Copper Development Association

Aluminium Bronze Alloys for Industry

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Acknowledgements

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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.

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Introduction

The aluminium bronzes are a range of copper based alloys in which aluminium up to 14% is the primary alloying element. Their combination of strength and corrosion resistance makes them one of today's most important engineering materials for highly stressed components in corrosive environments. They are available in both cast and wrought form and are readily weldable into fabricated components such as pipes and pressure vessels. They can have a strength greater than that of carbon steels and a corrosion resistance better than most stainless steels.

Besides these notes, attention is drawn to the availability of extra information available from Copper Development Association.

Applications

The numerous and varied applications for aluminium bronze alloys reflect fully their versatility as engineering materials. Aluminium bronzes are finding increasing use in chemical, petrochemical and desalination plant, marine, offshore and shipboard plant, power generation, aircraft, automotive and railway engineering, iron and steelmaking, electrical manufacturing and building industries.

Application areas are best discussed with reference to the primary service property required, but there is of course an interplay of properties which finally governs the selection of a particular alloy.

It is worth noting that the excellent mechanical properties obtainable from both high integrity castings and wrought products makes it possible in most applications to interchange them to achieve maximum economy in developing final component design.

A typical list of both cast and wrought components is shown in Table 1. It is by no means an exhaustive list as new applications are being constantly developed. Many applications are related to the marine environment because of the outstanding performance in seawater of aluminium bronze.

Table 1 – Typical industrial sectors in which aluminium bronze is finding increasing applications

Chemical and petrochemical plant	Power generation (including nuclear)	Desalination plant	Aircraft and automotive engineering
Shipboard, marine and Offshore	Electrical plant	Building and construction	General engineering
		Iron & Steelmaking	

This list of component parts within these fields can be broadly categorised below, although it is important to appreciate that the list is not exhaustive and that new alloys and applications are in continuous development. Discussion with established manufacturers is recommended.

FOUNDRY PRODUCTS		WROUGHT PRODUCTS	
Impellers	Bearings	Drop forgings	Chain
Propellers	Gear selector forks	Tubeplates	Impellers
Shafts	Synchronising rings	Tubes and shells	Compressor blades
Pumps and valves	Non-sparking tools	Pressure vessels	Shafting
Water cooled compressors	Glass moulds	Reaction and distillation vessels	Gears

FOUNDRY PRODUCTS		WROUGHT PRODUCTS	
Tubeplates and other heat exchanger parts	Pipe fittings	Pipework	Non-sparking tools
Channel covers	Rudders and propeller brackets	Wear plates	Non-magnetic equipment
Gears & Gear blanks	Die-cast components	Springs	Masonry fixings
Deep drawing dies	Continuous cast bar & section	Bearings	Rod, Bar and section
Pickling equipment	Centrifugal castings	Fasteners	Free hammer forgings
Rolling mill equipment		Valve spindles	
Bushes			
Also metal sprayed surfacing and weld surfacing of steel components for wear, corrosion and sparking resistance.			

Alloy Composition

In addition to aluminium, the major alloying elements are nickel, iron, manganese and silicon. Varying proportions of these result in a comprehensive range of alloys to meet a wide range of engineering requirements.

There are four major types of alloy available:

a) The **single-phase alpha alloys** containing less than 8% of aluminium. These have a good ductility and are suitable for extensive cold working. CA102 is typical of this type. Alloys containing 3% iron, such as CA106, are single phase up to over 9% aluminium

b) The **duplex alloys** containing from 8% - 11% aluminium and usually additions of iron and nickel to give higher strengths. Examples of these are the casting alloys:

AB1 CuAl10Fe3

AB2 CuAl10Fe5Ni5

and wrought alloys:

CA105 CuAl10Fe3

CA104 CuAl10Fe5Ni5

DGS1043

c) The **copper-aluminium-silicon alloys** have lower magnetic permeability:

Cast AB3 CuAl6Si2Fe

Wrought CA107 CuAl6Si2

DGS1044

These are mainly alpha alloys and have good strength and ductility.

d) The **copper-manganese-aluminium alloys** with good castability developed for the manufacture of propellers.

CMA1 CuMn13Al8Fe3Ni3

Appendix One gives a table of the main cast and wrought alloys and includes a note on the effects on physical and mechanical properties of the various alloying additions.

Guidance on the selection of alloys and product forms suitable for particular applications can be obtained from manufacturers and specialist stockholders.

Mechanical Properties

Some of the aluminium bronze alloys are of comparable strength to low carbon steels and stronger than most stainless steels. They retain a substantial proportion of their strength at elevated temperature and gain strength slightly at low temperatures while retaining ductility.

Appendix Two gives a table of the mechanical properties of the main aluminium bronze alloys.

A separate C.D.A. Publication No. 82 gives fuller details of mechanical and physical properties for a range of temperature conditions.

Corrosion resistance and Freedom from Oxide Flaking

The outstanding corrosion resistance of aluminium bronzes in marine and chemical processing environments is due to the formation of an intrinsic, thin but tough adherent film of aluminium oxide. This film is self healing and once formed, prevents further oxidation and consequently eliminates flaking so often encountered with ferrous alloys. Furthermore, the nickel-aluminium bronzes have excellent resistance to stress corrosion and corrosion fatigue. This freedom from oxide flaking combined with corrosion resistance, together with good creep and fatigue properties at elevated temperature, makes aluminium bronzes ideal for high temperature service. Special alloys with a high aluminium content perform well as glass mould tooling where good thermal conductivity improves production speed. Unlike the high-tensile brasses (manganese bronzes) and other brasses, nickel aluminium bronzes are highly resistant to stress corrosion cracking. They are also rarely, if at all, susceptible to pitting and are generally far more resistant to selective attack.

