotted pins, and internally threaded fasteners. Most stud styles can be rapidly applied with portable equipment.

Capabilities. Because arc stud welding time cycles are very short, heat input to the base metal is very small compared to conventional arc welding. Consequently, the weld metal and heat-affected zones are very narrow. Distortion of the base metal at stud locations is minimal.

Studs can be welded at the appropriate time during construction or fabrication without access to the back side of the base member. Drilling, tapping, or riveting for installation is not required.

Small studs can be welded to thin sections by the capacitor discharge method. Studs have been welded to sheet as thin as 0.75 mm (0.03 in.) without melt-through. They have been joined to certain materials (stainless steel, for example) in thicknesses down to 0.25 mm (0.01 in.). Because the depth of melting is very shallow, capacitor discharge welds can be made without damage to a refinished opposite side. No subsequent cleaning or finishing is required.

Limitations. Only one end of a stud can be welded to the workpiece. If a stud is required on both sides of a member, a second stud must be welded to the other side. Stud shape and size are limited because the stud design must permit chucking of the stud for welding. The stud base size is limited for thin base metal thicknesses.

Studs applied by arc stud welding usually require a disposable ceramic ferrule around the base. It is also necessary to provide flux in the stud base or a protective gas shield to obtain a sound weld.

The arc stud welding process involves the same basic principles as any of the other arc welding processes. Application of the process consists of two steps:

(1) Welding heat is developed with an arc between the stud and the plate (work).

(2) The two pieces are brought into intimate contact when the proper temperature is reached.

Applications

Arc stud welding has been widely accepted by all the metalworking industries. Specifically, stud welding is used extensively in the following fields: automotive, boiler and building and bridge construction, farm and industrial equipment manufacture, railroads, and shipbuilding. Defense industry applications include missile containers, armored vehicles, and tanks.

Some typical applications are attaching wood floors to steel decks or framework; fastening linings or insulation in tanks, boxcars, and other containers; securing

Documents
Document Sharing Hub
Full document details: JWE-1997 scan

inspection covers, mounting machine accessories; securing tubing and wire harnesses; and welding shear connectors and concrete anchors to structures.

Equipment

The most basic equipment arrangement consists of the stud gun, a control unit (timing device), studs and ferrules, and an available source of d-c welding current. In terms of portability and ease of operation, the equipment involved in stud welding compares with that of manual SMAW.

Guns. There are two types of stud welding guns, portable hand-held and fixed production types. Automatic stud feeding systems are available for both.

Power Sources. A direct-current power source is used for arc stud welding. Alternating current is not suitable. The three basic types of d-c power sources that can be used are: transformer-rectifier; motor-generator, (motor or engine driven), and battery. The following are general characteristics desired in a stud welding power source:

(1) High open-circuit voltage, in the range of 70 to 100 V.

(2) A drooping output volt-ampere characteristic

(3) A rapid output current rise to the set value

(4) High current output for a relatively short time. The current requirements are higher, and the duty cycle is much lower for stud welding than for other types of arc welding.

Duty Cycle. The basis for rating special stud welding power sources is different from that of conventional arc welding machines. Because stud welding requires a high current for a relatively short time, the current output requirements of a stud welding power source are higher, but the duty cycle is much lower than those for other types of arc welding.

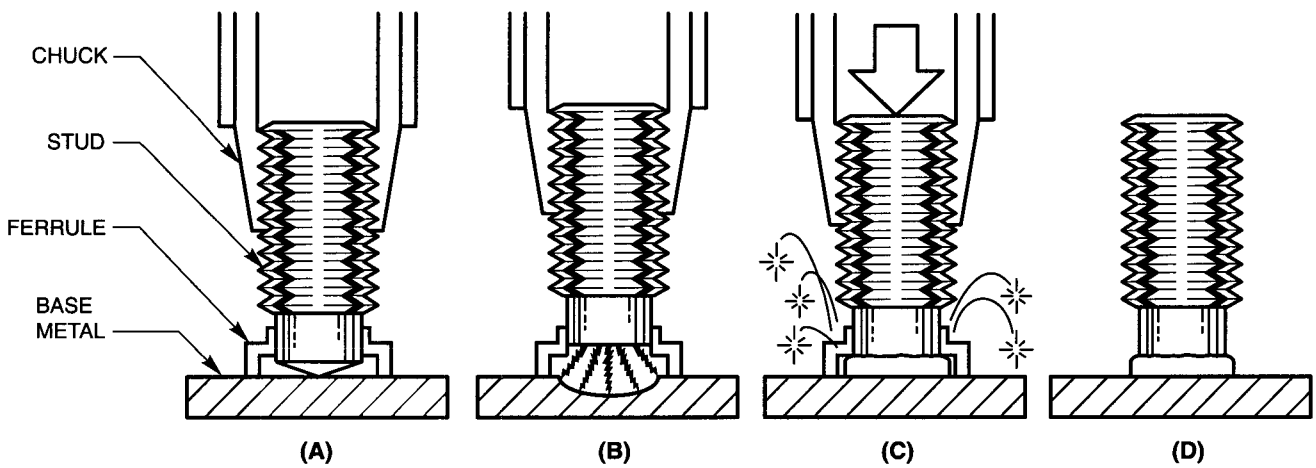
The duty cycle for stud arc welding machines is based on the formula:

