Edited by Arthur L. Phillips

Welding Handbook

Fifth Edition

SECTION ONE

Fundamentals of Welding

WELDING HANDBOOK

SECTION 1 | *Fifth Edition*

Fundamentals of Welding

Edited by Arthur L. Phillips

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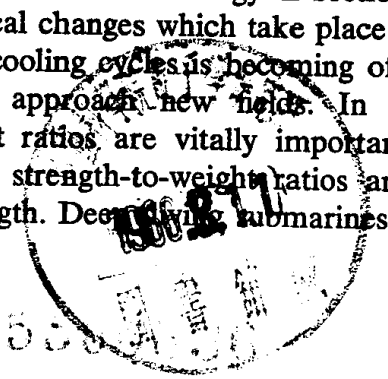
Preface

The experience gained during the preparation of the Fourth Edition of the *Welding Handbook* has clearly indicated the value of the sectional form of publication for technical material of this character. For the first time it has been possible to include information on processes, materials, and techniques almost as soon as they have passed the experimental stage and received industrial acceptance.

The same method of publication will be continued and the Fifth Edition of the *Welding Handbook* will be published in five sections. One section will be revised and brought up-to-date each year. This volume is the first of the new edition and a rearrangement of chapters has been made to group related subjects as closely as possible. Accordingly, the chapter on welding symbols has been transferred from Section 2 to Section 1, since the subject belongs under fundamentals of welding rather than under processes.

Welding involves many sciences and metallurgy and physics are among the most important. A chapter on the physics of welding has been included in response to many requests for authoritative material on this subject. A detailed treatment is obviously impossible because of space limitations and, in any case, would be beyond the scope of this handbook. A sincere effort, however, has been made to cover such subjects as heat flow, arc characteristics, metal transfer and similar complex facets of welding.

The increasing speed of technological development is reflected in the emphasis of metallurgy in Section 1. A knowledge of the metallurgical changes which take place in a metal during the heating and cooling cycles is becoming of even greater importance as we approach new fields. In space technology strength-to-weight ratios are vitally important. In underwater operations, while strength-to-weight ratios are important, emphasis is on strength. Deep diving submarines in future may be



constructed of nickel-chromium-molybdenum alloy plate up to four inches thick and in the 130,000 to 150,000 psi range. New alloys, developed for the space program, are coming into use and a knowledge of their metallurgical structure, properties and behavior is essential if they are to be used commercially.

In Chapter 6, Properties of Welded Joints, we have departed from *Handbook* policy to some extent. The *Welding Handbook* is concerned with established practices and does not concern itself with experimental data. In Chapter 6 the standard tests are reviewed, but also included are the recent investigations into the testing of welded joints. One of the more serious problems under consideration is that of finding a small-scale, inexpensive test as accurate and reliable as full-scale destructive tests. Another problem is how to obtain results which will be of equal value to the designer, the production man, and the user, each of whom may be interested in different properties of the same joint. The work of various research engineers, the National Bureau of Standards, and the Naval Research Laboratory is reviewed and evaluated. In this way a possible inadequacy in testing procedures is revealed and techniques are discussed which may prove to be a more realistic approach to the universal objective of greater accuracy and higher efficiency.

In order to make the *Welding Handbook* even more useful to our friends abroad, we have made use of available material and included in the bibliographies references to appropriate works by authors from other countries.

ARTHUR L. PHILLIPS, *Editor*

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CHAPTER

I

Standard AWS Welding and Cutting Definitions

A

Actual Throat: See Throat of a Fillet Weld.

Air-Acetylene Welding: A gas-welding process wherein coalescence is produced by heating with a gas flame or flames obtained from the combustion of acetylene with air, without the application of pressure and with or without the use of filler metal.

Air Carbon-Arc Cutting: An arc-cutting process wherein the severing of metals is effected by melting with the heat of an arc between an electrode and the base metal and an air stream is used to facilitate cutting.

All-Weld-Metal Test Specimen: A test specimen wherein the portion being tested is composed wholly of weld metal.

Alternate Polarity Operation: A mode of operation of a resistance-welding machine in which succeeding welds are made with pulses of alternating polarity.

Angle of Bevel: See Bevel Angle.

Arc Blow: The swerving of an electric arc from its normal path because of magnetic forces.

Arc Brazing: A brazing process wherein coalescence is produced by heating with an electric arc and by using a nonferrous filler metal, having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction. Also see Twin-Carbon Arc Brazing.

