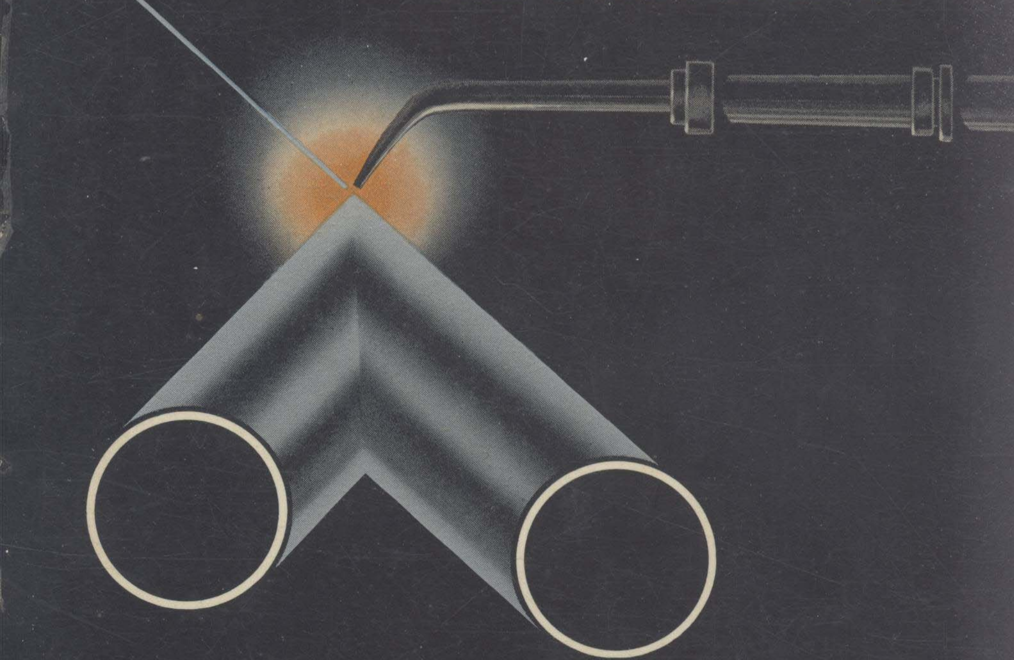
WELDING ALUMINUM



WELDING • BRAZING • SOLDERING

REYNOLDS ALUMINUM

REYNOLDS METALS COMPANY

WELDING ALUMINUM

INCLUDING

BRAZING AND SOLDERING

Foreword: This book will tell the engineer already familiar with the welding of the older metals what he needs to know about welding, brazing, and soldering aluminum. It is intended to be a handbook on welding ALUMINUM rather than a book on *welding.*

CONDENSED CONTENTS

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REYNOLDS METALS COMPANY

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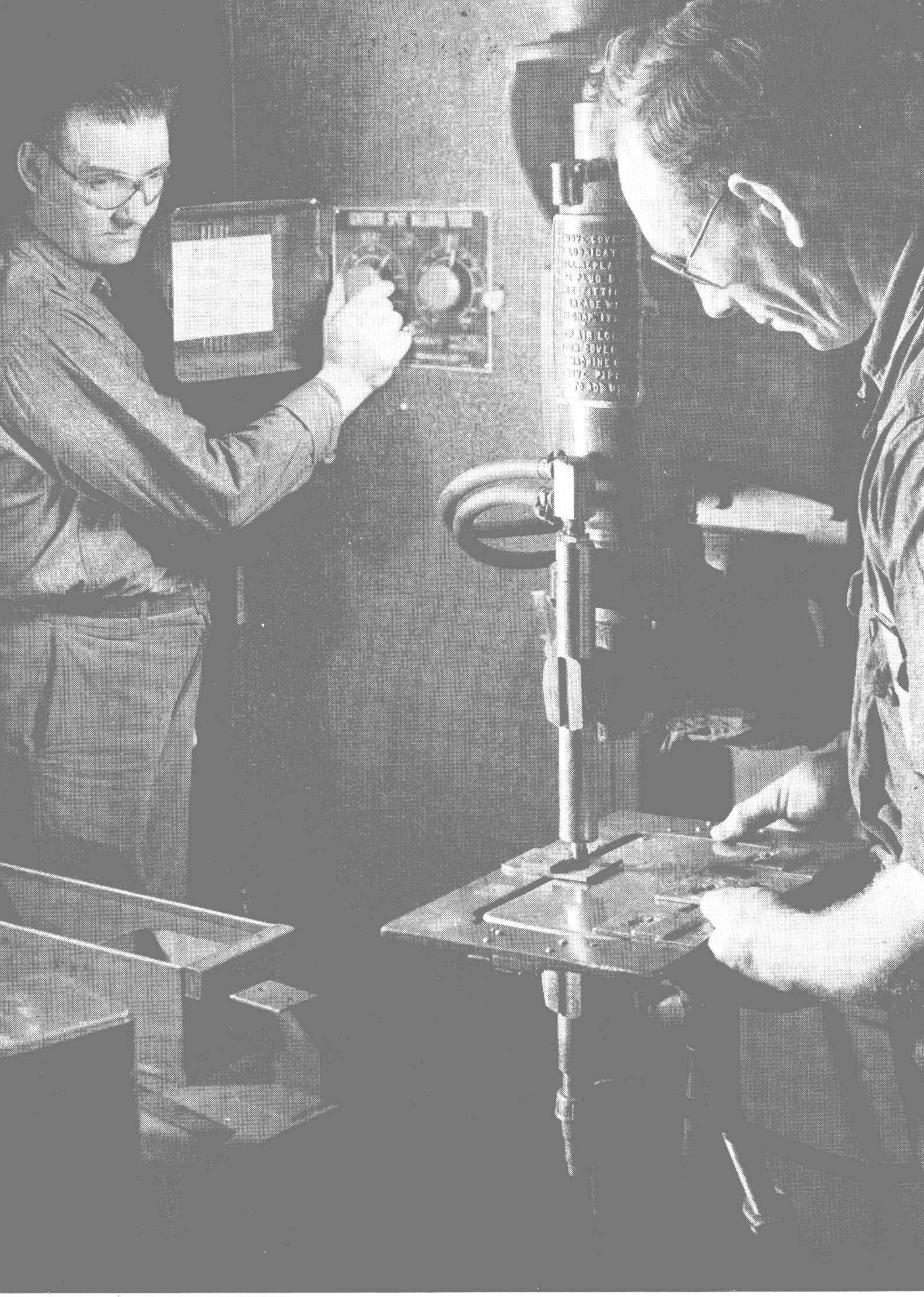