In view of the fact that their strength is comparable to many ferrous alloys, it is possible, without radical re-design, to substitute aluminium bronzes where even mild corrosion of ferrous components is a potential problem. This applies particularly in critical areas of plant operation such as pumps and valves. Table 2 gives a comparison of the resistance to corrosion of various ferrous and non-ferrous alloys. Aluminium bronzes are resistant to attack from a wide range of chemicals which are listed in Appendix Three. For further information on corrosion resistance see CDA. Publication No. 80.

The data in Table 2 is taken from Defence Standard 01/2 "Guide to Engineering Alloys Used in Naval Service: Data Sheets". The figures for general corrosion rate and crevice corrosion were determined using samples fully immersed beneath rafts in Langstone Harbour for one year. General corrosion results were provided by freely exposed specimens; crevice corrosion results by specimens held in Perspex jigs providing crevice conditions between the metal sample and the Perspex. The corrosion/erosion resistance tests were carried out using the Brownsdon and Bannister test, the specimens were fully immersed in natural sea water and supported at 60°C to a submerged jet, 0.4 mm diameter placed 1 - 2 mm away, through which air was forced at high velocity. From the minimum air jet velocity required to produce corrosion/erosion in a fourteen-day test, the minimum sea water velocity required to produce corrosion/erosion under service conditions was estimated on the basis of known service behaviour of some of the materials.

Table 2 – Resistance to general corrosion and crevice corrosion in flowing seawater

Alloys	**General Corrosion Rate mm/year**	**Crevice Corrosion mm/year**	**Corrosion/ Erosion Resistance ft/s**
Wrought Alloys:			
Phosphorus deoxidised copper C106 or C107	0.04	<0.025	6
Admiralty brass CZ111	0.05	<0.05	10
Aluminium brass CZ110	0.05	0.05	13
Naval brass CZ112	0.05	0.15	10
HT brass CZ115	0.18	0.75	10
90/10 copper-nickel	0.04	<0.04	12
70/30 copper-nickel	0 025	<0 025	15
5% aluminium bronze CA101	0.06	<0.06	14
8% aluminium bronze CA102	0.05	<0.05	14
9% aluminium bronze CA103	0.06	0.075	15
Nickel aluminium bronze CA104	0.075	see note (1)	
Aluminium silicon bronze DGS1044	0.06	<0.075	see note (1)
17% Cr stainless steel 430	<0.025	5.0	>30
Austenitic stainless steel 304	<0.025	0.25	>30
Austenitic stainless steel 316	0.025	0.13	>30
Monel	0.025	0.5	>30
Cast Alloys:			
Gunmetal LG2	0.04	<0 04	12
Gunmetal G1	0.025	<0.025	20
High tensile brass HTB1	0.18	0.25	8
Aluminium bronze AB1	0.06	<0.06	15
Nickel aluminium bronze AB2	0.06	see note (1)	
Manganese aluminium bronzes CMA1/CMA2	0.04	3.8	14
Austenitic cast iron (AUS 202)	0.075	0	>20
Austenitic stainless steel 304	<0.025	0.25	>30
Austenitic stainless steel 316	<0.025	0.125	>30
3% or 4% Si Monel	0.025	0.5	>30

Note (1)

The Defence Standard Data Sheets from which the figures in Table 7 are taken give "up to 0.5 mm/year" as the crevice corrosion rate and 14 ft/sec as the corrosion/erosion resistance limit for nickel aluminium bronze AB2 or CA104 and 8 ft/sec for aluminium silicon bronze DGS 1044. Ship Department Publication 18 "Design and Manufacture of Nickel-Aluminium-Bronze Sand Castings", Ministry of Defence (PE), 1979, gives the following corrosion data:

"Self-corrosion rate: For general long-term use over several years a reasonable design value is 0.05 mm/year but under ideal conditions for nickel aluminium bronze in sea water a black film slowly forms which reduces the corrosion rate in accordance with an equation of the form: Corrosion rate varies with $(time)^{-0.2}$

Crevice corrosion: After the initiation period which can be about 3 - 15 months with negligible corrosion the crevice corrosion propagates at about 1 mm/year.

Impingement resistance: 4.3 m/s is an appropriate design value in clean flowing sea water."

Crevice corrosion in nickel aluminium bronze takes the form of selective phase dealloying as described in Sections 3 (iii), 3 (iv) and 3 (v) and is usually of little practical significance since it has only a minimal effect on the surface finish. Crevice corrosion of austenitic stainless steels 304 and 316 - although shallower - takes the form of pitting with consequent serious deterioration of surface finish.

The Defence Standard Data Sheets suggest slightly higher corrosion/erosion resistance for aluminium bronze AB1 and CA103 than for nickel aluminium bronze AB2 and CA104 and much lower resistance for aluminium silicon bronze. Practical experience indicates, however, that the nickel aluminium bronzes are superior and aluminium silicon bronze only marginally inferior to other aluminium bronzes in this respect. It is perhaps significant that the Defence Standard Data Sheet figures for corrosion/erosion resistance were derived from Brownsdon and Bannister test results. Table 2 compares other Brownsdon and Bannister test results with those of jet impingement tests which are considered to be more representative of service behaviour.