Arc Cutting: A group of cutting processes wherein the severing or removing of metals is effected by melting with the heat of an arc between an electrode and the base metal. See Carbon-Arc Cutting, Metal-Arc Cutting, Gas Metal-Arc Cutting, Gas Tungsten-Arc Cutting, and Air Carbon-Arc Cutting. Compare with Oxygen-Arc Cutting.

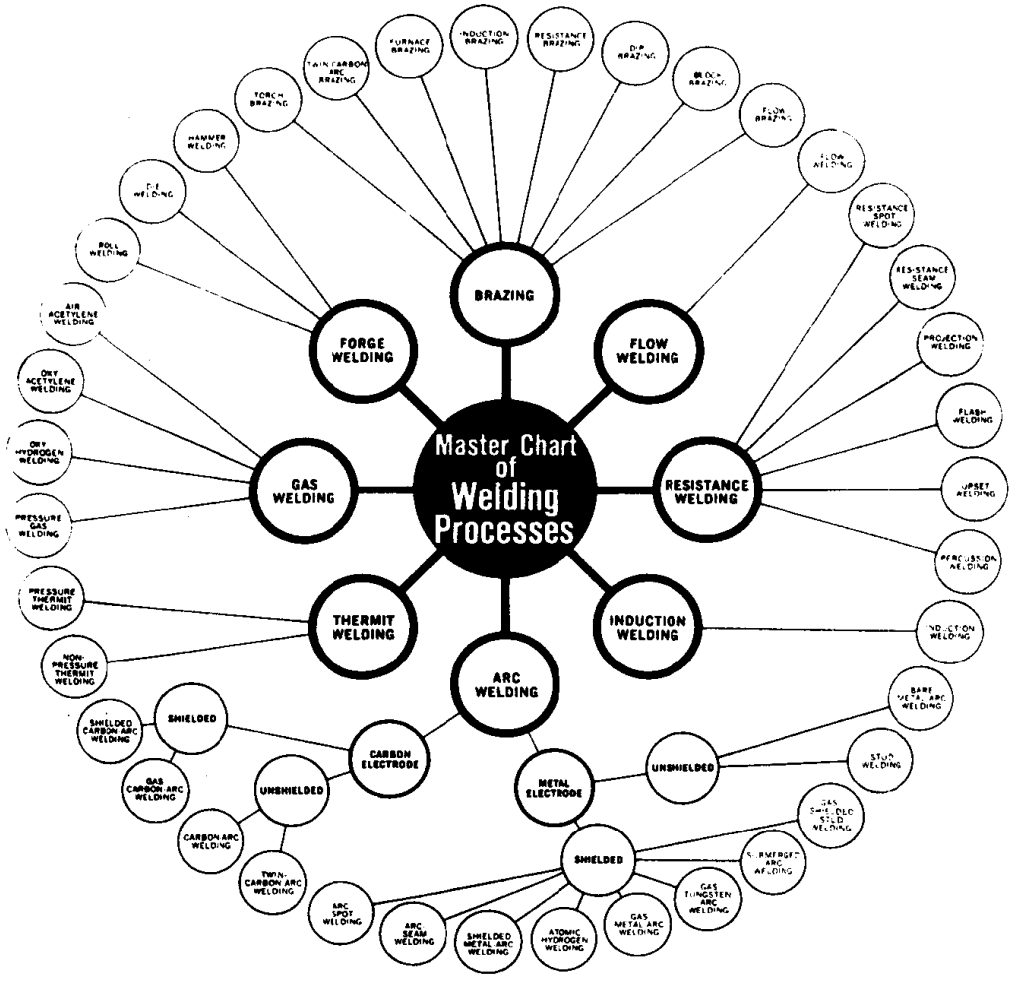

*Fig. 1.1.—Master Chart of Welding Processes**

Arc Gouging: An application of arc cutting wherein a chamfer or groove is formed.

Arc Oxygen Cutting: See Oxygen-Arc Cutting.

Arc-Seam Welding: An arc-welding process wherein coalescence at the faying surfaces is produced continuously by heating with an electric arc between an electrode and the work. The weld is made without preparing a hole in either member. Filler metal or a shielding gas or flux may or may not be used. See Fig. 1.19.

Arc-Spot Welding: An arc-welding process wherein coalescence at the faying surfaces is produced in one spot by heating with an electric arc between an electrode and the work. The weld is made without preparing a hole in either member. Filler metal or a shielding gas or flux may or may not be used. See Fig. 1.20.