Fig. 1—Ignitron (electronic) controls being set to measure off 8 cycles of 48,000-ampere welding current for spot welding two 0.062-inch thick aluminum parts. Control is easily adjusted to handle various thicknesses. Westinghouse Electric photo.

INTRODUCTION

Aluminum,* together with its alloys, is among our lightest structural metals. It weighs only about 1/3 as much as steel, but its high-tensile-strength alloys have displaced steel in many applications. Commercial annealed aluminum has an ultimate tensile strength of approximately 13,000 pounds per square inch. Cold working will readily double this strength. The addition of alloying elements together with utilization of certain thermal treatments materially increases the strength of aluminum (as much as 6 times) so that it competes with steel structurally.

Besides light weight and strength, many other factors have contributed to the increase in popularity of aluminum. It stands third on the scale of malleability, fifth in ductility and is exceeded only by copper and silver with regard to electrical conductivity. Its thermal conductivity is high, also, and it is noted for its resistance to corrosion.

Whether the ultimate use is a component of an airplane or an everyday domestic utensil, aluminum could scarcely be fabricated on the present wide scale without recourse to welding. The term "welding," as used here, includes metal-arc welding, carbon-arc welding, atomic-hydrogen welding, inert-gas-shielded arc welding, and gas welding, as well as the various forms of resistance welding such as spot, seam and flash welding, and other processes detailed on the following pages. All of these methods are being employed to weld aluminum today, and all of them are discussed in this text. See process charts, Figs. 2-4.

In addition, this book covers brazing by furnace, dip and torch methods; and the soldering of aluminum with recommended procedures and materials. See the condensed table of contents, Page 1, and the itemized cross index, Page 168. Definitions of processes start on Page 6.

* *Throughout this manual, the term "aluminum" will be used in its broad sense to include not only high purity aluminum but also the entire family of aluminum alloys, both wrought and cast.*

PROCESSES SUITABLE FOR ALUMINUM

CHART on the opposite page indicates the great many widely diversified methods that can be used for welding, brazing, and soldering aluminum. In most cases, these processes can be applied to aluminum using the same equipment already in the shop for joining other metals. In some cases, certain equipment modifications are recommended to obtain the best results with aluminum. In a few cases, special equipment will be indicated.

It should be emphasized right here at the start that aluminum is one of the most weldable of all our metals. As used in this book, the term "aluminum" includes not only high purity aluminum but also the entire family of aluminum alloys, both wrought and cast.

Equipment and procedures available today make the welding of aluminum as easy as the joining of any other metal. This applies to brazing and soldering as well. In fact all through this manual, the term "welding" will be used in its broadest sense to include brazing, soldering.

The important facts to remember when welding aluminum are outlined briefly below. It must be remembered that aluminum has individual characteristics which must be thoroughly understood. For example, consider that pure aluminum melts at 1216°F, while aluminum alloys melt at even lower temperatures. The melting point of steel is around 2500°F.

In welding aluminum, oxidation must be understood. Aluminum oxides form a film or coating on all exposed surfaces. This must be removed before welding, in most cases. Its removal is frequently accomplished by the use of fluxes which combine chemically with the oxide to form a fluid slag.

Also, the apparent weakness of aluminum alloys at high temperatures must be appreciated. Many aluminum alloys are partially molten over wide ranges of temperature, and may show a tendency to collapse if overheated. For some alloys, melting begins at 900°F.

This condition also necessitates precautions to avoid subjecting the hot metal to shrinkage and reaction stresses. Adequate support is necessary for all of the areas of an aluminum object which are to be subjected to appreciable temperature rises. In designing the support for an aluminum weldment, it must be remembered that heat applied to the edges to be welded soon spreads rapidly through the entire piece because of the high thermal conductivity of aluminum.

Because aluminum does not change color at any temperature up to and including the melting point, it is necessary for the operator to watch for the "wet" appearance of the surface, indicating surface melting.