Cavitation Erosion

Nickel-aluminium bronze has a greater resistance to cavitation erosion than cast steel, Monel alloys and the 400 and 300 series of stainless steel. By the same token, it has excellent resistance to impingement attack by gas bubbles. These characteristics make it particularly suitable for propellers, pump impellers and casings and turbine runners, giving them long service lives and optimum operating efficiency. Although more resistant to impingement attack by abrasive substances than grey cast iron and gunmetal, they are more vulnerable than cast steel and stainless steels. Filtration is sometimes necessary, therefore, in the case of high-speed pumps requiring the good corrosion and cavitation-erosion resistance properties of aluminium bronze but which have to handle water contaminated by sand or other abrasives.

Tables 3 and 4 give comparisons of cavitation erosion of various ferrous and non-ferrous alloys in fresh water and in 3% NaCl solution. For more information, see C.D.A. Publication No. 80.

Table 3 – Cavitation erosion in 3% NaCl solution

Material	**Depth of Attack**
Nickel aluminium bronze AB2	0.025 mm in 7 hours
Austenitic stainless steel 321	0.305 mm in 7 hours
High tensile brass HTB1	0.280 mm in 6 hours

Table 4 – Cavitation erosion rates in fresh water

Material	Cavitation Erosion Rate mm^3/hour
Nickel aluminium bronze AB2	0.6
Aluminium bronze AB1	0.8
Manganese aluminium bronze CMA1	1.5
High tensile brass HTB1	4.7
Gunmetal G1	4.9
Monel K500 (cold drawn)	2.8
Monel K500 (aged)	1.2
Austenitic stainless steel 321	1.7
Austenitic stainless steel 316	1.7
Cast martensitic stainless steel 420	1.7
Cast austenitic stainless steel 347	1.0
Spheroidal-graphite cast iron	1.3
Ni-resist iron	4.4

Wear Resistance

For straight resistance to wear, aluminium bronzes often provide excellent service in both cast and wrought forms. Spray or weld deposits of aluminium bronze on steel also provide effective wear resistant surfaces. Wear and abrasion resistant properties of special aluminium bronze alloys containing up to 14% aluminium, extend their application to deep drawing dies and similar tooling.

Bearing and Frictional Properties

Although the bearing properties of aluminium bronzes are not comparable with those of the traditional bearing bronzes, they do provide excellent results in slow speed, heavily loaded applications where the traditional bronzes have insufficient strength. Best results are usually achieved when running against hardened surfaces.

When lubrication of sliding surfaces is less than ideal, aluminium bronzes are superior to ferrous materials. Both wrought and cast alloys are used. Die casting provides an excellent production method for the quantity batch production of such items as selector forks.

Further information on bearing applications is available in C.D.A. Publication TN45.

Shock Resistance

Aluminium bronze alloys, and in particular the wrought products, have excellent resistance to shock provided the material is sound, and stress concentration is avoided in design.

Fatigue Strength

Aluminium bronzes possess exceptional resistance to fatigue, which is one of the most common causes of deterioration in marine engineering equipment.

Damping Capacity

Aluminium Bronzes are twice as effective as steel in their ability to dampen vibrations.

Magnetic Permeability

Aluminium bronzes can be made with exceptionally low permeabilities and are ideal for non-magnetic instrumentation, mine-sweeper components and critical marine parts where permeability must not exceed 1.05. The magnetic permeability of certain aluminium bronzes is often less than 1.01.

Non-Sparking Characteristics

Excellent non-sparking characteristics make aluminium bronzes suitable for the manufacture of tools and equipment used in the handling of explosives, in mines, in petroleum and chemical plant, in gas equipment, and many other similar applications.

Cast Aluminium Bronze

Aluminium bronze castings are produced by the recognised techniques of sand, shell, die, ceramic,investment, centrifugal and continuous casting. The size of castings ranges from tiny investment cast components to very large propellers weighing 70 tons. Standard compositions are shown in Table 8.

One of the very attractive characteristics of aluminium bronzes is that, due to their short cooling range, they solidify compactly as do pure metals. This means that, provided defects are avoided, the metal is inherently sound, more so than alloys such as gunmetal which may be porous unless cooled very rapidly.

To avoid internal defects, however, certain techniques have to be used which are fundamentally different from conventional foundry methods. Given this, castings of very high integrity are produced by foundries with the required specialised expertise.

Because aluminium bronze is often selected for severe and critical applications, it is important that the casting be well designed so as to achieve optimum results. Consultation with an experienced founder is therefore essential at a relatively early stage of design development. A leaflet giving guidance on the design of aluminium bronze castings is available from Copper Development Association. It is helpful in the initial design work and gives a good basis for consultation between the designer and the founder.

Castings may be heat treated to improve the microstructure of the alloy, giving improved corrosion resistance and greater strength for only a slight reduction in ductility. The treatment recommended is to soak at 660°C and cool in still air. The time at temperature depends on casting size and section thickness but is of the order of two hours.

Wrought Aluminium Bronze

A wide variety of wrought products are made in aluminium bronze alloys, including forgings, rods, bar, sections, flats, sheets and plates, filler rods and wire. An indication of this variety is given in Tables 5 and 6.

