Welding of Aluminium Bronzes

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Copper Development Association

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and user industries and maintains close contact with other copper development associations throughout the world.

Website: www.cda.org.uk

Email: helpline@copperdev.co.uk

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Introduction

Besides their considerable strength and toughness, Aluminium Bronzes possess a unique combination of other properties including corrosion resistance in a wide range of aggressive media, wear resistance and low magnetic permeability. They can be readily cast, fabricated and machined. They can also be readily welded in either cast or wrought form and this is a successful, common method of fabrication used for components specified for the most critical of applications.

These notes provide a guide to successful welding practice that will enable strong, corrosion-resistant welds to be made reproducibly. As with many other materials, instances of unsatisfactory welds have been reported. These are normally found to have been caused by a lack of appreciation of material characteristics, poor welding practice, inadequately specified material or a combination of these features. Use of the basic considerations included in these notes will help the avoidance of these pitfalls. If further help is required, liaison with manufacturers, suppliers or other specialist organisations will be of value.

Types of Copper Aluminium Alloy (Aluminium Bronze)

The Copper-aluminium alloys, commonly known as Aluminium Bronzes, are a range of copper-based alloys in which aluminium up to 14% is the primary alloying element. In addition, other major alloying elements are nickel, iron, manganese and silicon. Varying the proportions of these results in a range of alloys to meet a wide variety of engineering requirements. There are four major groups of Aluminium Bronze, these being listed in Table 1 & Table 2:

Group 1

The alloys containing less than 8% of aluminium, typically CA102 and 106. Being single phase alloys these have a good ductility and are suitable for extensive cold working.

Group 2

The two-phase (duplex) alloys two-phase alloys containing from 8 to 11% of aluminium, frequently also with additions of iron and nickel to increase strength. This represents the largest tonnage, typical compositions being the casting alloys AB1 and AB2 and the wrought alloys CA105, CA104 and those ex-DGS specifications recently revised and re-issued in Naval Engineering Standard (NES) form as NES 747 when cast and NES 833 in wrought form.

Group 3

The Aluminium-Silicon-Bronzes of lower magnetic permeability such as AB3, CA107 and NES 834.

Group 4

The copper-manganese-aluminium alloys with good castability originally developed for the manufacture of propellers such as CMA1

Table 1 - Compositions of Cast Copper Aluminium Alloys

BS 1400 Designation	Alloy Composition (wt %) - remainder Cu*				
	Al	Fe	Ni	Mn	Si
AB1	8.5 - 10.5	1.5 - 3.5	1.0 max	1.0 max.	
AB2	8.5 - 10.5	3.5 - 5.5	4.5 - 6.5	1.5 max.	
AB3	6.0 - 6.4	0.5 - 0.7			2.0 - 2.4
CMA1	7.5 - 8.5	2.0 - 4.0	1.5 - 4.5	11.0 - 14.0	
CMA2	8.5 - 9.0	2.0 - 4.0	1.5 - 4.5	11.0 - 14.0	

* Alloying elements only, impurities also specified in BS1400

Table 2 - Compositions of Wrought Copper-Aluminium Alloys

BS Designation	Alloy Composition (wt%) - remainder Cu*				
	Al	Fe	Ni	Mn	Si
CA101	4.5 - 5.5				
CA102	6.0 - 7.5	(Fe + Ni + Mn 1.0 optional)			
CA103	8.8 - 10.0	(Fe+Ni 4.0 ma			
CA104	8.5 - 11.0	4.0 - 5.5	4.0 - 5.5	0.5 max.	
CA105	8.0 - 11.0	1.5 - 3.5	4.0 - 7.0	0.5 - 2.0	
CA106	6.5 - 8.0	2.0 - 3.5			
CA107	6.0 - 6.4	0.5 - 0.7		0.5 max.	2.0 - 2.4

* Alloying elements only, impurities also specified in the standards.

Naval Engineering Standards

For Aluminium Bronzes, the following apply:

NES 747 - Nickel-Aluminium-Bronze Castings and Ingots

Pt 1 - Centrifugal castings and ingots (naval alloy)
Pt 2 - Sand castings and ingots (naval alloy, replaces DGS 348)
Pt 3 - Sand castings and ingots (commercial alloy - replaces DGS 361A)
Pt 4 - Sand castings and ingots (welding restricted to non-wetted surfaces)

NES 833 - Nickel-Aluminium Bronze

Pt 1 - Sheet, strip and plate
Pt 2 - Forgings, forging stock and sections (replaces DGS 1043)

NES 834 - Silicon-Aluminium-Bronze

Pt 1 - Ingots and castings (replacing DGS 128A)
Pt 2 - Sheet, strip and plate (replacing DGS 8453)
Pt 3 - Forgings, forging stock, rods and sections (replacing DGS 1044)

Much more information on the Aluminium Bronzes is contained in a series of publications available free of charge from the Copper Development Association.