Percent duty cycle = 1.7 × number of one-second loads per minute, where the one-second load is the rated output.

Thus, if a machine can be operated six times per minute at rated load without causing its components to exceed their maximum allowable temperatures, then the machine would have a 10% duty cycle rating.

Power Control Units. The control unit consists fundamentally of a contactor suitable for conducting and interrupting the welding current, and a weld timing device with associated electrical controls. Once set, the control unit maintains the proper time interval for the size of stud being welded.

Procedure. The mechanics of the process are illustrated in Figure A-7. The stud is loaded into the chuck,



(A) Gun is Properly Positioned, (B) Trigger is Depressed and Stud is Lifted, Creating an Arc, (C) Arcing Period is Completed and Stud is Plunged Into Molten Pool of Metal on Base Metal, (D) Gun is Withdrawn From the Welded Stud and Ferrule is Removed.

Figure A-7—Steps in Arc Stud Welding

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

the ferrule (*arc shield*) is placed in position over the end of the stud, and the gun is properly positioned for welding. The trigger is then depressed, starting the automatic welding cycle. A solenoid coil within the body of the gun is energized. This lifts the stud off the work, and at the same time, creates an arc. The end of the stud and the workpiece are melted by the arc. When the preset arc period is completed, the welding current is automatically shut off and the solenoid is de-energized by the control unit. The mainspring of the gun plunges the stud into the molten pool on the work to complete the weld. The gun is then lifted from the stud, and the ferrule is broken off. The time required to complete a weld varies with the cross-sectional area of the stud. An average rate is approximately 6 studs per minute, although a rate of 15 studs per minute can be achieved for some applications.

Inspection. The latest edition of ANSI/AWS D1.1, *Structural Welding Code-Steel*, contains provisions for the installation and inspection of steel studs welded to steel components. Quality control and inspection requirements for stud welding are also included. ANSI/AWS C5.4, *Recommended Practices for Stud Welding*, latest edition, briefly covers inspection and testing of both steel and aluminum stud welds.

Capacitor Discharge Stud Welding

Capacitor discharge stud welding is a stud arc welding process in which d-c arc power is produced by a rapid discharge of stored electrical energy with pressure applied during or immediately following the electrical discharge. The process uses an electrostatic storage system as a power source in which the weld energy is stored in capacitors of high capacitance. No ferrule or fluxing is required.

There are three different types of capacitor discharge stud welding: initial contact, initial gap, and drawn arc. They differ primarily in the manner of arc initiation. Initial contact and initial gap capacitor discharge stud welding studs have a small, specially designed projection (tip) on the weld end of the stud. Drawn arc stud welding creates a pilot arc as the stud is lifted off the workpiece by the stud gun. That version is similar to arc stud welding.

Initial Contact Method. In initial contact stud welding, the stud is placed against the work. The stored energy is then discharged through the projection on the base of the stud. The small projection presents a high resistance to the stored energy, and it rapidly disintegrates from the high current density. This creates an arc that melts the surfaces to be joined. During arcing, the pieces to be joined are being brought together by action of a spring, weight, or an air cylinder. When the two surfaces come in contact, fusion takes place, and the weld is completed.

Initial Gap Method. To begin, the stud is positioned off the work, leaving a gap between it and the work. The stud is released and continuously moves toward the work under gravity or spring loading. At the same time, open-circuit voltage is applied between the stud and the work. When the stud contacts the work, high current flashes off the tip and initiates an arc. The arc melts the surfaces of the stud and work as the stud continues to move forward. Finally, the stud plunges into the work, and the weld is completed.