Table 5 – Availability of wrought aluminium bronzes

Plate, sheet, strip, up to 4000 kg	0.5 to 127 mm thick
Bar, rod, section	7 to 200 mm diameter
Tube and hollow bar	Up to 108 mm diameter, 9.5 mm wall thickness. Hollow bar up to 500 mm diameter
Welded tube	By arrangement
Forgings	Up to 200 mm diameter in weights up to 4000 kg

Table 6 – Shapes, sizes available and working properties of wrought aluminium bronzes

BS/DGS designation product forms		**Machinability index (free-cutting brass CZ121 Pb3 = 100)**	**Cold working**	**Hot working**
CA101	Sheet, strip, foil	20	Good	Fair
CA102	Tube, plate	30	Good	Poor
CA103	Rods, sections, forgings	50	Limited	Good
CA104	Rods, sections, forgings	40	Poor	Good
CA105	Plate	20	Limited	Good
CA106	Rods, sections, forgings, plate	30	Fair	Good
CA107	Rods, sections, forgings, plate	50	Fair	Good
DGS1043 (was DGS8452)	Rods, sections, forgings, plate	40	Poor	Good
DG1044 (was DGS 8453)	Rods, sections, forgings, plate	50	Fair	Good

BS - British Standard
DGS - British Naval Material Standard (being replaces be Naval Engineering Standard)

The billets from which wrought products are made, have to be cast by a special process in order to ensure freedom from entrapped oxide defects which would carry through to the final product.

These billets are then hot worked by all conventional methods such as extrusion, rolling or forging.

Rolling, extrusion or rotary forging produces sections which are to final or near final dimensions thus avoiding costly machining and providing design flexibility.

Forgings may be produced freehand in simple shapes to relatively wide tolerances, or they can be drop-forged in dies to close tolerances, if the quantity required justifies the initial cost of the die.

Other variants of the forging process are used such as hot pressing, stamping and hot processing to produce flanged shafts, bolts, etc. These may be made from stock of rolled, extruded or forged material.

Fabrication and Welding of Aluminium Bronze

Thanks to the ductility and weldability of the alloy, aluminium bronze sheets can be worked into curved sections which can then be welded together to produce fabricated components such as pressure vessels and pipes.

One attractive feature of the aluminium bronzes is that it is possible to incorporate castings as well as forgings in a fabricated assembly.

The single phase alloys are easier to cold work than the complex alloys and are therefore less expensive to roll into shape. The complex alloys are, however, stronger and are less sensitive to the stresses resulting from the heating and cooling cycles caused by welding.

Table 6 gives indications of the cold working characteristics of various standard wrought alloys.

Gas shielded arc welding is the most popular method of welding aluminium bronze.

Table 7 shows the standard B.S. Welding Alloys. C.12 which is a simple duplex phase alloy is best for hot ductility but of inferior corrosion resistance to C.20, the more complex alloy. The welding performance of the latter is, however, perfectly satisfactory for most applications.

To avoid the possible effects of the different microstructure present in the weld bead and heat affected zone, post weld heat treatment may be recommended for the complex alloys. After a soak at 660°C and cooling in still air there is an improvement in corrosion resistance.

Table 7 – Welding alloys suitable for joining aluminium bronzes

(BS 2901 Filler Alloys for gas shielded arc welding Pt 3: Copper and Copper Alloys)

BS Designation	**Alloy Composition per cent (remainder Cu)**					
	Al	**Fe**	**Ni**	**Mn**	**Si**	
C12	6.0 - 7.5	(Fe + Ni + Mn)1.0 - 2.5			-	Welding alloys are available in standard diameters, reeled for MIG welding and in straight lengths for TIG welding
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	-	

It is advisable to use a weld filler which matches as closely as possible the parent metal. Fabricators are advised to consult manufacturers of wrought aluminium bronze regarding the choice of the most suitable alloys for sheets and filler wire. Details of basic welding procedures are included in two publications (see References).

The weldability of aluminium bronze permits the repair of damaged or locally defective castings and forgings. It is also possible to rectify machining errors.

The Machining of Aluminium Bronzes

Because of their outstanding combination of high strength and excellent abrasion and corrosion resistance, aluminium bronzes are increasingly being used in all branches of industry. It will be appreciated that to ensure the most economical production, materials of this calibre require correct machining methods. Though many machine shops have developed their own standard practice to suit their particular requirements, these notes will serve as a general guide for machining aluminium bronze. Little distortion normally occurs on machining but, in cases where dimensions are critical it may be found useful to carry out a stress relief heat treatment of one hour at 350°C prior to final machining.

The handling of aluminium bronze need present no difficulty to the average machine shop, and can readily be machined using modern tools, steels and the correct workshop technique. Definite values for maximum feeds, speeds and depth of cut cannot be stated since these are influenced by several factors; the equipment being used, the operator, and his experience in handling the material. The various recommendations may be taken as representing a reliable average, offering maximum production with reasonable tool life and efficiency. Whilst, therefore, some machine shops may fail to achieve the recommended values, others will exceed standard practice.

Aluminium bronze must not be confused with free machining brass; rather should it be considered as a bronze with mechanical properties similar to those of a high grade steel.

1. Turning

The use of tungsten carbide tipped tools is considered desirable. It is most important that the work should be held rigidly and that tools should be properly supported, with minimum overhang from the tool post. To obtain the best results, plant must be kept in good condition: excessively worn headstock bearings and slides will give rise to tool chatter and rapid tool breakdown. The first roughing cut on a casting should be deep enough to penetrate the skin, and a steady flow of soluble oil is essential for both roughing and finishing cuts. The work must be kept cool during precision machining; if it is allowed to heat up, difficulty will be experienced in maintaining accuracy.

Suitable designs for tungsten carbide roughing and finishing tools are illustrated in figure 1, and speeds and feeds recommended for use with these tools are given in Table 12. High efficiency with carbide tipped tools is attained by using a light feed, a moderately heavy depth of cut and the highest cutting speed consistent with satisfactory tool life.