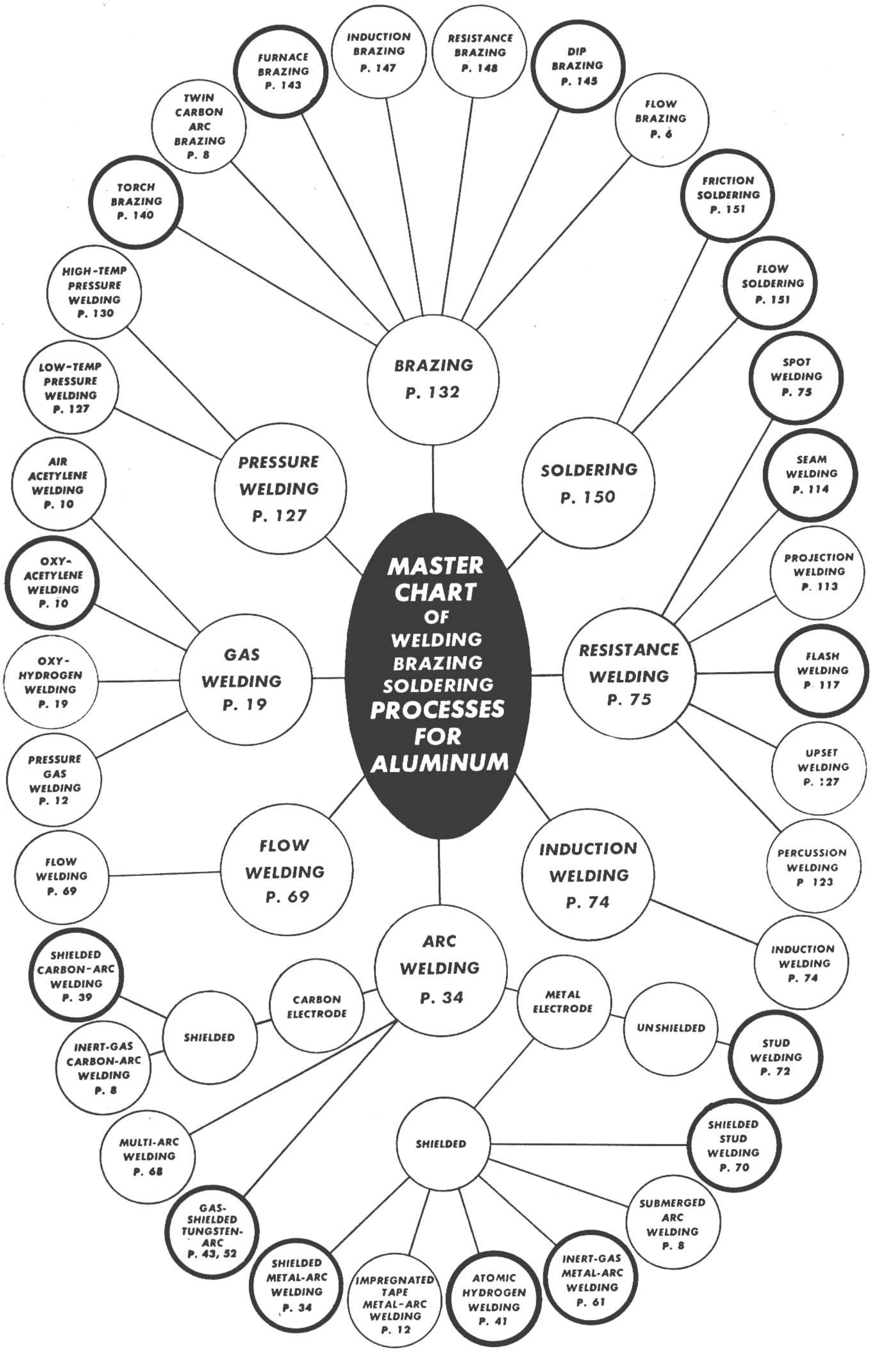


Fig. 2—Aluminum can be joined by all processes shown above. Those most widely used are circled heavy. Numbers are page references in this manual. For definitions of processes, see Pages 6 - 12.

This is contrary to the circumstances in welding most ferrous metals, where the color of the heated piece indicates the temperature.

With these factors properly evaluated, aluminum can be welded by an amazing variety of processes as is indicated by the master chart on Page 5. It should be pointed out that not all aluminum alloys can be welded by all processes. See the additional process charts on Pages 7 and 9 for a further breakdown of the wrought and cast alloys.

There are basically two factors that determine whether or not an aluminum alloy can be welded by a particular process. First of these is copper content. High copper content (3-4 percent or more) causes embrittlement of weld metal and great loss of mechanical properties in adjoining metal when fusion welded unless heat treated after welding. Thus these alloys are not recommended for the fusion welding process . . . but are suited to the resistance welding method.

Second factor is magnesium content. A high magnesium content tends to produce a heavier oxide coating. This means those alloys are not recommended for brazing or soldering operations where oxide formation is a critical factor. These alloys are suitable for all other methods of joining as is indicated by the charts, and tables on Pages 10 and 11.

Throughout the charts, note that certain processes are enclosed in circles or boxes much heavier than others. This is to indicate the processes most suitable and most widely used for aluminum. The processes in the lighter circles and boxes are ones which investigation has disclosed appear to be suitable for aluminum but which have not yet been widely used for aluminum.

For example, the "impregnated-tape metal-arc" welding process is inherently suitable for aluminum because shielding is supplied. Yet at this writing, no tape designed for use with aluminum has been developed. A similar comment applies to "submerged-arc" welding. While the method is inherently suitable for aluminum, so far no granular flux has been developed for aluminum.

Definitions: Some of the processes listed in the charts are not too well known. So for sake of clarity, brief process definitions* are given below. "Coalescence" used in these definitions denotes growing together to form a single body or continuous grain structure. A "weld" is a localized coalescence of metal.

Aircomatic: See "Inert-Gas-Shielded Metal-Arc Welding", Page 61.

Brazing, Dip: Coalescence is produced by heating in a molten salt bath . . . same as "salt bath" brazing. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Flow: Coalescence is produced by pouring molten filler metal over the joint. Filler metal must melt above 800°F and below base metal; is distributed through joint by capillary attraction.