Welding Behaviour

The following notes are applicable to the welding of Aluminium Bronzes:

a) The natural presence of the aluminium-rich oxide surface films is vital to the outstanding corrosion resistance of the alloys, but they can impede welding, both on solid metal and when formed on the molten weld pool. If entrapped in the weld, soundness is of course affected. Pre-weld and inter-pass cleaning of the metal and correct choice of welding process help to avoid this problem.

b) Allowance must be made for aluminium bronzes having a higher thermal conductivity and thermal expansion rate than common steels. These properties mean that heat is dissipated more uniformly and that therefore the heat-affected zone is smaller; undue restraint should not be present. The effects of these differences can be catered for by correct joint design and jigging to avoid undue restraint, and by correct choice of welding process and technique to restrict unnecessary heat spread.

c) The alloys, especially those of lower aluminium content (single phase) have reduced ductility in the temperature range of about 400-600°C. This gives a potential hazard of cracking during cooling after solidification which may be reduced by avoiding restraint, by correct joint design and by management of heat input through control of welding technique.

d) As when all metals are welded, the aluminium bronzes undergo metallurgical changes, both the weld zone and the heat-affected zone varying to some extent from the parent metal. This variation in structure and properties may have a potentially deleterious effect on corrosion resistance in the heat-affected zone. Depending on the severity of service conditions expected, it may be advisable to give either a post-weld stress-relief or a full heat treatment to restore properties and homogenise the structure.

Choice of Welding Process

The basic characteristics of the alloys outlined, their form and their previous fabrication history must all be considered when choosing the process to be used and the filler metal.

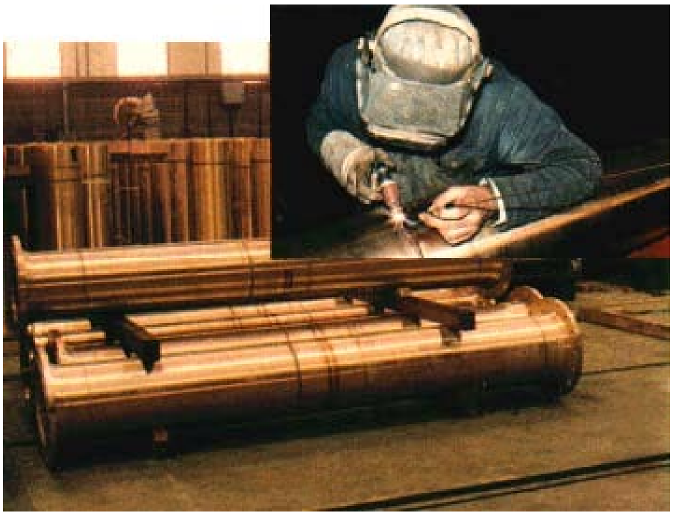
Oxy-acetylene gas welding is barely practicable on any but the very simplest of work.

Manual metal arc welding is occasionally used in maintenance and repair. Flux-coated filler rods are available commercially for the purpose, but, in both gas and metal-arc welding, fluxes capable of dealing with the refractory alumina film are required and the entrapment of such residues can seriously impede production of a satisfactory weld.

It is therefore recommended that, for best results, **gas-shielded arc welding** is employed in which the weld area is shielded from significant oxidation by an inert gas cover. The action of the arc effectively disperses any oxide which may be present. Welding in the downhand position is the most successful.

The choice between TIG and MIG welding, or the possible use of the wide range of techniques such as pulsed current or plasma arc developed to supplement these basic techniques is subject to individual judgement based on component design and experience.

For routine construction, it is normally considered good practice to secure good and controllable root penetration with TIG welding for the root runs, followed by TIG or MIG for subsequent weld build-up. MIG welding is faster and pulsed MIG gives much more controllability. It is found that pulsed MIG enables satisfactory root runs to be made, of quality equal to the best manual TIG practice.



The large quantities of water required by offshore platforms are provided by submersible pumps suspended from piping which may be from 6 to 18" nominal bore. Aluminium Bronze is ideal, having the necessary strength, ductility and resistance to corrosion and fatigue. The pipes are frequently spuncast in two sections with a flange on one end of each. After proof maching and joint preparation, these are then welded, stress relieved and non-destructively tested. Shown are 18" pipes ready for delivery.