Figure 1 – Suitable designs for tungsten carbide roughing and finishing tools

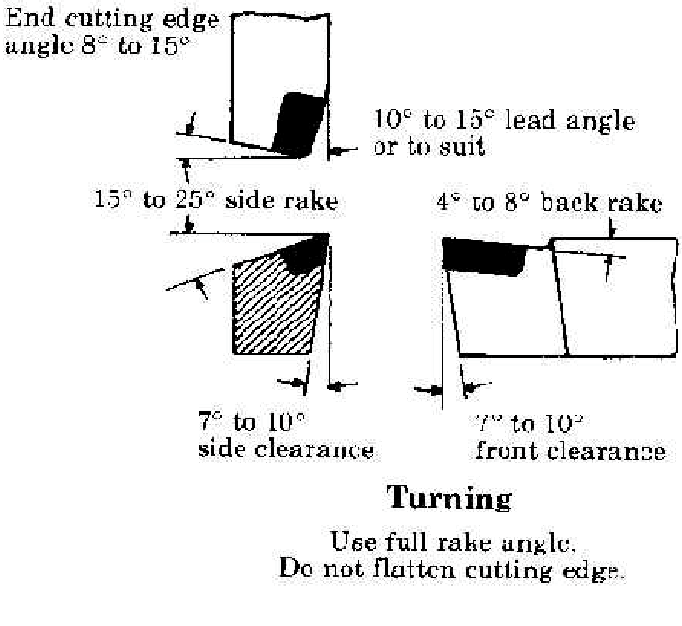


Table 8 – Turning speeds and feed rates for aluminium bronzes

		Roughing	Finishing
Cut	mm	3 - 6	0.12 - 0.25
	in	1/8 - 1/4	0.005 - 0.010
Speed	m/min	30 - 60	120 - 180
	ft/min	100 - 200	400 - 600
Feed	mm/rev	0.25	0.12
	in/rev	0.010	0.005

2. Drilling

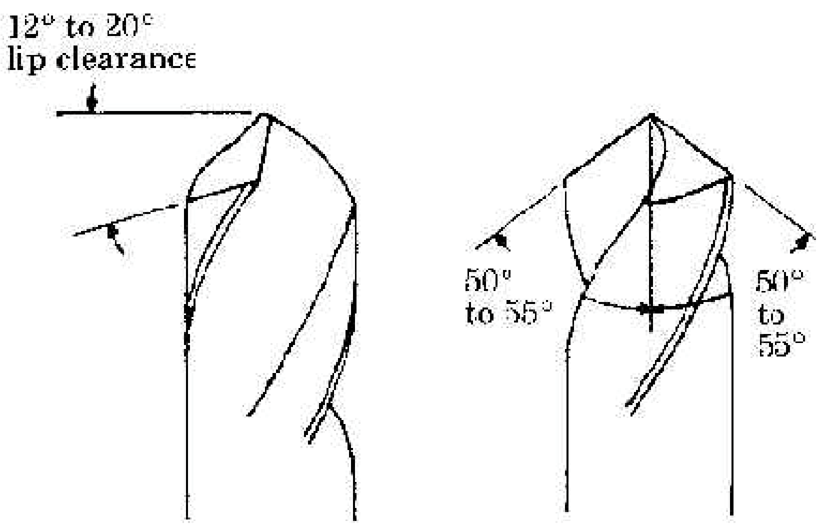
Since aluminium bronze is hard, close grained and free from the "stringy" characteristics of copper, a fine drilled finish is obtainable. The best results are achieved with high speed steel drills ground with negative rake at an included angle of 110° to 120°. Straight fluted drills will give a fine surface finish. Binding in the hole can be overcome by grinding the drill very slightly "off centre", thereby providing additional clearance.

Where countersinking is required, a counterboring tool will give the best results. If a counterboring tool is not available, it may be found preferable to carry out countersinking before drilling.

A coolant must be used, especially with the harder grades, and overheating must be avoided. Medium speeds and moderate feeds give the best results.

Speed	15 40 m/min
	50 130 ft/min
Feed	0.075 0.5 mm/rev
	0.003 0.02 in/rev

Figure 2 – Drill point and clearance angles



3. Reaming

Excellent results can be obtained, but normal reaming practice is not suitable. It has been found that a simple "D" bit, made up with a tungsten carbide insert will maintain the closest limits and give a highly finished bore. Approximately 0.12mm (.005") of metal should be removed. Adjustable type reamers with carbide inserts can also be used, and it will be found that chatter is eliminated if a reamer having an odd number of inserts is chosen. If hand reaming is carried out, a left-hand spiral type is to be preferred. Avoid undue heating and use coolant.

4. Tapping

Possibly the principal reason for torn threads or broken taps is the selection of a tap drill which is either too small or too close to the size of the root diameter. In the majority of cases where a specified thread fit is not needed, and where the depth of hole is at least equal to the diameter of the tap, a 75% to 80% depth of thread is sufficient. A 100% thread is only 5% stronger than a 75% thread, yet it needs more than twice the power to tap and presents problems of chip ejection and makes it necessary for the tap to be specially designed for the particular alloy.

For hand tapping where the quantity of work or nature of the part does not permit use of a tapping machine, regular commercial two and three flute high-speed steel taps should prove satisfactory. The rake should be correct for the metal being cut and the chamfer should be relatively short so that work-hardening or excess stresses do not result from too many threads being cut at the same time.

High-speed steel taps with ground threads are used in machine tapping. In instances where the threads tend to tear as the tap is being backed out, a rake angle should be ground on both sides of the flute.