* New or revised definitions will appear in the *Welding Journal*, published by the American Welding Society, as they are approved by the *AWS Committee on Definitions and Symbols*.

Arc Time: The time the arc is maintained in making an arc weld.

Arc Voltage: The voltage across the welding arc.

Arc Welding: A group of welding processes wherein coalescence is produced by heating with an electric arc or arcs, with or without the application of pressure and with or without the use of filler metal.

Arm: A projecting beam extending from the frame of a resistance-welding machine, which transmits the electrode force and may conduct the welding current.

As-Welded: The condition of weld metal, welded joints and weldments after welding prior to any subsequent thermal or mechanical treatment.

Atomic Hydrogen Welding: An arc-welding process wherein coalescence is produced by heating with an electric arc maintained between two metal electrodes in an atmosphere of hydrogen. Shielding is obtained from the hydrogen. Pressure may or may not be used and filler metal may or may not be used.

Automatic Gas Cutting: See Automatic Oxygen Cutting.

Automatic Oxygen Cutting: Oxygen cutting with equipment which performs the cutting operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform loading and unloading of the work. See Machine Oxygen Cutting.

Automatic Welding: Welding with equipment which performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work. See Machine Welding.

Axis of a Weld: A line through the length of a weld, perpendicular to the cross-section at its center of gravity. See Figs. 1.2, 1.3 and 1.4.

B

Back Bead: See Back Weld.

Backfire: The momentary recession of the flame into the torch tip followed by immediate reappearance or complete extinguishment of the flame.

Backhand Welding: A gas-welding technique wherein the flame is directed opposite to the progress of welding. See Fig. 1.6.

Backing: Material (metal, weld metal, asbestos, carbon, granular flux, etc.) backing up the joint during welding to facilitate obtaining a sound weld at the root.

Backing Bead: See Backing Weld.

Backing Filler Metal: Filler metal in the form of a backing ring or strip completely fused in a single-welded joint.

Backing Pass: A pass made to deposit a backing weld.

Backing Ring: Backing in the form of a ring, generally used in the welding of piping.

Backing Strap: See Backing Strip.

Backing Strip: Backing in the form of a strip.

Backing Weld: Backing in the form of a weld. See Fig. 1.8.

Back Pass: A pass made to deposit a back weld.

Back Weld: A weld deposited at the back of a single-groove weld. See Fig. 1.9.

Backstep Sequence: A longitudinal sequence wherein the weld bead increments are deposited in the direction opposite to the progress of welding the joint. See Block Sequence, Longitudinal Sequence, etc. See Fig. 1.10.

Backup: A locator used in flash or upset welding to transmit all or a portion of the upsetting force to the work pieces.

Bare Electrode: A filler-metal electrode, used in arc welding, consisting of a metal wire with no coating other than that incidental to the drawing of the wire.

Bare Metal-Arc Welding: An arc-welding process wherein coalescence is produced by heating with an electric arc between a bare or lightly-coated metal electrode and the work and no shielding is used. Pressure is not used and filler metal is obtained from the electrode.

Base Metal: The metal to be welded or cut.

Base-Metal Test Specimen: A test specimen composed wholly of base metal.

Beading: See String Beading and Weave Beading.

Bead Weld: See Surfacing Weld.

Bevel: A type of of edge preparation.

Bevel Angle: The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member. See Fig. 1.27.

Beveling: A type of chamfering.

Blacksmith Welding: See Forge Welding.

Block Brazing: A brazing process wherein coalescence is produced by the heat obtained from heated blocks applied to the parts to be joined and by using a nonferrous filler metal having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction.

Block Sequence: A combined longitudinal and build-up sequence for a continuous multiple-pass weld wherein separated lengths are completely or partially built up in cross-section before intervening lengths are deposited. See Backstep Sequence, Longitudinal Sequence, etc. See Fig. 1.11.

Blowhole: See Gas Pocket.

Blowpipe: See Welding Torch or Cutting Torch.

Bond: The junction of the weld metal and the base metal, or the junction of the base metal parts when weld metal is not present. See Fig. 1.30.

Bottle: See Cylinder.

Boxing: The operation of continuing a fillet weld around a corner of a member as an extension of the principal weld. See Fig. 1.31.