(Spunalloys Ltd and Scotmark Engineering)

Filler metals to match the commercial range of Aluminium Bronze alloys are available to National Specifications, see Table 3.

Filler Metals

Aluminum Bronze filler metals suitable for use with gas-shielded TIG and MIG welding processes are readily available commercially for the full range of alloys. They are manufactured, and available certified to, BS 2901 "Filler Metals for Gas-shielded Arc Welding, Pt.3 Copper and Copper Alloys", to other national and international standards and under a variety of trade names.

The following are a recommended selection from BS 2901: Pt3 and are available in straight rod form for TIG welding and as wire on reels for MIG welding, in ranges of appropriate diameters.

Table 3 - Recommended Filler Metals (from BS 2901: Pt 3)

BS Designation	**Nominal Composition (wt%) - remainder Cu***				
	Al	**Fe**	**Ni**	**Mn**	**Si**
C12	6.0 - 7.5	(Fe + Ni + Mn 1.0 - 2.5 optional)			
C12Fe	6.5 - 8.5	2.5 - 3.5			
C13	9.0 - 11.0	0.75 - 1.5			
C20	8.0 - 9.5	1.5 - 3.5	3.5 - 5.0	0.5 - 2.0	
C22	7.0 - 8.5	2.0 - 4.0	1.5 - 3.0	11.0 - 14.0	
C23	6.0 - 6.4	0.5 - 0.7			2.0 - 2.4
C26	8.5 - 9.5	3.0 - 5.0	4.0 - 5.5	0.6 - 3.5	

* alloying additions only, impurity maxima are fully specified in the standard

The factors influencing choice of filler metals for particular applications are covered in Welding Practice.

Welding Practice

These notes on good welding practice are restricted to coverage of the recommended gas-shielded arc welding techniques. It is assumed that all equipment is in full working order, that working conditions are carefully controlled and that approved standard practices are followed at all times.

Joint Design and Preparation

Joints must be designed to ensure free thermal movement so that the material is not placed under excessive restraint during the weld cycle. For normal thicknesses, a root gap of 1.5mm is recommended to ensure satisfactory weld metal penetration.

The type of edge preparation used, such as single-V, square-butt., should be in accordance with normal good welding practice.

The area within and around the weld must be scrupulously clean and free from grease, dirt, non-volatile marker and visible oxide. Scratch-brushing with a bronze (not steel!) brush immediately before welding is recommended.

Preheat and Inter-Run Temperature Control

It is seldom necessary to employ preheat to higher than 150-200°C, and in most cases it is sufficient to heat the work only sufficiently to drive off dampness and ensure no further condensation. Excessive preheat can lead to the heat-affected zone being excessive, with a greater volume of metal at risk of hot cracking and distortion problems. Likewise, inter-run temperatures should be kept similarly limited, if necessary by allowing the work to cool between further runs. The use of the scratch brush to remove oxide between runs is recommended to reduce the risk of weld porosity.

Selection of Shielding Gas

TIG Welding

Argon or helium is commonly used, or sometimes a mixture of the two. With argon, it is normal to use an a.c. arc in which oxide film dispersion on the weld pool is achieved by the cyclical reversing polarity. For routine work on uncomplicated thin gauge (<5mm) components, this is satisfactory but it is necessary to use high-frequency re-ignition injection circuitry to keep the arc established.

Helium shielding is recommended on more complex structures in any gauge and especially in the welding of thick to thin sections, wrought to cast materials and where it is difficult to avoid restraint. Although a more expensive gas, its use is justified because it gives very clean welding conditions using d.c., electrode-negative working, a hotter arc and faster welding. The overall heat input is therefore less and the weld likely to be cleaner and freer from porosity and other defects.

MIG Welding

Conventional MIG welding using argon shielding with d.c., electrode- positive working is recommended when the MIG welding process is selected. However, argon-helium mixtures, containing up to 30% helium, can improve heat input and make for faster welding - the chief reason for using the process.

Selection of Filler Metal

Group 1 Alloys (single phase)

Single-run welds in thin gauge Group 1 alloys may be welded using matching filler metal to BS 2901 C12 type to achieve fully matching corrosion resistance across the weld area.