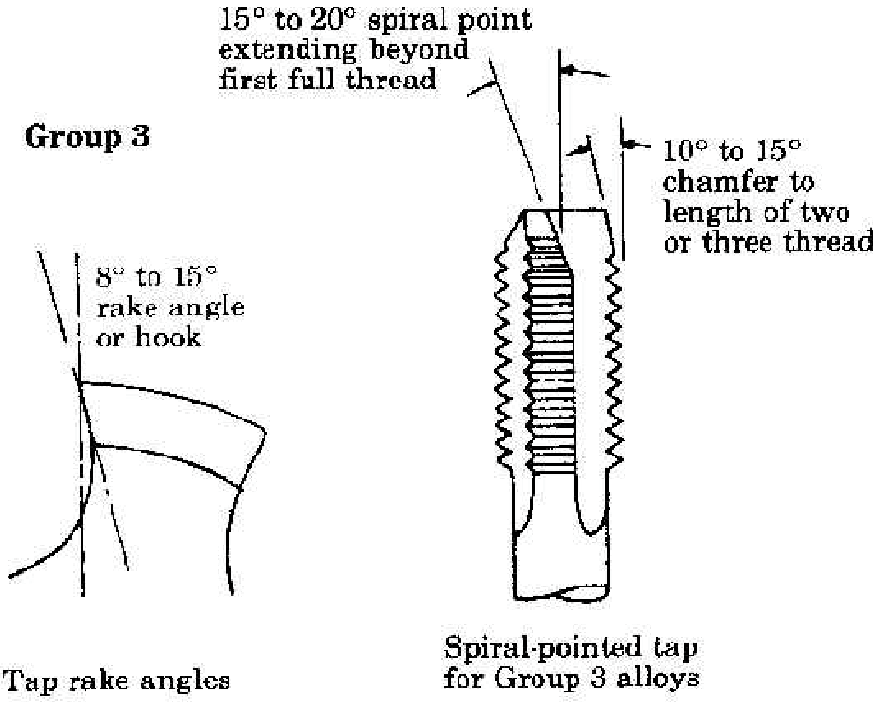
For aluminium bronzes which produce tough, stringy chips, spiral pointed taps with two or three flutes are preferred for tapping through holes or blind holes drilled sufficiently deep for chip clearance. These taps produce long, curling chips, which are forced ahead of the tap.

Spiral fluted bottoming taps can be used for machine (and hand) tapping of blind holes in copper and all types of copper alloys, and wherever adequate chip relief is a problem.

Rake angles should be 8 - 15o, modified for the particular conditions of the job and used at 10 - 20 m/min (30 - 60 ft/min). The speeds indicated are based on the use of taps to produce fine to moderate pitch threads. Appreciably lower speeds should be used for coarse pitch threads, and speeds should be reduced by about 50% if carbon steel taps are used.

If the work is allowed to overheat, a re-tapping operation may be necessary. The use of a tapping compound having a high tallow content will prevent binding in the case of softer grades, and will prevent cracking of the work in the harder grades.

Figure 3 – Tapping



5. Milling

Undue heating must be avoided and a coolant should be used. Good results can be achieved by employing standard steel practice. It is recommended that the cutting edges of teeth should be on a radial line with the centre of the cutter; this applies to end mills as well as standard milling cutters. Speeds and feeds will depend upon the job and machining conditions, but the work must not be "forced", or tearing and chipping may result.

6. Grinding

All grades of aluminium bronze can readily be given an excellent ground finish, and even the softer grades will not clog the grinding wheel. Again, a coolant must be used and overheating must be avoided. A bauxilite type wheel gives satisfactory results and the grades recommended for particular operations are as follows: 30 grit for roughing; 46 grit for general purposes; and 60 grit for fine finish work. Since aluminium bronze is non-magnetic, it cannot be finished using a magnetic chuck.

Further information on the machining of aluminium bronzes and other copper alloys is contained in CDA Technical Note TN44 "Machining Copper and its alloys".

The scrap value of aluminium bronze swarf is relatively high. This can help offset machining costs and should be considered when costing component manufacture.

The references quoted give much more detail of the properties of the aluminium bronzes. If further information is required contact Copper Development Association via their website www.cda.org.uk/enquiry-form.htm.

Appendix One – Composition

*Table 9 – Cast aluminium bronze standard compositions**

BS 1400 Copper Alloy Ingots and Copper and Copper Alloy Castings

BS Designation	Alloy Composition per cent (remainder Cu)					
	Al	Fe	Ni	Mn	Si	
ABl	8.5 - 10.5	1.5 - 3.5	1.0 max.	1.0 max.		All alloys are available in most cast forms
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	
CMAI	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		

* For comparisons with other Standards see Appendix Four.

*Table 10 - Wrought Aluminium Bronze Standard Compositions**

BS 2870 Rolled Copper and Copper Alloys - Sheet Strip and Foil
BS 2871 Copper and Copper Alloys - Tubes
BS 2872 Copper and Copper Alloys - Forging Stock and Forgings
BS 2873 Copper and Copper Alloys - Wire
BS 2874 Copper and Copper Alloys - Rods and Sections other than forging stock
BS 2875 Rolled Copper and Copper Alloys – Plate

BS/DGS Designation	Alloy Composition per cent (remainder Cu)					Availability to British Standard					
	Al	Fe	Ni	Mn	Si	2870	2871 Part 3	2872	2873	2874	2875
CA101	4.5 - 5.5										
CA102	6.0 - 7.5	(Fe+Ni+Mn) 1.0-2.5 optional					x				x
CA103	8.8 - 10.0	(Fe+Ni) 4.0						x		x	
CA104	8.5 - 11.0	4.0 - 5.5	4.0 - 5.5	0.5 max.		x		x		x	
CA105	8.0 - 11.0	1.5 - 3.5	4.0 - 7.0	0.5 - 2.0							x
CA106	6.5 - 8.0	2.0 - 3 5						x		x	x
CA107	6.0 - 6.4	0.5 - 0 7		0.5 max.	2.0 - 2.4			x		x	
DGS1043	8.5 - 10.0	4.0 - 5.5	4.0 - 5.5	0.5 max.							
DGS1044	6.0 - 6.4	0.5 - 0.7			2.0 - 2.4						

* For comparisons with other Standards see Appendix Four.

