

# WELDING OF NON-FERROUS METALS

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## Abstract

The paper deals with various methods of welding both by gas and electric welding processes, although it deals chiefly with the oxy-acetylene process.

## Introduction

**T**HE non-ferrous metals such as aluminium, copper, magnesium, lead, tin, zinc, nickel, etc., and their various alloys today form one of the most important groups of materials available to the discerning engineers. Although the output of iron and steel far exceeds the total tonnage of the non-ferrous metals, their true value can be assessed by reference to the special wide range of properties presented. Their cost most often is more than that of mild steel or cast iron, but their special characteristics make their choice obvious and economic. It is, therefore, quite natural that in the present day, welding of these non-ferrous metals should engage the attention of the engineers.

It may be stated at the outset that almost all non-ferrous metals and alloys are weldable by one process or another. The word 'Weldability', which is very often used in practice, can be defined as 'the capacity of a metal to be welded under fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service'. Although this definition is quite expressive, it cannot be evaluated quantitatively and can only be expressed as a personal opinion.

The process normally used for welding the non-ferrous metals can be broadly divided into two groups—fusion processes and pressure processes.

The fusion processes are: gas welding, inert-gas shielded arc welding (argon arc and argonaut welding), metallic arc welding,

carbon arc welding and atomic hydrogen welding.

The pressure processes are: spot, seam, butt and flash welding (all being resistance welding processes), manual forge welding and pressure welding.

The essential difference between the fusion and pressure welding is that in the former the weld is made by melting the parent metal with or without the addition of extra metal and allowing the metal to solidify, while in the latter the joining is effected by pressure without fusing the metal, but this desirable aim is not always realized in practice and some melting may take place.

It will not be out of place to refer here to brazing processes which are considerably employed in the fabrication of aluminium and certain of its alloys, copper and its alloys, nickel and its alloys, and some precious metals using appropriate brazing filler rods.

## Welding Process

The processes used for welding non-ferrous metals are now described in brief.

*Gas Welding Process*—The oxy-acetylene welding is by far the most important and mainly used. The oxy-acetylene flame has a very high temperature exceeding 3000°C. and the versatile nature of the flame obtainable adds to its advantage.

The equipment used for oxy-acetylene welding is too well known and needs no introduction. The supply of oxygen is normally obtained from cylinders which are charged to 2000 lb./sq. in., or from a pipe-line where such installation exists. Acetylene is drawn either from generators or from cylinders, the latter being commonly known as dissolved acetylene. For welding

certain metals the use of dissolved acetylene is preferable because of its higher purity.

The welding blowpipes are mainly of two types — the injector type for use with generated acetylene and the non-injector type for use with high-pressure system, i.e. with dissolved acetylene. Regulators for controlling the flow of the gases from cylinders are also necessary.

Three types of flames are used for welding non-ferrous metals; they are neutral flame, carburizing flame (excess acetylene) and oxidizing flame (excess oxygen).

The manipulation of the blowpipe for welding is important and it is dependent on various factors. There are three well-known manipulative techniques, and they are 'Leftward', 'Rightward' and 'Vertical Upward' techniques.

As to the other fuel gases such as hydrogen, coal-gas, etc., their uses are very limited and are often restricted to the welding of zinc, lead and in some cases to brazing.

*Inert-gas Shielded Arc Processes* — The introduction of inert-gas shielded arc process in the field of welding is very recent but no doubt very important. The most important in this field are: argon arc welding and the argonaut welding — the former employing a non-consumable tungsten electrode and the latter a consumable electrode, which is also the filler rod.

The main advantage of this process is that it can be employed for welding a large majority of the non-ferrous metals without the use of any flux.

*Arc Welding* — The impact of arc welding in the fabrication of non-ferrous metals is being felt every day. The equipment used for arc welding of non-ferrous metals by this process is similar to those used for steels and is familiar to every engineer. Both motor generator and transformer type welding sets are extensively used. It will be, however, significant to note that for welding certain non-ferrous metals with a transformer type welding set it is necessary to use an arc stabilizer which superimposes a high-fre-

quency alternating current of the order of about 5 to 3 megacycles per second. This H.F. current not only stabilizes the arc in running conditions, but also increases the ease with which an arc may be struck.

In view of the very limited use of the carbon arc and atomic hydrogen welding, it is not proposed to dilate on these two processes.

*Pressure Process* — The majority of the welding processes used in this group are one or another form of resistance welding. In the short space of time available at our disposal, it is not possible to go into details of the types of plants used for these welding processes. Both alternating and direct currents are used, the latter being mainly used in the condenser discharge type resistance welding machines which give a large impulse of current for an extremely short period. Such machines are employed for welding some of the non-ferrous metals.

The choice of the process and technique of welding non-ferrous metals is governed to a large extent by their physical, mechanical, chemical and metallurgical properties. They are:

- i) Physical — Melting point, specific and latent heats, boiling point, conductivity, coefficient of expansion, change in volume on freezing (effect of alloying constituents on the physical properties).
- ii) Mechanical properties and the changes effected by the variation of temperature.
- iii) Chemical, including physico-chemical properties — Oxidation and gas solubility.
- iv) Metallurgical properties — Cast metal, wrought products, heat-treated alloys and effect of heat on the parent metal.