When more than one weld run is required, it is recommended that C13 filler metal is used for root runs, followed by a capping run of C12 when a matching corrosion resistance is required. This is because the C12 type filler, being single phase, is more susceptible to hot cracking. Welding on top of previous C12 weld runs is therefore likely to cause the root run material to reach the hot cracking temperature range and fail under the influence of any restraint. The C13 material is far more ductile and accommodating in this respect.

Group 2 Alloys (duplex)

These materials are normally satisfactorily welded using matching filler metal to BS 2901 such as C13, C20 and C26. C20 and C26 have better corrosion resistance but are less ductile during cooling after solidification. Where restraining conditions are present it is possible for the weld to crack on cooling, under these circumstances C13 should be used for the root and filling runs, followed by a capping of C20 or C26 as appropriate to provide matching corrosion resistance. If restraint is minimal, C20 or C26 can be used for all weld passes.

Group 3 Alloys (Aluminium-Silicon-Bronzes)

These alloys are readily welded with the matching filler metal, C23.

Group 4 Alloys (Manganese-Aluminium-Bronzes)

Matching filler C22 should be used.

Welding of Castings

The welding of Aluminum Bronze castings is commonly used for assembly of components difficult to produce as a single casting and to rebuild worn components during overhaul. It is also used on occasions to repair casting defects which are too deep to be smoothly ground out but is no substitute for good foundry practice and is not acceptable for the wetted faces of class 1 high-integrity, safety-critical components for naval use.

Where welding is carried out, the recommendations are largely as previously considered:

Matching filler-metals should be employed when possible.

Preheat and inter-run temperatures should be kept to a minimum, not above 200°C in order to prevent hot cracking and distortion.

The weld preparation must be smooth, clean and have a profile to enable access of the welding torch to all the excavated surface in order to avoid cavity formation.

Any defective metal must be completely removed and the clearance of the defects monitored by NDT methods before and after welding.

The weld preparation should be over-filled to allow for machining back to fully sound metal below the uneven weld metal surface.

Where operators are expected to work on high-integrity castings, it is usual to apply a welding procedure and operator qualification test including the preparation and completion of a specified weld specimen which is then subjected to testing by dye-penetrant, macro-etching and tensile testing techniques.

Weld-repairs can be carried out on castings as large as this 80-ton propeller.

(Stone Manganese Marine Ltd.)

Post-Weld Heat Treatment

In many cases, no post-weld heat treatment is necessary. However, when the material is required to have the utmost reliability under severe corrosive conditions, it is advisable to consider a heat treatment to ensure that the weld and heat-affected zone is fully restored to an optimum corrosion-resistant structure. This also ensures the relief of any residual internal stresses retained after welding which might otherwise initiate stress-corrosion.

A simple stress-relief anneal may be carried out at temperatures as low as 300-350°C for a time dependent on section thickness. The heat treatment needed to develop optimum corrosion resistance will depend on alloy, section thickness(es) and properties required and should therefore be determined from experience after expert advice. As an example, for weld-fabricated continuously cast tubes to be used in severe conditions, one treatment specified is a soak at 700-730°C for 6 hours followed by a cooling rate not exceeding 250°/hour. For thicker cast sections, such as propellers, some specifications call for soaking times of at least 20 minutes per 25mm of section thickness and rates of cooling not exceeding 50°/hour down to 100°C

Very much improved properties can be obtained in the duplex alloys by a full heat treatment such as a soak at 925-950°C and quench followed by tempering at 650-700°C and slow cool to restore corrosion resistance. This type of treatment is not often called for because of its cost, the tendency for it to cause distortion and the fact that existing properties are frequently adequate.

Testing

The general specification covering both destructive and non-destructive testing of fusion welds in copper and copper alloys is BS 4206 but many variations on this are called up in different specifications according to the severity of operating conditions expected.

Besides optical inspection, unaided or aided, dye-penetrant testing, radiography and ultrasonic inspection techniques may be specified as applicable.

The aluminium bronzes absorb X-rays and gamma rays to a greater extent than steel and test conditions are therefore different. Typically 300kV X-rays can be used up to 50mm thickness and Co60 gamma-rays up to 160mm thickness dependent on the minimum agreed porosity and defect levels to be detected.

Ultrasonic testing of castings is difficult due to their high damping capacity, especially of the propeller alloys containing high manganese levels. It can be used with advantage, however, on the thinner sections of wrought materials.

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Copper Development Association
5 Grovelands Business Centre
Boundary Way
Hemel Hempstead
HP2 7TE

Website: www.cda.org.uk
Email: helpline@copperdev.co.uk