Effect of Composition on Properties

The mechanical properties of aluminium bronze depend primarily on aluminium content. Alloys with up to about 8% aluminium have a ductile single phase structure and are the most suitable for cold working into tube, sheet, strip and wire. As the aluminium content is increased to between 8% and 10% the alloys are progressively strengthened by a second, harder phase which makes them more suitable for hot working and casting. Above 10% an even greater strength and hardness is developed for specialised wear resistant applications.

The other major alloying elements also modify the structure to increase strength and corrosion resistance: iron improves the tensile strength and acts as a grain refiner; nickel improves proof stress and corrosion resistance and has a beneficial stabilising effect on the metallurgical structure; manganese also performs a stabilising function.

Two further alloy types complete the range of commercial alloys: silicon up to about 2% with aluminium up to about 6% form a range of alloys known as aluminium silicon bronze; these have a higher strength than the normal single-phase aluminium bronzes but are cast and hot-worked more readily, have a similarly low magnetic permeability and excellent resistance to shock loading. Silicon also improves machinability. The alloys are available in wrought and cast forms.

Manganese, at about 13%, is the major addition in a series of manganese aluminium bronzes with aluminium levels of 8 - 9%. Their foundry properties are better than the aluminium bronzes and they have good resistance to impingement and cavitation, as well as being heat treatable to low magnetic permeability. They have excellent welding properties.

Further information on alloys and alloy selection for particular purposes is available from Copper Development Association.

Appendix Two – Mechanical and Physical Properties

Table 11 – Typical mechanical properties

(For guidance only. Contact manufacturers for details)

Mechanical Properties						
BS/DGS Designation	**Tensile Strength N/mm^2**	**0.2% Proof Stress N/mm^2**	**Elongation %**	**Hardness HV**	**Shear Strength N/mm^2**	**Impact Strength J**
WROUGHT						
CA101	370 - 650	140 - 540	15 - 65	90 - 190	280 - 400	66 - 90
CA102	420 - 540	90 - 230	10 - 50	110 - 180	280 - 340	68 - 108
CA103	570 - 650	260 - 340	22 - 30	170 - 190	430 - 500	21 - 48
CA104	700 - 850	350 - 600	15 - 25	190 - 260	460 - 520	14 - 27
CA105	660 - 770	260 - 400	17 - 22	180 - 220	490 - 590	18 - 20
CA106	480 - 620	200 - 310	35 - 45	120 - 180	370 - 450	45 - 55
CA107	550 - 620	230 - 370	30 - 40	150 - 200	370 - 430	35 - 48
DGS1043	620 - 740	280 - 350	25 - 30	190 - 220	415 - 500	27 - 45
DGS1044	550 - 620	230 - 370	30 - 40	150 - 200	370 - 430	35 - 48
CAST						
AB1	500 - 590	170 - 200	18 - 40	90 - 140	-	38 - 42
AB2	640 - 700	250 - 300	13 - 20	140 - 180	-	22 - 24
AB3	460 - 550	170 - 180	20 - 25	100 - 130	-	27 - 35
CMA1	650 - 730	280 - 340	10 - 35	160 - 210	-	34 - 48
CMA2	740 - 820	380 - 460	9 - 20	200 - 260	-	14 - 23
(100 N/mm^2 is approximately equal to 6.5 tons/in^2).						

NOTE: In common with all materials, the mechanical properties of aluminium bronzes in heavy sections are lower than in lighter sections. Manufacturers will advise on actual properties which can be achieved on specific wrought and cast dimensions.

Table 12 – Typical physical properties

Physical Properties					
BS/DGS Designation	**Young's Modulus N/mm^2 x 10^3**	**Density kg/m^3**	**Coeff. Of Linear Exp per °C x 10-^{6}**	**Electrical Conductivity % IACS**	**Thermal Conductivity W/m°C**
WROUGHT					
CA101	123	8200	17.5	17	80
CA102	108	7860	17.1	15	71
CA103	116	7840	16.8	7	42
CA104	125	7590	17.1	8	46
CA105	135	7600	16.0	8	42
CA106	123	7800	16.0	13	65
CA107	105	7700	18.0	9	44
DGS1043	115	7650	17.0	8	46
DGS1044	125	7750	18.0	8	42
CAST					
AB1	100	7600	17.0	13	61
AB2	120	7600	17.0	8	42
AB3	100	7700	18.0	9	44
CMA1	120	7500	18.6	3	14
CMA2	120	7500	18.6	3	14

Appendix Three – Corrosion Resistance Guide

Table 13 – Corrosion Resistance Guide

Aluminium Bronze alloys may be considered for service in the following chemicals, particularly where there is a combination of stress and erosion, but selection must take account of the actual temperature and other service conditions.