Drawn Arc Method. Arc initiation is accomplished in a manner similar to that of arc stud welding. The stud does not require a tip on the weld face. An electronic control is used to sequence the operation. Weld time is controlled by an electronic circuit in the unit. The welding gun is similar to that used for arc stud welding.

The stud is positioned against the work; the trigger switch on the stud welding gun is actuated, energizing the welding circuit and a solenoid coil in the gun body. The coil motion lifts the stud from the work, drawing a low amperage pilot arc between them. When the lifting coil is de-energized, the stud starts to return to the work. The welding capacitors are then discharged across the arc. The high amperage from the capacitors melts the end of the stud and the adjacent work surface. The spring action of the welding gun plunges the stud into the molten metal to complete the weld.

Applications

Some industrial applications of capacitor discharge stud welding are aircraft and aerospace, appliances, building construction, maritime construction, metal furniture, stainless steel equipment, and transportation.

It is possible to weld studs to dissimilar metals with capacitor discharge stud welding because the penetration into the work from the arc is so shallow that there is very little mixing of the stud metal and work metal. A few of the combinations that may be welded are steel to stainless steel, brass to steel, copper to steel, brass to copper, and aluminum to die cast zinc.

The process can be used on parts that have had the face surface painted, plated, polished, or coated with ceramic or plastic, because postweld cleaning or finishing operations on the side of the base metal opposite to the stud attachment are eliminated.

Documents Document Sharing Hub

Full document details: JWE-1997 scan

Safety Precautions

Personnel operating stud welding equipment should be provided with face and skin protection to guard against burns from spatter produced during welds. Eye protection in the form of goggles or a face shield with a No. 3 filter lens should be worn to protect against arc radiation. Before repairs to equipment are attempted, electrical power should be turned off and electric switch boxes locked out. Capacitors used in capacitor discharge equipment should be completely drained of electrical charge before attempting repairs.

Reference: American Welding Society, *Welding Handbook*, 8th Edition, Vol. 2. Miami, Florida: American Welding Society, 1991.

ARC TIME

The time during which an arc is maintained in making an arc weld. See STANDARD WELDING TERMS.

ARC VOLTAGE

The voltage across the welding arc. See STANDARD WELDING TERMS.

Arc voltage is the total voltage between the electrode holder and the base metal immediately adjacent to the arc terminals. It is the summation of the cathode voltage drop, the anode voltage drop and the arc stream voltage drop.

Arc voltage may vary with a number of conditions, such as length of the arc, temperature, and gaseous content of the arc. Usually, as long as the welding current remains constant, arc voltage increases as the arc is lengthened and decreases as the arc is shortened. This change in voltage, however, is not in direct proportion to the length of the arc. The voltage across a given arc length may also vary with current changes, because of the peculiar characteristics of the arc in which resistance decreases as current passing through it is increased.

When the arc torch uses two electrodes, the welding arc voltage is the total voltage between the two electrode holders.

ARC WELDER

Arc welder is another term for *arc welding machine* applied to a source of electric energy which produces welding currents within reasonable limits for use in arc welding. *See* ARC WELDING.

ARC WELDING (AW)

A group of welding processes that produces coalescence of workpieces by heating them with an arc. The processes are used with or without the application of pressure and with or without filler metal. See STANDARD WELDING TERMS. *See also* Appendix 12.

Arc welding is a nonpressure (fusion) welding process in which the welding heat is obtained from an arc either between the base metal or weld metal and an electrode, or between two electrodes.

Historical Background

1881–1887. Arc welding had its practical beginning shortly after the introduction of arc lights in 1881. Early experiments in arc welding provided the basic theories for the development of two systems of arc welding five or six years later.

In some respects, arc welding might be considered an outgrowth of the electric furnace. In the electric furnaces of Henry Moissan, a French chemist, and others, the metal to be melted was placed between two carbon electrodes in the path of electric current. While this was considered at that time to be an internal resistance process to melt metal by an electric current, it is now realized that these furnaces represented the earliest examples of metal melting with the electric arc.

Arc welding experiments were first undertaken by DeMeritens in 1881. In his experiments the various parts of a battery plate were joined by lead welding using a carbon arc as the heat source. Guided by these early experiments, N. Von Benardos, a Russian, perfected and patented a carbon arc welding process. The patents were filed on this process in Petrograd on December 3, 1885 and issued May 17, 1887.