In this brief résumé it is not possible to detail the procedures of welding all the non-ferrous metals and alloys. Therefore, the procedure of welding two major non-ferrous metals — aluminium and copper — will be described in detail.

## Welding of Aluminium and Its Alloys

Aluminium and its alloys, because of their low specific gravity, high conductivity, good resistance to corrosion and other characteristics as required for a particular application, are being used increasingly for fabrication purposes. Thus pure aluminium is employed extensively for chemical plants and food-processing equipment, certain aluminium magnesium alloys for marine work, high strength heat-treated alloys for aircrafts, etc.

Broadly, for welding purposes aluminium and its alloys can be classified into two main groups, i.e. non-heat-treatable and heat-treatable.

The chief characteristics influencing the weldability of aluminium and its alloys are their (i) low melting point (there is no visible colour change on heating), (ii) high specific heat, (iii) high electrical and thermal conductivity, (iv) hot-shortness, (v) high thermal expansion and contraction, (vi) ready surface oxidation at all temperatures, (vii) capacity to absorb hydrogen in molten and solid state, and lastly (viii) the effect of welding on their properties, specially in the case of heat-treated alloys.

*Gas Welding* — Before the introduction of argon arc or argonaut welding, oxy-acetylene welding was by far the most widely practised method of welding aluminium and its non-heat-treatable alloys.

(i) *Design* — The design of welded structures in these metals requires careful consideration mainly due to the necessity for the use of a corrosive flux. This necessitates access to both sides of the joints in order to ensure adequate provision for the removal of flux residue after welding and prohibits the employment of lap, fillet, edge and corner joints in order to avoid flux entrapment. Thus the necessity for the employment of butt joints and for accessibility on both sides of the joint; this often produces problems in design.

(ii) *Edge preparation* — It is most important that the edges should be well cleaned

immediately prior to welding. Oil or grease must be removed by degreasing and the edges of the metal may be scratch brushed to remove the oxide skin, but the use of emery cloth is not recommended. Cleaning should be immediately followed by fluxing. Sheets up to  $\frac{1}{8}$  in. thick need not be bevelled, but over  $\frac{1}{8}$  in. the edges should be bevelled to 30° or 45°.

Alignment of edges should be preserved by tacking or by using clamps and jigs. Taper-spacing may also be used allowing about  $\frac{3}{16}$  to  $\frac{1}{2}$  in. opening per foot of joint. In case of long seams tacking or the use of jigs is preferable and the weld should be started inches away from the end and the short unwelded portion completed subsequently.

(iii) *Flux* — The use of a good quality flux is essential and many proved proprietary brands are readily available. The flux, which is mainly a mixture containing alkali halides, readily dissolves the refractory oxide and ensures adequate protection of the metal while welding.

The usual method of applying the flux is to make paste with water or alcohol and then painting the welding rod and the welding edges. The welding rod may also be fluxed by dipping the heated end of the welding wire in the powdered flux and melting down the 'tuft' with flame. The use of flux must be kept under control as otherwise the use of excessive flux may lead to some flux entrapment.

(iv) *The welding flame and blowpipe manipulation* — For welding aluminium and its alloys, a strictly soft neutral flame is essential; any tendency to use an oxidizing flame will be detrimental and the use of harsh flame should be avoided. Some often use a flame with a haze of excess of acetylene, but this is quite unnecessary. In case of welding heavy sections it may be necessary to use a nozzle size one size larger than that used for steel of the same thickness and also to preheat the area with the blowpipe before commencing welding operations.

For light sections the leftward or forward technique is used; but very often, especially for heavier sections, the vertical technique, preferably double-operator vertical technique, is used with advantage.

(v) *Filler rod* — In general it is desirable to use filler rods which on deposition will give a composition same as the parent metal. This is very essential where service conditions do not allow any variation between the composition of the parent metal and the weld deposit. It may, however, be noted that aluminium-silicon (5 per cent) alloy rods are often used for welding various aluminium alloys including some heat-treated alloys. A large number of proprietary brand of filler rods suitable for welding aluminium and its alloys are available.

(vi) *Finishing of welds* — The article after welding should be thoroughly scrubbed with hot water and scrubbing brush to remove all traces of flux, to be followed by a final wash in 5 per cent nitric acid and water. Cold-working and blowpipe annealing will improve the mechanical properties of a weld.

*Argon Arc and Argonaut Welding* — These processes are fast replacing other conventional methods of welding aluminium and its alloys. Since these processes do not require the use of flux, no restriction on the design is placed, with their resultant advantages; and also the speed of welding is considerably higher.

*Arc Welding* — The introduction of this process for welding aluminium and its alloys is of comparatively recent origin. Direct current is normally used, but alternating current may be used with H.F. arc stabilizer. The electrodes commonly used have a core wire of aluminium-silicon alloy, though a few other types with magnesium, magnesium-silicon as alloying constituents are also available. The flux coating used for these electrodes is highly hygroscopic and corrosive.