Braze: A weld wherein coalescence is produced by heating to suitable temperatures above 800° F. and by using a nonferrous filler metal, having a melting

point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

Braze Welding: A method of welding whereby a groove, fillet, plug or slot weld is made using a nonferrous filler metal, having a melting point below that of the base metals but above 800° F. The filler metal is not distributed in the joint by capillary attraction. (Bronze Welding, formerly used, is a misnomer for this term.)

Brazed Joint: A union of two or more members produced by the application of a brazing process.

Brazing (Noun): A group of welding processes wherein coalescence is produced by heating to suitable temperatures above 800° F. and by using a nonferrous filler metal, having a melting point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

Brazing Filler Metal: Filler metal used in brazing.

Brazing Technique: See Welding Technique.

Build-Up Sequence: The order in which the weld beads of a multiple-pass weld are deposited with respect to the cross-section of the joint. Block Sequence, Longitudinal Sequence, etc. See Fig. 1.12.

Burner: See Oxygen Cutter.

Burning In: See Flow Welding.

Buttering: See Surfacing.

Butt Joint: A joint between two members lying approximately in the same plane. See Fig. 1.24.

Butt Weld: A weld in a butt joint.

Button: That part of a weld, including all or part of the nugget, which tears out in the destructive testing of resistance-spot, resistance-seam- or projection-welded specimens.

C

Capillary Attraction: The phenomenon by which adhesion between the molten filler metal and the base metals, together with surface tension of the molten filler metal, distribute the filler metal between the properly fitted surfaces of the joint to be brazed.

Carbon-Arc Cutting: An arc-cutting process wherein the severing of metals is effected by melting with the heat of an arc between a carbon electrode and the base metal.

Carbon-Arc Welding: An arc-welding process wherein coalescence is produced by heating with an electric arc between a carbon electrode and the work and no shielding is used. Pressure may or may not be used and filler metal may or may not be used.

Carbon Electrode: A non-filler-metal electrode, used in arc welding, consisting of a carbon or graphite rod.

Carbon-Electrode Arc Welding: A group of arc-welding processes wherein carbon electrodes are used. See Shielded Carbon-Arc Welding, Gas Carbon-Arc Welding, Carbon-Arc Welding and Twin-Carbon Arc Welding.

Carbonizing Flame: See Reducing Flame.

Carburizing Flame: See Reducing Flame.

Cascade Sequence: A combined longitudinal and build-up sequence wherein weld beads are deposited in overlapping layers. (In manual shielded metal-electrode arc-welding a backstep sequence is normally used.) See Block Sequence, Build-Up Sequence, Longitudinal Sequence, etc. See Fig. 1.13.

Chain Intermittent Fillet Welding: Two lines of intermittent fillet welding on a joint wherein the fillet weld increments in one line are approximately opposite to those in the other line. See Fig. 1.32.

Chamfer: See Edge Preparation.

Chamfering: The preparation of a contour, other than for a square groove weld, on the edge of a member for welding.

Chemical Flux Cutting: An oxygen-cutting process wherein a chemical flux is used to facilitate cutting.

Chill Ring: See Backing Ring.

Chill Time: See Quench Time.

Circular Resistance-Seam Welding: See Transverse Resistance-Seam Welding.

Circumferential Resistance-Seam Welding: See Transverse Resistance-Seam Welding.

Cladding: See Surfacing.

Coated Electrode: See Covered Electrode and Lightly-Coated Electrode.

Cold Welding: A form of pressure welding wherein pressure is used to initiate the weld.

Collar: The reinforcing metal of a non-pressure thermit weld.

Commutator-Controlled Welding: The making of a number of resistance-spot or projection welds wherein several electrodes, in simultaneous contact with the work, progressively function under the control of an electrical commutating device.

Complete Fusion: Fusion which has occurred over the entire base-metal surfaces exposed for welding. See Fig. 1.35.

Complete Joint Penetration: Joint penetration which extends completely through the joint. See Joint Penetration. See Fig. 1.38.

Complete Penetration: See Complete Joint Penetration.

Composite Electrode: A filler-metal electrode, used in arc welding, consisting of more than one metal component combined mechanically. It may or may not include materials which protect the molten metal from the atmosphere, improve the properties of the weld metal or stabilize the arc.

Composite Joint: A joint wherein welding is used in conjunction with a mechanical joining process.

Concave Fillet Weld: A fillet weld having a concave face. See Fig. 1.40.

Concavity: The maximum distance from the face of a concave fillet weld perpendicular to a line joining the toes. See Fig. 1.40.

Concurrent Heating: The application of supplemental heat to a structure during a welding or cutting operation.