In the light of present day welding practice, the Benardos system of arc welding seems difficult and hazardous. It was a direct-current welding process operating on voltages ranging from 100 to 300 volts with a welding current of 600 to 1000 amp. The equipment was operated on straight polarity, which is still the preferred method in carbon arc welding, using carbon electrodes varying in size from 6 to 38 mm (0.25 to 1.5 in.) in diameter. It was common practice to weld with an arc from 50 to 100 mm (2 to 4 in.) long. The equipment was cumbersome and awkward to handle; the electrode holder alone was nearly 50 cm (20 in.) long and very heavy.

1889–1908. A short time later the Slavinoff system of arc welding, in which the carbon electrode of the Benardos system was replaced by a bare metal electrode, came into use. American patents on the metal arc process were issued to Coffin in 1889. In 1908 Kjellberg applied a coating to the bare electrode and began the development of coated metal arc welding. It

AWS Documents Educational Learning Hub

Full document details: JWE-1997 scan

is estimated that more than 90% of present day manual arc welding is accomplished using the principles developed by Kjellberg.

As has been the case with many inventions, the industrial world was slow to recognize the inherent possibilities of the process. Many years elapsed before electrical equipment, welding wire, and process control had been sufficiently well developed so that the processes could be economically and safely applied for general manufacturing purposes. Then, too, the engineering community had to be sold on the merits of the welding processes.

1916–1926. Welding was used in a very limited way for manufacturing purposes prior to the World War I period (1914–1918). The war emergency resulted in the use of welding for many applications previously considered inadvisable. During this period, the need for better and less expensive ships allowed persons familiar with ship design and those familiar with the merits of welding to carry out a great deal of design work involving all-welded steel construction. A few small all-welded vessels were produced. If the war had not been terminated by the Armistice (Nov. 11, 1918), all-welded ships would have been produced in quantities within the following few years.

During the war the U. S. Government authorized formation of the U. S. Shipping Board-Emergency Fleet Corporation, which in turn (March 13, 1918) established a sub-committee on welding. At the close of the war this committee had accomplished so much in laying the foundation for welded ship construction that it was considered an economic necessity to continue the work, and to extend the applications in all metal working industries. As a result, the membership of the subcommittee on welding was reorganized in the spring of 1919 under the name "American Welding Society." The reorganization expanded the scope of activities and offered membership to all interested individuals and industries.

From 1919 to 1925, much fundamental research work was carried out by various manufacturers, but the general application of welding in the construction of buildings and bridges did not occur until the latter part of 1925 and early in 1926. This was the beginning of the implementation of welding on a large scale, not only of plain steel but also alloy steels and nonferrous alloys.

1926–1950. A desire to improve the quality of welds produced by arc welding led to the development of several welding processes which combine gas and arc welding. The first of these is the atomic hydrogen process on which basic patents were obtained in 1924 by Dr. Irving Langmuir. This process employs a pair of tungsten electrodes to maintain an arc which is shielded by a stream of hydrogen. It may be used for either manual or automatic welding.

During this period various carbon steel welding electrodes were manufactured which have produced improved welds in terms of reduced slag inclusions and greater resistance to corrosion. Welds were made with ultimate tensile strengths in the range of 480 MPa (70 000 psi), and ductility such as 28% elongation in 50 mm (2 in.) and 60% reduction of area. Similarly, electrodes were developed for welding various alloy steels such as 12% manganese steel, and stainless steel of the low carbon 18% chromium,8% nickel class. Also, electrodes for welding nonferrous metals, i.e., copper and aluminum, were developed, making it possible to weld practically all commercial metals and alloys in all positions.

During this period, the submerged arc welding (SAW) process was developed for welding carbon steel.

World War II put additional demands on the metal fabricating industry. The search for a method to weld magnesium resulted in the gas tungsten arc welding (GTAW) process. It was originally called Heliarc™ welding because it used helium to shield the arc.

1951–Present. This period saw commercialization of a number of welding processes: gas metal arc, electron beam, laser beam, friction, inertia, electroslag, electrogas, explosion, plasma arc, and hot wire.

