Copper Development Association

Aluminium Bronze - Essential for Industry

CDA Publication No 86, 1989

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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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Marine

The outstanding corrosion resistance of Aluminium Bronze in marine environments coupled with its high strength and wear resistance, have made it a first choice for ships' propellers for many years. Modern vessels are fitted with smaller variable pitch propellers and these are cast in Aluminium Bronze as are the associated gearboxes. Figure I illustrates a typical component being machined. Pumps and valves for sea water cooling systems are found on most vessels. Another less familiar application is in mine hunting vessels where the low magnetic permeability is an essential feature when Aluminium Bronze is specified for chains, slings and other specialised components.

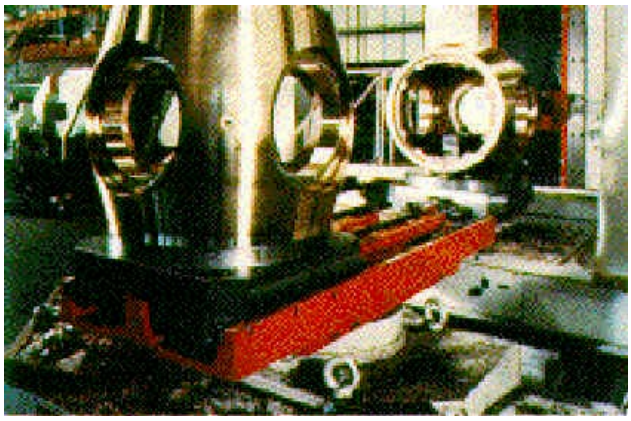


Figure 1 – Typical component being machined

Offshore Platforms

Aluminium Bronze is widely used for pumps, valves and pipes on oil and gas platforms. Sea water is used for cooling and firefighting and is pumped up 30 metres or more from sea level. The pipes which are centrifugally cast in one metre lengths vary in diameter from 150mm up to 500mm. Sections are welded, together with flanges to make sub assemblies up to 9 metres in length. Figure 2 shows a unit under construction with a variety of Aluminium Bronze components clearly visible.

Figure 2 – Unit under construction – aluminium bronze components clearly visible

Power Generation

Impellers with their associated casings, valves and pipework are found in power stations where the corrosion resistance and strength of Aluminium Bronze is required for long term reliability.

Figure 3 – Impeller in aluminium bronze

Building and Construction

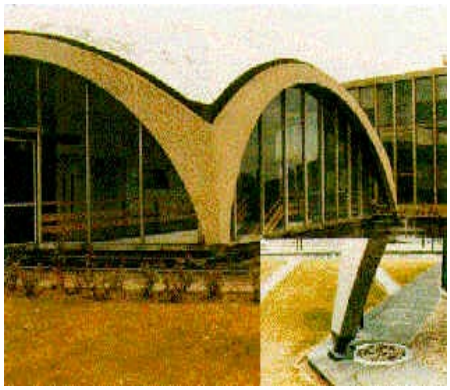


Figure 4 – Dome roof supported on aluminium bronze spherical joints

Figure 5 – Aluminium bronze masonry fixings

The entire weight of this dome roof at Aberdeen University (Figure 4) is supported on Aluminium Bronze spherical joints set in concrete. Many modern buildings and large bridges use Aluminium Bronze expansion joints, masonry fixings (Figure 5) and concrete reinforcing bars.

General Engineering

Aluminium Bronze components are found in many general engineering applications where high strength coupled with wear and corrosion resistance is required.

Figure 6– The non-galling property is an added advantage Rolls Royce appreciate when they specify aluminium bronze for their wheel nuts

Figure 7 – Picking hooks working in the most aggressive environment use aluminium bronze for strength and toughness

Figure 8 – Gear wheels for British Rail braking systems are cast in aluminium bronze

Bearings

The excellent bearing properties particularly in difficult environments are demonstrated by the variety of sizes and wide range of successful applications.

Figure 9 – This marine tailshaft bearing is over 0.5 metre in diameter

Figure 10 – This shows a 70mm diameter ballrace assembly used on a load bearing water jet for fire fighting equipment.

Figure 11 – Composite self-lubricating bearings with graphite inserts are available in a wide range of shapes and sizes for applications where conventional lubrication is difficult

Tooling

Aluminium Bronze tooling (Figure 12) is used in the forming of deep drawn stainless steel components where the hardness and low coefficient of friction eliminates galling and pickup.