Acetic Acid	Carbolic Acid	Glucose	Sewage
Acetic Anhydride	Carbon Dioxide and	Glycerine	Soaps
Acetate Solvents	Carbonic Acid	Glycerol	Sodium Bisulphate
Acetone	Carbon Tetrachloride	Hydrocarbon Gases	Sodium Carbonate
Alcohols	Caustic Potash	Hydrochloric Acid	Sodium Chloride
Aldehydes	Caustic Soda	Hydrofluoric Acid	Sodium Hypochlorite
Aluminium Chloride	Chlorine (dry)	Hydrogen	Sodium Nitrate
Aluminium Fluoride	Chloroform	Inert Gases	Sodium Silicate
Aluminium Hydroxide	Citric Acid	Lactic Acid	Sodium Sulphate
Aluminium Sulphate	Coal Tar	Magnesium Chloride	Sodium Sulphide
Ammonia (dry)	Coal Tar Solvents	Mineral Oils	Sulphur
Amyl Chloride	Copper Sulphate	Naphthenic Acids	Sulphuric Acid
Asphalt	Esters	Nickel Sulphate	Sulphurous Acid
Barium Chloride	Ethers	Nitrogen	(moist SO2)
Benzole	Fats	Oxalic Acid	Tannic Acid
Borax	Fatty Acids	Oxygen	Tartaric Acid
Boric Acid	(Oleic, Palmytic, Stearic)	Paints	Trichlorethylene
Brine	Fluosilicic Acid	Petroleum products	Tri-Sodium Phosphate
Bromine (dry)	Formaldehyde	Phosphoric Acid	Zinc Chloride
Calcium Chloride	Formic Acid	Pickling solutions	Zinc Sulphate
Calcium Hydroxide	Freon	Potassium Sulphate	
Calcium Hypochlorite	Fuel Gases	Refrigeration	

See also Aluminium Bronze Alloys Corrosion Resistance Guide

Appendix Four - Aluminium Bronze related standards

Table 14 – Aluminium bronze related standards

Wrought Alloys				Standard Specifications (See specifications for full details)				General Composition Range % (Remainder Copper)				
BS	DGS/AD.SPEC *	AUWE	DTD	DIN	ASTM	UNS	ISO	Al	Fe	Ni	Mn	Si
CA101				17665: CuAl5	B169: 60600	C60600 C60800	428: CuAl5	4.5— 5.5	—	—	—	—
CA102	8555							6.0— 7.5	(Fe+Ni+Mn) 1.0— 2.5 optional			—
CA103				17665: CuAl10Fe	B124, 150 283: 62300	C62300	428: CuAl10Fe3	8.8— 10.0	(Fe+Ni)	4.0 max.	—	—
CA104			197A	17665: CuAl10Ni	B150: 63200	C63200	428: CuAl10Fe5Ni5	8.5— 11.0	4.0 —6.0	4.0 —6.0	—	—
CA105					B171: 63000	C63000		8.5— 10.5	1.5 —3.5	4.0 —7.0	0.5 — 2.0	—
CA106				17665: CuAl8Fe	B150, 169 171: 61400	C61400	428: CuAl8Fe3	6.5— 8.0	2.0 —3.5	—	—	—
	1044	930.2 & 930.9			B124, 283: 64200	C64200		6.0— 6.4	0.5 —0.7	—	—	2.0 —2.4
	1043	930.14			B150: 63200	C63200	428: CuAl10Fe5Ni5	8.5— 10.0	4.0 —5.5	4.0 —5.5	—	—
	1076D *							8.4— 9.1	(Fe+Ni)	3.0 max.	—	—
			160					9.0— 9.8		—	—	—
			164A					9.0— 10.0	0.5 —2.5	1.0 —3.0	—	—
				17665: CuAl8			428: CuAl8	7.0— 9.0		—	—	—
				17665: CuAl19Mn			428: CuAl9Mn2	7.7— 9.7		—	1.5 — 3.0	—
				17665: CuAl11Ni				10.5 —12.5	4.8 —7.3	5.0 —7.0	—	—
Cast Alloys												
AB1	1070D *			1714: CuAl10Fe	B148 A: 95200	C95200	1338: CuAl10Fe3	8.5— 10.5	1.5 —3.5	—	—	—
AB2	361A	930.3		1714: CuAl10Ni	B148 D: 95500	C95500	1338: CuAl10Fe5Ni5	8.5— 10.5	3.5 —5.5	4.5 —5.5	—	—
CMA1	140				B148 F: 95700	C95700		7.5— 8.5	2.0 —4.0	1.5 —4.5	11.0 — 15.0	—
CMA2								8.5— 9.0	2.0 —4.0	1.5 —4.5	11.0 — 15.0	—
	8520F	930.15						8.8— 10.0	4.0 —5.5	4.0 —5.5	—	—
			174A					7.5— 10.5	1.5 —3.5	4.0 max.	—	—
			412					8.0— 12.0	3.0 —6.0	3.0 —6.0	—	—
	129	930.1 & 930.8				C95600		6.0— 6.4	0.5 —0.7	—	—	2.0 —2.4
	348							8.8— 9.5	4.0 —5.0	4.5 —5.5	0.75— 1.3	—
						C95200		8.5— 9.5	2.5 —4.0	—	—	—
						C95300		9.0— 11.0	0.8 —1.5	—	—	—
						C95400		10.0 —11.5	3.0 —5.0	—	—	—
						C95500		10.0 —11.5	3.0 —5.0	3.0 —5.5	—	—

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The above publications are available from Copper Development Association www.cda.org.uk/enquiry-form.htm.

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