**Adapted from "Welding Handbook" published by American Welding Society.*

Processes Suitable for Joining WROUGHT ALUMINUM ALLOYS

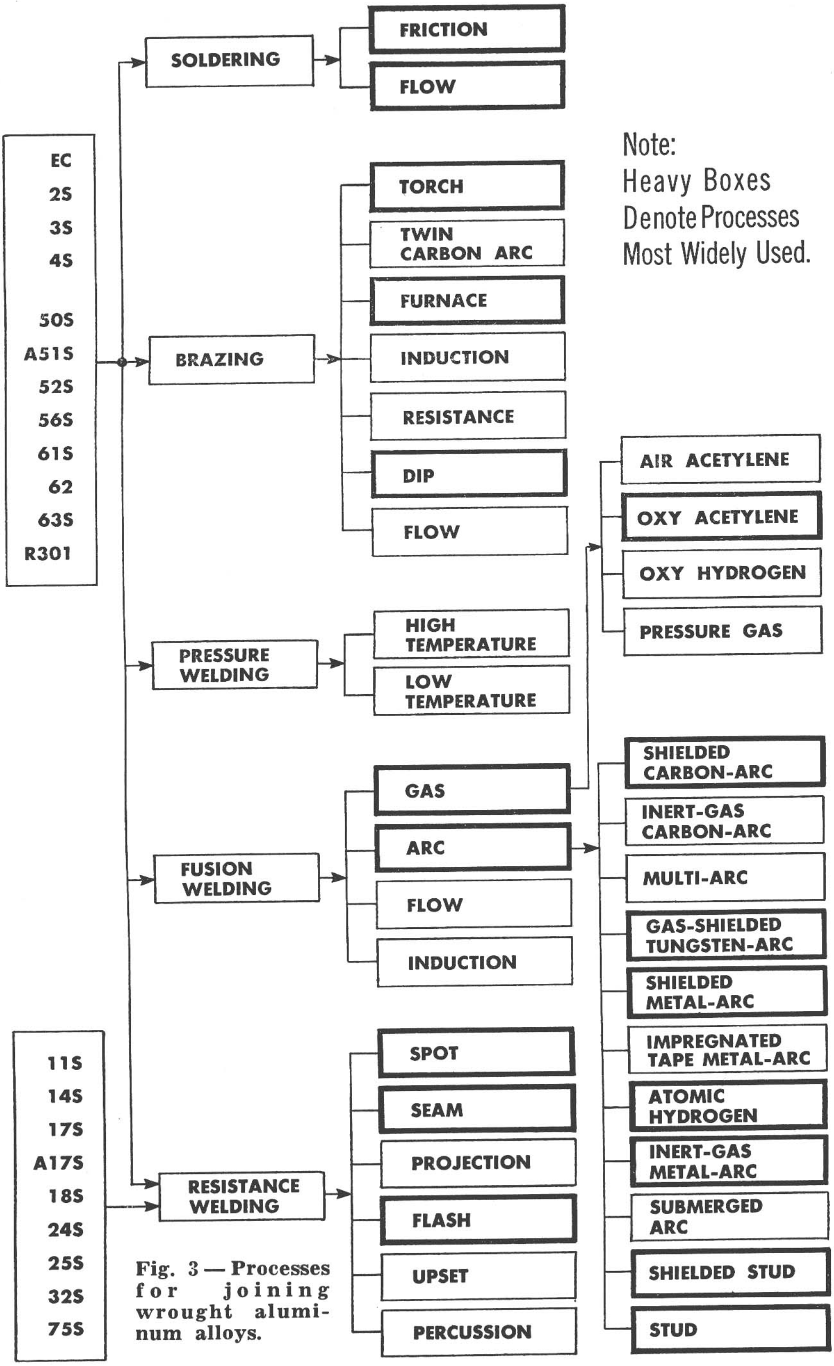


Fig. 3 — Processes for joining wrought aluminum alloys.

Brazing, Furnace: Coalescence is produced by heating in a furnace. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Induction: Coalescence is produced by heat from resistance of work to flow of induced electric current. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Resistance: Coalescence is produced by heat from resistance of work to flow of electric current. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Salt Bath: Coalescence is produced by heating in a molten salt bath . . . same as "dip" brazing. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Torch: Coalescence is produced by heat from a torch. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Brazing, Twin Carbon-Arc: Coalescence is produced by heat from an electric arc between two carbon electrodes. Filler metal must melt above 800°F and below base metal; is distributed in joint by capillary attraction.

Heliarc; Heliweld: See "Gas-Shielded Tungsten-Arc Welding", Page 43.

Sigma: See "Shielded Inert-Gas Metal-Arc Welding,' Page 61.

Soldering, Friction: A soldering method for aluminum in which the aluminum oxide surface coating is broken by abrading the work surface through an overlying layer of molten solder. Solder then bonds directly to the underlying clean metal surface which is prevented from oxidizing by the layer of molten solder.

Soldering, Flow: A soldering method for aluminum in which the aluminum oxide surface coating is dissolved by appropriate flux, allowing the solder to bond to the base metal.

Welding, Arc, Atomic Hydrogen: Coalescence is produced by electric arc between two tungsten electrodes in a hydrogen envelope. Hydrogen provides shielding and aids heat transfer. Pressure and filler metal may or may not be used.

Welding, Arc, Submerged: Coalescence is produced by electric arc between bare filler metal electrode and work; shielded by blanket of granular, fusible material on work. No pressure. Filler metal may also be added from supplementary rod.

Welding, Carbon-Arc, Gas-Shielded: Coalescence is provided by electric arc between carbon electrode and work; with or without pressure and filler metal; shielded by inert-gas envelope.