Cone: The conical part of a gas flame next to the orifice of the tip. See Figs. 1.47, 1.48 and 1.49.

Continuous Sequence: A longitudinal sequence wherein each pass is made continuously from one end of the joint to the other. See Backstep Sequence, Longitudinal Sequence, etc.

Continuous Weld: A weld which extends continuously from one end of a joint to the other; where the joint is essentially circular, completely around the joint.

Convex Fillet Weld: A fillet weld having a convex face. See Fig. 1.41.

Convexity: The maximum distance from the face of a convex fillet weld perpendicular to a line joining the toes. See Fig. 1.41.

Cool Time: The time interval between successive heat times in multiple-impulse or resistance-seam welding. See Figs. 1.65, 1.66, 1.67 and 1.68.

Corner-Flange Weld: A flange weld with only one member flanged at the location of welding. See Fig. 1.21.

Corner Joint: A joint between two members located approximately at right angles to each other in the form of an *L*. See Fig. 1.24.

Corona: The area sometimes surrounding the nugget of a resistance-spot weld at the faying surfaces, which provides a degree of bonding.

Cover Glass: A clear glass used in goggles, hand shields and helmets to protect the filter glass from spattering material.

Covered Electrode: A filler-metal electrode, used in arc welding, consisting of a metal core wire with a relatively thick covering which provides protection for molten metal from the atmosphere, improves the properties of the weld metal and stabilizes the arc.

Crater: In arc welding, a depression at the termination of a bead or in the weld pool beneath the electrode.

Crater Crack: A crack in the crater of a weld bead.

Cross Wire Weld: A projection weld made between crossed wires or bars.

Cutting Attachment: A device which is attached to a gas-welding torch to convert it into an oxygen-cutting torch.

Cutting Nozzle: See Cutting Tip.

Cutting Tip: That part of an oxygen-cutting torch from which the gases issue.

Cutting Torch: A device used in oxygen cutting for controlling and directing the gases used for preheating and the oxygen used for cutting the metal.

Cylinder: A portable cylindrical container used for transportation and storage of a compressed gas.

Cylinder Manifold: See Manifold.

D

Deposit Sequence: See Deposition Sequence.

Deposited Metal: Filler metal that has been added during a welding operation.

Deposition Efficiency: The ratio of the weight of deposited metal to the net weight of electrodes consumed, exclusive of stubs.

Deposition Rate: The weight of metal deposited in a unit of time.

Deposition Sequence: The order in which the increments of weld metal are deposited. See Longitudinal Sequence and Build-Up Sequence.

Depth of Fusion: The distance that fusion extends into the base metal from the surface melted during welding. See Fig. 1.34.

Die:

Resistance Welding.—A member usually shaped to the work contour to clamp the parts being welded and conduct the welding current.

Forge Welding.—A device used in forge welding primarily to form the work while hot and apply the necessary pressure.

Die Welding: A forge-welding process wherein coalescence is produced by heating in a furnace and by applying pressure by means of dies.

Dip Brazing: A brazing process wherein coalescence is produced by heating in a molten chemical or metal bath and by using a nonferrous filler metal, having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction. When a metal bath is used, the bath provides the filler metal.

Double-Bevel Groove Weld: A type of groove weld. See Fig. 1.14.

Double-J Groove Weld: A type of groove weld. See Fig. 1.14.

Double-U Groove Weld: A type of groove weld. See Fig. 1.14.

Double-Vee Groove Weld: A type of groove weld. See Fig. 1.14.

Double-Welded Joint: In arc and gas welding, any joint welded from both sides. See Fig. 1.25.

Downhand: See Flat Position.

Down-Slope Time: The time during which the welding current continuously decreases in resistance-spot, resistance-seam, projection or upset welding. It starts at the end of weld-heat time. See Figs. 1.67 and 1.68.

Drag: The distance between the point of exit of the cutting oxygen stream and the projection, on the exit surface, of the point of entrance. See Fig. 1.42.

Dynamic Electrode Force: See Electrode Force.

E

Edge-Flange Weld: A flange weld with two members flanged at the location of welding. See Fig. 1.22.

Edge Joint: A joint between the edges of two or more parallel or nearly parallel members. See Fig. 1.24.

Edge Preparation: The contour prepared on the edge of a member for welding.

Effective Length of Weld: The length of weld throughout which the correctly proportioned cross-section exists.