Figure 12 – Aluminium bronze tooling was used to form components such as this

Corrosion Resistance

The corrosion resistance of the aluminium bronzes is, in many respects, better than conventional stainless steels. A great deal of development work has been carried out to ensure that the alloys are fit for use for some of the most critical applications required by the Navy's underwater and surface ships; industry is now obtaining the consequential benefits.

The aluminium bronzes in both cast and wrought forms have the excellent natural corrosion resistance of all copper alloys enhanced by the protective film of aluminium oxide formed rapidly under normal oxidising conditions. If damaged, this film is self-healing which means that the alloys can be used under service conditions where abrasion can be expected.

The alloys have an excellent resistance to atmospheric corrosion and, having been developed primarily for use in sea water pumping and piping applications, are also resistant to exposure to chlorides and similar chemicals and also to many acids. Service conditions can include water flow at high velocities with the presence of significant quantities of suspended abrasive solids. Naturally, they are also resistant to organic solvents and, like all other common metals, do not degrade in sunlight.

These properties make the alloys suitable for use in most types of sea water service including pumps, valves, propellers, heat exchangers and pipework, similarly in the water supply industry and oil and petrochemical industries. Their resistance to wear as well as corrosion make them ideal also for the manufacture of heavy-duty bearings for the engineering industry and for masonry fixings and concrete reinforcement in the building and construction industry. They are also ideal for the manufacture of pickling hooks for use in sulphuric acid and for the pickling of steel in hydrochloric acid. Their resistance also to hydrofluoric acid makes them useful in the manufacture of equipment for the etching or 'frosting' of glass.

Types of Corrosion

More data on the corrosion resistance of aluminium bronze is contained in CDA Publication No 80 'Aluminium Bronze Alloys - Corrosion Resistance Guide'. The following generalisations will be a useful guide:

Uniform or general corrosion, in air, water or chemical solutions, is not a problem when aluminium bronzes are used as recommended.

Crevice corrosion occurs when two components, such as flanges, are in close contact but there is a thin film of water between them. In these circumstances the free access of oxygen is limited and anaerobic, reducing conditions prevail, preventing the oxidation of the metal surface. While conventional stainless steels are prone to significant attack under these condition, the susceptibility of the aluminium bronzes is much less. This is one of the main reasons for which these materials were selected for naval applications.

Corrosion fatigue is rarely a problem because of the high mechanical strength of the alloys and the self-healing nature of the oxide film.

Stress corrosion susceptibility is also less than with many other alloys due to the good mechanical properties and general corrosion resistance. Normal design precautions should be taken, such the avoidance of sharp corners likely to act as stress raisers. Where conditions are likely to be severe a stress-relief anneal may be advised. Exposure to ammoniacal environments should be avoided.

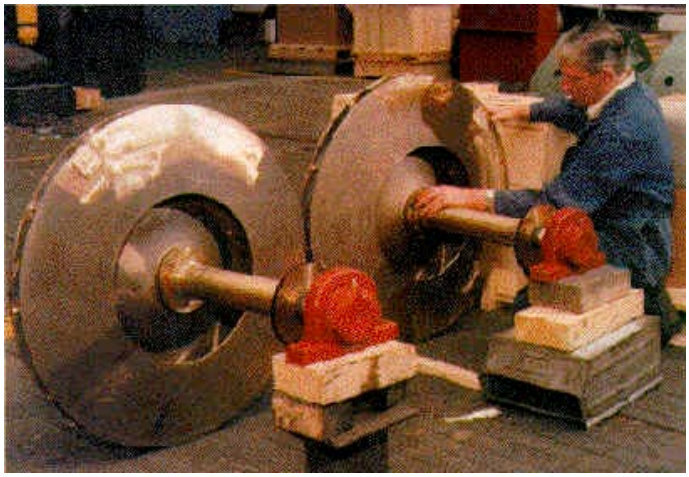


Figure 13 –Aluminium bronze is widely used for the impellers and shafts of the blowers used to circulate these gases

To reduce the risk of explosion or fire on board oil tankers. An atmosphere of inert gas is maintained over the oil in the tanks. This gas is sea water scrubbed boiler flue gas which is very corrosive. Aluminium Bronze is widely used for the impellers and shafts of the blowers (Figure 13.) used to circulate these gases.