Welding, Carbon-Arc, Shielded: Coalescence is produced by electric

Processes Suitable for Joining ALUMINUM CASTING ALLOYS

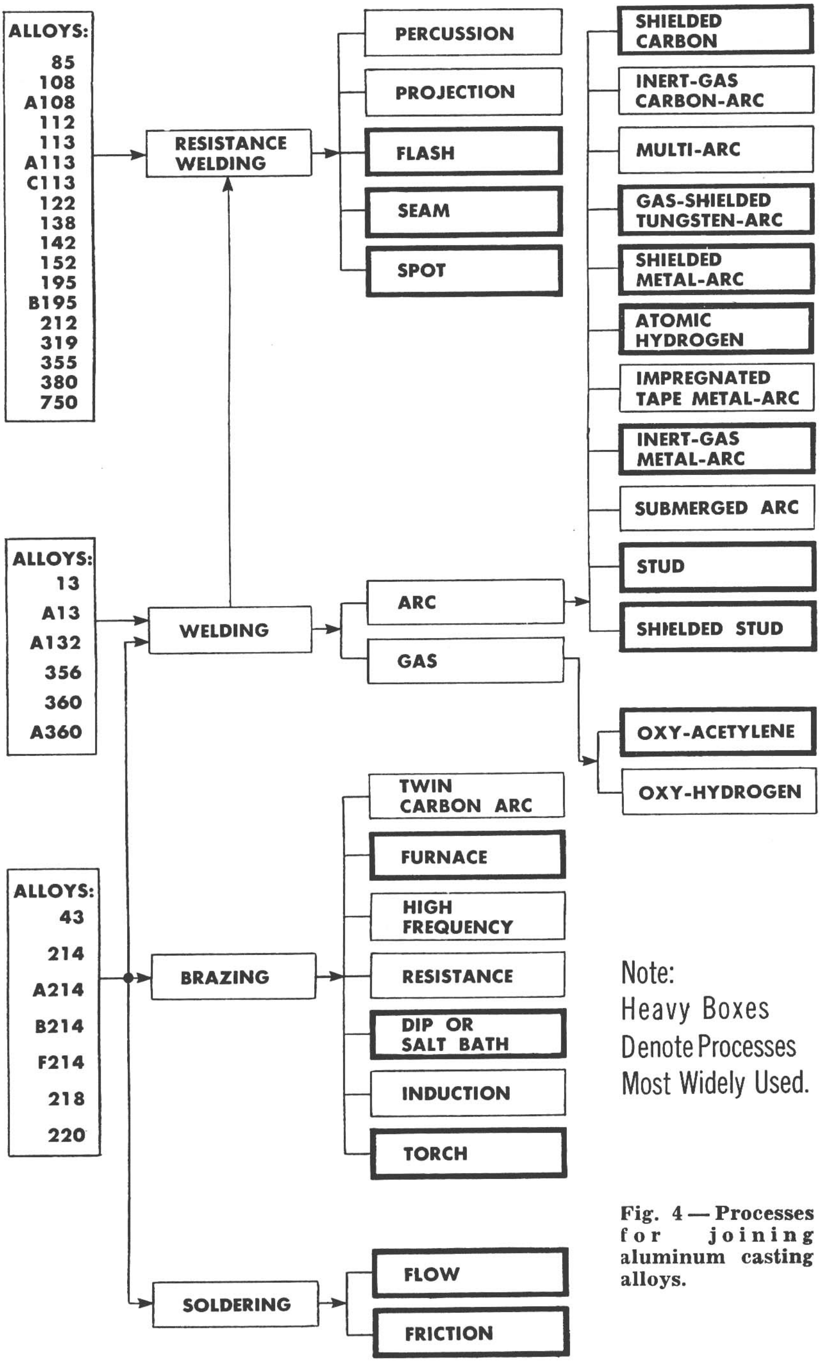


Fig. 4 — Processes for joining aluminum casting alloys.

TABLE 1—WELDABILITY RATINGS FOR WROUGHT ALUMINUM ALLOYS

ALLOY AND TEMPER	RELATIVE WELDABILITY RATING[1]					
	Gas Welding	Arc Welding	Resistance Spot and Seam Welding	Brazing	Soldering	
					Flow	Friction
EC	A	A	B	A	A	A
2S	A	A	B	A	A	A
3S	A	A	B	A	A	A
4S	A	A	A	A	A	A
11S	D	D	A	X	D	A
14S	D	D	C	X	D	A
17S	D	D	C	X	D	A
A17S	D	D	C	X	D	A
18S	D	D	C	X	D	A
A18S	D	D	C	X	D	A
24S-O	D	D	C	X	D	A
24S-T3	D	D	B	X	D	A
24S-T36	D	D	B	X	D	A
Alclad 24S	D	D	A	X	D	A
25S	D	D	D	X	D	A
32S	D	D	D	X	A	A
50S	A	A	B	A	A	A
A51S	A	A	A	A	A	A
52S	B	A	A	B	B	A
Alclad X55S	A	A	A	A	A	A
56S	A	A	B	A	A	A
61S	A	A	A	A	A	A
63S	A	A	A	A	A	A
Alclad R301	D	D	C	X	C	A
75S-O	D	C	C	X	D	A
75S-T6	D	C	B	X	D	A
R317	D	C	D	X	C	A

(1) Ratings "A" = Excellent, "B" = Good, "C" = Fair, "D" = Poor, and "X" = Not recommended.

arc between carbon electrode and work. Shielding may be from combustion of solid material fed into arc or from flux on the work, or both. Pressure and filler metal may or may not be used.

Welding, Flow: Coalescence is produced by heating with molten filler metal poured over surfaces to be joined. Distribution of filler metal does not depend on capillary attraction.

Welding, Gas, Air-Acetylene: Coalescence is produced by gas flame burning acetylene in air; no pressure; with or without filler metal.