ARC WELDING, Automatic

Automatic arc welding equipment involves mechanical or electronic means of controlling welding conditions such as welding current, arc length, filler wire or electrode feed, and travel speeds. Movement and guidance of the electrode, torch or welding head along the line of weld can be similarly controlled.

The advantages of such equipment are numerous. A less experienced operator can handle the welding machine and produce satisfactory results. A smaller percentage of welding electrode is lost in stub ends. A much shorter arc is uniformly maintained by the automatic machine than is possible by a manual operator. A much higher current can be used with a given size of welding wire to produce better fusion. A much higher welding speed can be obtained. Welding is continuous from the beginning to the end of the seam, thereby

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan

eliminating intermediate craters unavoidable in manual work. The elimination of craters makes for a stronger, more homogenous, better weld for retaining liquids under pressure. Welding wire in coils for the automatic machine, though more expensive, provides for nearly continuous welding with either a-c or d-c automatic equipment.

ARC WELDING, Carbon

See CARBON ARC WELDING.

ARC WELDING DEPOSITION EFFICIENCY

The ratio of the weight of filler metal deposited in the weld metal to the weight of filler metal melted, expressed in percent. See STANDARD WELDING TERMS.

ARC WELDING ELECTRODE

A component of the welding circuit through which current is conducted and that terminates at the arc. See STANDARD WELDING TERMS.

ARC WELDING GUN

A device used to transfer current to a continuously fed consumable electrode, guide the electrode, and direct the shielding gas. See STANDARD WELDING TERMS. *See also* Appendix 10, Figure D.

ARC WELDING TORCH

A device used to transfer current to a fixed welding electrode, position the electrode, and direct the flow of shielding gas. See STANDARD WELDING TERMS. *See also* Appendix 10, Figures A and B.

ARGON

(Chemical symbol: Ar) A colorless, tasteless, odorless, nonflammable gaseous element; atomic number: 18; atomic weight: 39.94; specific gravity (air = 1) 1.378; critical temperature: –122.5°C (–188.5°F); critical pressure: 4865 kPa (705.6 psia).

Argon was discovered in 1895 by Lord Rayleigh and Sir William Ramsey. About 0.8% of the earth's atmosphere is made up of argon, and it is also found in volcanic gases. Argon is an inert gas; inert gases do not react with other elements. It is used as a shielding gas in certain forms of arc welding.

Argon is commercially available in purity exceeding 99.996% in the gaseous and liquid form. One gallon of liquid argon will produce 113.2 cu ft at 70°F. The boiling point of argon is –185.9°C (–302.6°F).

ARM, Resistance Welding

A projecting beam extending from the frame of a resistance welding machine that transmits the electrode force and may conduct the welding current. See STANDARD WELDING TERMS. *See also* HORN.

ARMATURE

The part of a dynamo that rotates, consisting of coils wound around an iron core. Also, the moving part of an electromagnetic device that supplies a motor or generator with direct current. As a part of a generator, an armature delivers or receives electrical energy. Also, a piece of iron or steel that connects the poles of an electromagnet.

ARMOR WELDING

The technique of welding armor varies only slightly from the techniques used in welding other alloy steels.

Armor plate is essentially a high carbon-chrome-nickel-molybdenum alloy. Specifications for electrodes which produce successful welds on this high-carbon alloy include ballistic requirements, high weld strength, and good toughness, yet with sufficient ductility so that there is some flexibility under impact. The welds must also be relatively free of porosity and should have all these physical characteristics without preweld or postweld heat treatment.

Historical Background

During World War II, welding armor plate for the armed services became a critical issue for the United States, and the welding industry responded with the development of electrodes that would perform this job.

The carbon content of early armor plate ranged between 0.45 and 0.50%. Because of this high carbon content and the combination of alloys, a very difficult welding problem was presented. The solution seemed to be to weld with a 25% chrome, 20% nickel stainless steel electrode. This type of welding material was satisfactory; however, it became necessary to change because of a critical shortage of nickel and chrome.

The next electrode developed for welding armor plate was an 18/8 stainless steel, modified with 1.5% molybdenum, which was used until a shortage of molybdenum developed. A third electrode used to weld armor plate was a 3.5% manganese-modified 18/8 stainless. Some difficulties were experienced with the manganese-modified electrode, because root cracks would frequently develop when weld metal was deposited without preheating. This condition was not wholly caused by the electrode, since the high carbon

AVA Documents Document Sharing Hub

Full document details: JWE-1997 scan