Electrode:

Arc Welding.—See Bare Electrode, Carbon Electrode, Composite Electrode, Covered Electrode, Lightly-Coated Electrode, Metal Electrode and Tungsten Electrode.

Resistance Welding.—The part or parts of a resistance-welding machine through which the welding current and, in most cases, pressure are applied directly to the work. The electrode may be in the form of a rotating wheel, rotating roll, bar, cylinder, plate, clamp, chuck or modification thereof.

Electrode Force:

Dynamic.—The force (pounds) between the electrodes during the actual welding cycle in resistance-spot, resistance-seam or projection welding.

Theoretical.—The force, neglecting friction and inertia, in resistance-spot, resistance-seam or projection welding, available at the electrodes of a resistance-welding machine by virtue of the initial force application and the theoretical mechanical advantage of the system.

Static.—The force between the electrodes in resistance-spot, resistance-seam or projection welding under welding conditions, but with no current flowing and no movement in the welding machine.

Electrode Holder: A device used for mechanically holding the electrode and conducting current to it.

Electrode Lead: The electrical conductor between the source of arc-welding current and the electrode holder. See Figs. 1.43 and 1.44.

Electrode Skid: The sliding of an electrode along the surface of the work during resistance-spot, resistance-seam or projection welding.

Electronic Heat Control: A device for adjusting the heating value (rms value) of the current in making a resistance weld by controlling the ignition or firing of the tubes in an electronic contactor. The flow of current is initiated each half-cycle at an adjustable time with respect to the zero point on the voltage wave.

End Return: See Boxing.

F

Face of Weld: The exposed surface of a weld, made by an arc- or gas-welding process, on the side from which welding was done. See Fig. 1.29.

Face Shield: See Hand Shield.

Faying Surface: That surface of a member which is in contact with another member to which it is to be joined.

Filler Metal: Metal to be added in making a weld. See Electrode, Welding Rod, Backing Filler Metal and Brazing Filler Metal.

Fillet Weld: A weld of approximately triangular cross-section joining two surfaces approximately at right angles to each other in a lap joint, tee joint or corner joint. See Figs. 1.40 and 1.41.

Fillet Weld Size: See Size of Weld.

Filter Glass: A glass, usually colored, used in goggles, helmets and hand shields to exclude harmful light rays.

Flame Cutting: See Oxygen Cutting.

Flame Gouging: See Oxygen Gouging.

Flange Weld: A weld made on the edges of two or more members to be joined, at least one of which is flanged. See Figs. 1.21 and 1.22.

Flare-Bevel Groove Weld: A type of groove weld. See Fig. 1.14.

Flare-Vee Groove Weld: A type of groove weld. See Fig. 1.14.

Flash: The molten metal which is expelled, or which is squeezed out by the application of pressure, and solidifies around the weld.

Flashback: A recession of the flame into or back of the mixing chamber of the torch.

Flash-Butt Welding: See Flash Welding.

Flashing Time: The time during which the flashing action is taking place in flash welding.

Flash-Off Time: See Flashing Time.

Flash Weld: A weld made by flash welding. See Fig. 1.18.

Flash Welding: A resistance-welding process wherein coalescence is produced, simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to the flow of electric current between the two surfaces, and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

Flat Position: The position of welding wherein welding is performed from the upper side of the joint and the face of the weld is approximately horizontal. See Figs. 1.2, 1.3 and 1.4.

Flow Brazing: A brazing process wherein coalescence is produced by heating with molten nonferrous filler metal poured over the joint until brazing temperature is attained. The filler metal has a melting point above 800° F. but below that of the base metals and is distributed in the joint by capillary attraction.

Flow Welding: A welding process wherein coalescence is produced by heating with molten filler metal, poured over the surfaces to be welded until the welding temperature is attained and until the required filler metal has been added. The filler metal is not distributed in the joint by capillary attraction. (Burning In, formerly used, is a misnomer for this term.)

Flux: Material used to prevent, dissolve or facilitate removal of oxides and other undesirable substances.

Forehand Welding: A gas-welding technique wherein the flame is directed toward the progress of welding. See Fig. 1.7.

Forge-Delay Time: The time elapsing between the beginning of weld time or weld interval and the instant of application of forging force to the electrodes in resistance-spot or projection welding. See Figs. 1.65 and 1.66.

Forge Welding: A group of welding processes wherein coalescence is produced by heating in a forge or other furnace and by applying pressure or blows.

Full Fillet Weld: A fillet weld whose size is equal to the thickness of the thinner member joined.