Welding, Gas, Oxy-Acetylene: Coalescence is produced by gas flame

TABLE 2—WELDABILITY RATINGS FOR ALUMINUM CASTING ALLOYS

ALLOY	RELATIVE WELDABILITY RATING(1)					
	Gas Welding	Arc Welding	Resistance Spot & Seam Welding	Brazing	Soldering	
					Flow	Friction
SAND CASTING ALLOYS						
43	A	A	A	B	B	A
108	B	D	B	X	D	A
112	B	B	B	X	D	A
122	C	B	B	X	X	A
142	C	B	B	X	D	A
195	C	B	B	X	D	A
212	B	B	B	X	X	A
214	B	A	B	X	B	A
220	D	C	B	X	B	A
355	A	A	A	X	C	A
A355	A	A	A	X	C	A
356	A	A	A	X	B	A
PERMANENT-MOLD CASTING ALLOYS						
43	A	A	A	B	B	A
A108	A	A	A	X	D	A
B113	B	A	B	X	D	A
C113	B	A	B	X	D	A
122	D	C	B	X	X	A
A132	D	C	C	X	D	A
138	D	C	C	X	X	A
142	C	B	B	X	D	A
B195	C	B	B	X	D	A
A214	B	A	B	X	B	A
355	A	A	A	X	C	A
356	A	A	A	X	B	A
DIE-CASTING ALLOYS						
13	D	D	D	X	C	A
43	B	B	C	A	D	A
85	D	D	D	X	D	A
218	D	D	D	X	B	A
360	D	D	D	X	B	A
380	D	D	D	X	D	A

(1)Relative Weldability Rating "A" = Excellent, "B" = Good, "C" = Fair, "D" = Poor, and "X" = Not recommended.

burning acetylene and oxygen; with or without pressure or filler metal.

Welding, Gas, Pressure: Coalescence is produced simultaneously over entire area of abutting surfaces by heating with gas flames and applying pressure; no filler metal used.

Welding, Metal-Arc, Impregnated-Tape: Coalescence is produced by electric arc between filler metal electrode and work. Shielded by decomposition of impregnated tape wrapped on electrode as it is fed to arc.

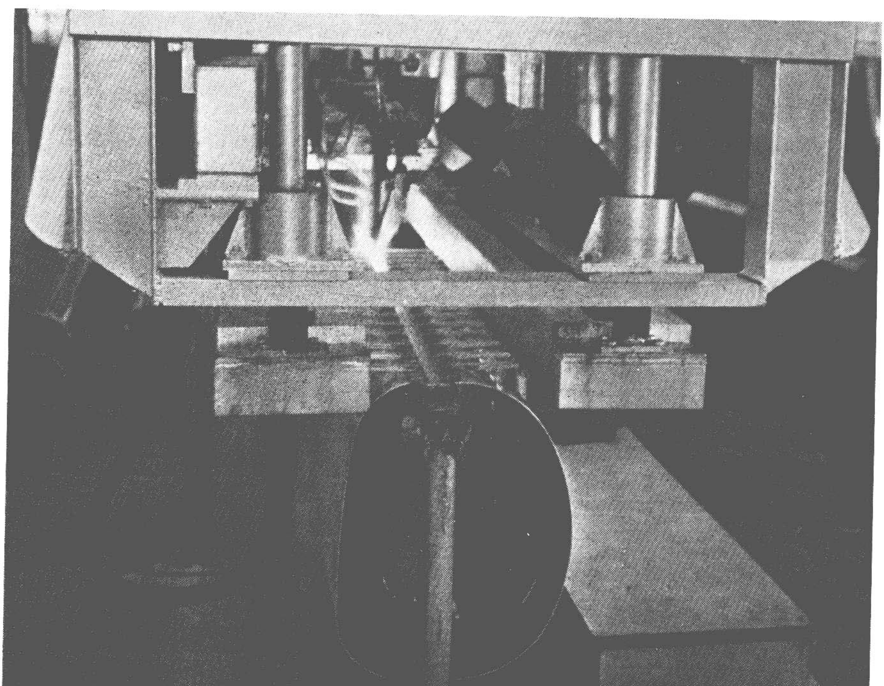
Welding, Resistance, Upset: Coalescence produced by heat from resistance to flow of electric current from one abutting surface to other as light pressure is applied, followed by application of high pressure to "upset" metal at abutting surfaces.

Welding, Stud, Shielded: Coalescence is produced by electric arc between metal stud and work surface; shielded by inert-gas envelope; pressure always used.

Welding, Stud, Unshielded: Coalescence is produced by electric arc drawn between metal stud and work surface and subsequent application of pressure. No filler metal added. No shielding.

Welding, Tungsten-Arc, Gas-Shielded: Coalescence is produced by electric arc between tungsten electrode and work; with or without filler metal; shielded by inert-gas envelope. Also known as the "Heliarc" or "Heliweld" process.

Fig. 5—Here a special fixture is suspended from overhead to facilitate loading and unloading when welding large and non-uniform objects such as shown here. Automatic carbon-arc welding.



ALUMINUM ALLOYS

There are two major groups of wrought aluminum alloys: (1) Non-heat-treatable alloys and (2) Heat-treatable alloys. The non-heat-treatable alloys can be strengthened only by means of cold work. The heat-treatable alloys require suitable thermal treatment to develop optimum properties.

Wrought aluminum alloys are known commercially by a series of letters and numbers (2S, 24S, X55S, etc.) arbitrarily assigned by the producers. *Alloy designations* indicate definite chemical compositions, but unlike designations for certain other materials they have no relation to each other. All producers use the same alloy designation system.