*Resistance Welding Process* — The application of resistance welding process to aluminium and its alloys has progressed very

rapidly during the past few years, mainly due to the demands of the aircraft industry. Spot, seam and flash welding are considerably used for welding aluminium and its alloys, including many of the heat-treated alloys. In view of the high thermal and electrical conductivities of this metal and its alloys, special type machines are necessary for their satisfactory welding.

In view of the very limited use of the other processes, their reference here is hardly merited.

### Welding of Copper

*Oxy-acetylene Welding* — For fusion welding deoxidized copper is preferable, but tough pitched copper is suitable for bronze welding.

The most outstanding characteristics governing the weldability of copper are its (i) high thermal conductivity, (ii) high thermal expansion, (iii) hot-shortness, (iv) high fluidity when molten, (v) reaction with oxygen at high temperature, and (vi) capacity to dissolve hydrogen at high temperature.

(i) *Edge preparation* — For fusion welding only butt joint should be used, lap or fillet joints owing to extreme hot-shortness of the metal are not recommended. The edges should be cleaned and freed from surface oxide. The edges of thin sheets can be flanged, but when the thickness exceeds  $\frac{1}{16}$  in. the edges should be square, over  $\frac{1}{8}$  in. they should be bevelled to 30°-45° with a slight nose.

Long seams should be taper-spaced, allowing about  $\frac{3}{16}$  in. gap per foot. Owing to the hot-shortness of the metal, tacking is not recommended. Aligning clamps and jigs may be used, but expansion and contraction should not be restricted. In down-hand welding backing strip covered with dry asbestos to provide a support is used.

(ii) *Flux* — The use of flux is not essential, but its use is recommended to prevent the formation of oxide during welding. The welding edges, top and underside of the sheet

should be painted with the flux made into a paste.

(iii) *The welding flame and blowpipe manipulation* — The flame should be neutral and to ensure this often the flame is adjusted with a slight excess acetylene feather. Also owing to high conductivity of copper it is desirable to use a nozzle size one or two sizes larger than that used for steel of the same thickness. Often for welding thick sections it is desirable to use two blowpipes, one for preheating and the other for welding. Leftward or rightward techniques, depending on the thickness to be welded, are employed. Vertical welding and often double-operator vertical welding is employed with advantage.

(iv) *Filler rods* — Completely deoxidized filler rods containing either phosphorus or silver or both as deoxidizer are the commonest types. The use of silicon as a deoxidizer is not also uncommon, but best results have been obtained with the former types. Good proprietary brand rods are readily available.

(v) *Finishing the weld* — The strength of the weld is improved and the weld metal contraction countered by hammering. This must be done from red to black heat; if the metal is hammered too hot cracks may occur, and cold hammering will harden and embrittle the metal.

*Inert-gas Shielded Arc Welding* — Copper can also be satisfactorily welded by argon arc process.

Other processes of welding copper are not generally used.

### Summary of the Processes Commonly Used for Welding of Aluminium and Copper and Their Alloys

#### A. Aluminium and Its Alloys

- i) Aluminium — Oxy-acetylene welding, argon arc and argonaut welding, brazing, metallic arc welding.
- ii) Aluminium alloys (non-heat-treatable) — Oxy-acetylene welding, argon arc and argonaut welding, metallic arc welding, spot and seam welding.

- iii) Aluminium alloys (heat-treatable) — Argon arc, spot, seam and flash welding.

#### B. Copper and Its Alloys

- i) Copper — Oxy-acetylene welding, argon arc and argonaut welding and brazing.
- ii) Copper-zinc alloys including nickel-silver and high tensile brass — Oxy-acetylene welding, argon arc welding (only for alloys containing less than 30 per cent zinc), metallic arc welding and brazing.
- iii) Copper-tin alloys — Oxy-acetylene welding, metallic arc welding, brazing, carbon arc welding and argon arc welding.
- iv) Copper-aluminium alloys — Oxy-acetylene welding, argon arc welding, carbon arc welding and spot welding.
- v) Copper-silicon alloys — Oxy-acetylene welding, argon arc welding, metallic arc welding, spot and seam welding.
- vi) Copper-nickel (cupro-nickel) alloys — Oxy-acetylene welding, argon arc welding, metallic arc welding and brazing.

#### C. Lead

Lead — Oxy-acetylene, oxy-hydrogen, oxy-coal gas, air-acetylene, air-coal gas.

#### D. Magnesium Alloys

Oxy-acetylene welding, oxy-hydrogen and oxy-coal gas welding, argon arc welding, spot welding.

#### E. Nickel and Its Alloys

- i) Nickel — Oxy-acetylene welding, argon arc welding, metallic arc welding, carbon arc welding, spot, seam, butt and flash welding.
- ii) Nickel-copper alloys (monel) — Oxy-acetylene welding, argon arc welding, metallic arc welding, carbon arc welding, brazing and spot, seam, butt and flash welding.
- iii) Nickel-chromium-non-alloy inconel — Oxy-acetylene welding, argon arc welding, metallic arc welding.

#### F. Zinc and Zinc-base Diecasting

Oxy-acetylene and oxy-hydrogen welding.