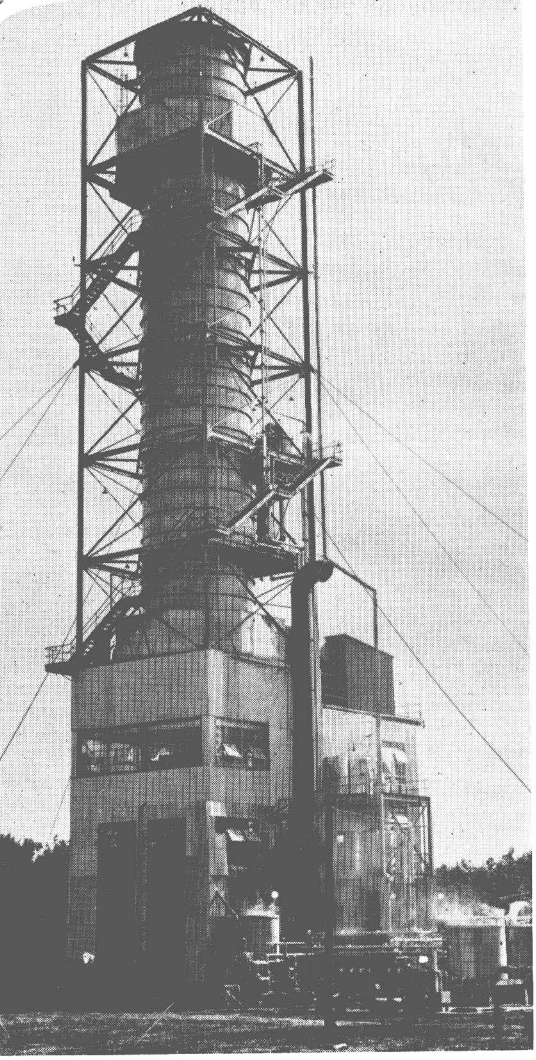
Temper designations are also standardized and are suffixed to the alloy designation to signify mechanical and/or thermal treatment:

- –F As fabricated.
- –O Annealed, recrystallized (wrought products only).
- –H Strain hardened.
  - –H1 Strain hardened only.
  - –H2 Strain hardened and then partially annealed.
  - –H3 Strain hardened and then stabilized.
- –W Solution heat treated–unstable temper.
- –T Treated to produce stable tempers other than –F, –O, or –H.
  - –T2 Annealed (cast products only).
  - –T3 Solution heat treated and then cold worked.
  - –T4 Solution heat treated.
  - –T5 Artificially aged only.
  - –T6 Solution heat treated and then artificially aged.
  - –T7 Solution heat treated and then stabilized.
  - –T8 Solution heat treated, cold worked, and then artificially aged.
  - –T9 Solution heat treated, artificially aged, and then cold worked.
  - –T10 Artificially aged and then cold worked.

Note: Additional digits are sometimes added to the "–H" group to indicate the *degree* of strain hardening or annealing; or to the "–T" group to indicate certain variations in treatment.

Some heat-treatable alloys are not produced in the –W temper because after quenching they rapidly age at room temperature to the –T temper. Alloys which are produced in –W temper may be converted to –T temper by a low-temperature, artificial aging treatment.

Space here does not permit complete listing of chemical analyses, mechanical properties, etc. of the various alloys and tempers. For all this



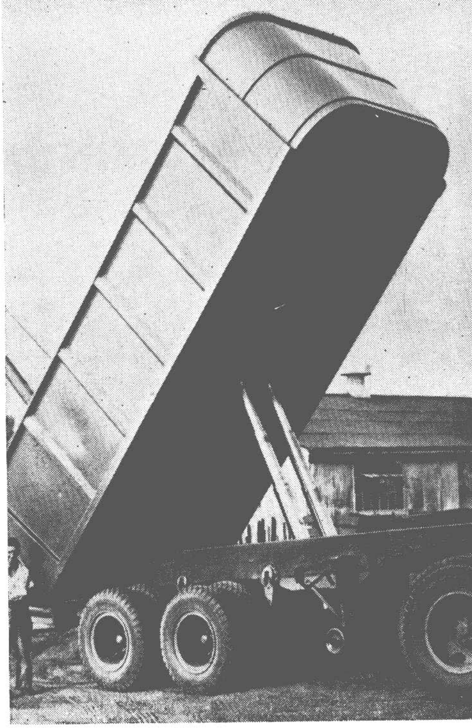


Fig. 7 — All-aluminum all-welded dump truck body for tractor-trailer trucking has 594 cubic feet capacity, will carry 40,000 pounds of gravel. Use of welded aluminum cut weight more than 50 percent, permits hauling 2455 pounds bigger pay load with same highway load limit. Marion Metal Products Co. photo.

Fig. 6—Aluminum tower for chemical processing work. Tank is 122 feet long, stands 184 feet high. Built by Girdler Corp., Louisville, for Mississippi Chemical Corp. Photo from The Linde Air Products Co.

information, see Reynolds manual "The Aluminum Data Book" containing almost 200 pages of tables and other useful facts on aluminum.

Commercially pure aluminum, or 2S, is the most weldable aluminum alloy. This non-heat-treatable alloy contains a minimum of 99% aluminum and small quantities of iron and silicon, present as impurities. Because of its high purity, 2S has excellent corrosion resistance and workability, but low strength.

For applications requiring slightly higher strength and similar welding characteristics, 3S is frequently used. It is a non-heat-treatable alloy containing a minimum of 98% aluminum and from 1% to 1½% manganese.

Another non-heat-treatable alloy, 52S, has approximately twice the strength of 3S. It is an aluminum-magnesium-chromium alloy, combining strength with good corrosion resistance and workability. For best results, butt or edge welds should be made rather than lap or fillet welds, since it is more subject to cracking near the weld zone.

4S is 1.25% manganese and 1% magnesium. 50S is a 1.3% magnesium alloy. These alloys have more strength than 3S but not as much as 52S. However, they are both similar to 52S as far as weldability is concerned.

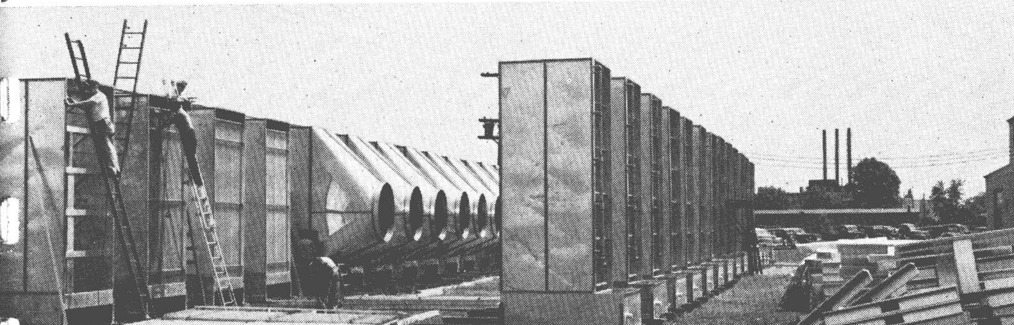
The heat-treatable alloys of aluminum are in general not as suitable for welding as the non-heat-treatable alloys. These alloys, however, if heat treated subsequent to welding, develop higher strengths, but if welded after heat treatment much strength will be lost by partial annealing.

Alloy 63S is a heat-treatable aluminum-magnesium-silicon-chromium alloy of intermediate strength. Its weldability is considerably better than that of 52S. This material should not be welded by a fusion process if a full strength joint is desired.

61S is similar to 63S, but has slightly higher strength. This material, used extensively in architectural and furniture fields, where strength and weldability are essential, is an aluminum-magnesium-silicon-copper-chromium alloy.

The dural type aluminum alloys, such as 14S, 17S, 24S, and R301, may also be welded. In the heat-treated or annealed condition, resistance welding is the only form of welding favorable to these alloys. Fusion welding not only produces a material having considerable reduction in strength, but also embrittles the metal in the area adjacent to the weld. Corrosion resistance is also seriously impaired. Reduction in corrosion resistance is similarly marked in clad alloys welded by the fusion method because of diffusion into the cladding.

Fig. 8—Large aluminum air-conditioning units have frames welded with tungsten arc and skins spot welded to frames. Tanks below units are welded by the inert-gas-shielded metallic-arc process. Air Reduction Sales Co. photo.



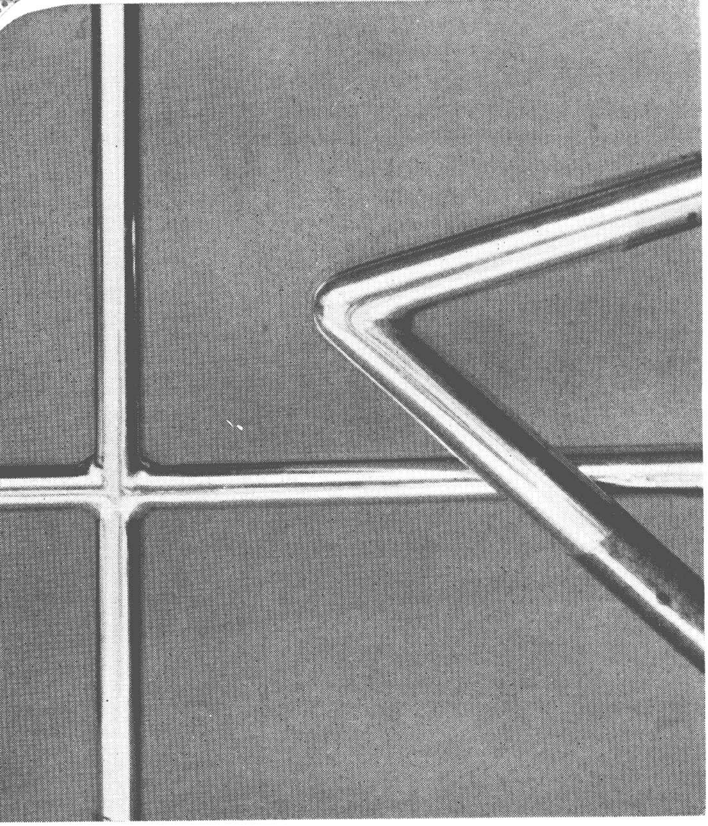


Fig. 9 — Aluminum tubing welded with a P & H 300-ampere H. F. AC welder. Note smooth, highly polished welds. Harnischfeger Corp. photo.

To summarize, 2S, 3S, 4S, 50S, 52S, 61S and 63S may be welded by either gas or resistance welding processes. Generally, these materials can also be welded by the metal-arc or carbon-arc process as well as by the atomic-hydrogen process. The inert-gas-shielded arc welding process, wherein the arc is shielded in an atmosphere of helium or argon, is likewise adaptable to the welding of certain of the aluminum alloys. The dural type alloys should be welded by the resistance welding process for best results. See weldability charts and tables, Pages 5-11.

When cold work tempers of non-heat-treatable alloys are fusion welded, all the effects of previous cold work are removed at the weld area. Resistance welding likewise reduces the temper somewhat. The heat necessary to weld the material softens or anneals it. This fact must be remembered whenever welding is applied to cold work tempers of non-heat-treatable alloys used in a product because of the increased strength imparted by the cold working. Annealed material, however, when welded, has essentially the same strength as before welding. In some instances, the weld metal may even show higher mechanical properties than the annealed parent metal.

Heat-treatable alloys welded in the T4 or T6 conditions do not necessarily return to the fully annealed condition as a result of the heat of welding. However, the strength of the parent metal in the vicinity of the weld is lowered considerably. The extent of the loss in strength cannot