Corrosion erosion is normally insignificant in aluminium bronzes in normal service due to the rapid rate at which the protective oxide film reforms.

Pitting corrosion is not normally a problem with the aluminium bronzes except in the presence of excessive concentrations of sulphides.

Cavitation corrosion, caused by the collapse of voids generated on the negative-pressure side of components in service in turbulent, high-speed water flow, is not normally encountered in aluminium bronze propellers, impellers, turbine components or pumps, for which purposes the material is ideal.

Electrolytic corrosion, which occurs when dissimilar metals are in electrical contact in water, can be avoided by careful materials selection at the design stage. The aluminium bronzes are towards the 'noble' end of the electrochemical series. Any metals that are significantly less noble will therefore tend to corrode preferentially, though this effect may be of little importance if there is a large area exposed and a reasonable corrosion allowance.

Where service conditions are likely to be severe, a further improvement in the corrosion resistance of some aluminium bronzes may be obtained after a full homogenising heat treatment.

Availability

The Aluminium Bronzes are a range of copper alloys containing up to 14% of aluminium and frequently other alloying elements such as nickel, iron, manganese and silicon. Varying the proportions of these results in a range of strong, tough alloys with excellent resistance to corrosion and wear that are ideal for a wide variety of important engineering requirements. They are available as both high integrity castings in weights from a few grams up to many tons and in the usual wrought forms such as rolled plate and sheet, extruded or forged rods, bars and sections and as welding wire. They are readily weldable for the fabrication of components such as pipes, pipe fittings and pressure vessels.

There are three major groups of Aluminium Bronzes:

1. **The alloys containing less than 8% of aluminium**, typically those designated CA102 and 106 in wrought form. These are of a simple single phase structure, have a good ductility and are suitable for significant cold working.
2. **The two-phase (duplex) alloys**, including the nickel-aluminium bronzes, 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 ABI and AB2 and the wrought alloys CA105, CA104 and those ex-DGS specifications, such as DGS 1043, recently revised and reissued in Naval Engineering Standard (NES) form as NES 747 when cast and NES 833 in wrought form.
3. **The Aluminium-Silicon Bronzes** of lower magnetic permeability such as AB3, CA107 and NES 834 (formerly DGS 1044).

There are also the copper-manganese aluminium alloys with good castability originally developed and still only generally used for the manufacture of propellers. These have largely been replaced by the nickel-aluminium bronzes.

To ensure fitness for purpose, aluminium bronzes should always be purchased to a stipulated specification from a reputable supplier. Castings are covered in BS 1400, wrought materials in BS 2870 (sheet), 2871 (tube), 2872 (forgings), 2873 (wire), 2874 (rods and sections) and 2875 (plate). The common specifications are listed in the next section, together with the International Standards Organisation (ISO) designations typical of those used already by many national standards bodies and likely to be the bases of the forthcoming European Standards.

Compositions of Aluminium Bronzes - Available BS 1400 Cast Aluminium Bronzes

Designation		**Alloy Composition (wt %) - remainder Cu***					**Remarks**
BS	**ISO**	**Al**	**Fe**	**Ni**	**Mn**	**Si**	
AB1	G-CuAl10Fe3	8.5-10.5	1.5-3.5	1.0 max	1.0 max		Diecasting alloy
AB2	G-CuAl10Fe5Ni5	8.5-10.5	3.5-5.5	4.5-6.5	1.5 max		Usual alloy for most castings
AB3	G-CuAl6Si2Fe	6. 0-6.4	0.5-0.7			2.0-2.4	Used when very low magnetic permeability required

* Alloying elements only, impurities also specified in BS1400

Compostions of Wrought Aluminium Bronzes

Designation		**Alloy Composition (wt %) - remainder Cu***					**Remarks**
BS	**ISO**	**Al**	**Fe**	**Ni**	**Mn**	**Si**	
CA102	CuAl7	6.0-7.5 (Fe+Ni+Mn 1.0-2.5 optional)					Tube, plate
CA104	CuAl10Ni5Fe4	8.5-11.0	4.0-5.5	4.0-5.5	0.5 max		Rods, sections, forgings – good combination of strength and toughness
CA105	CuAl10Fe3	8.0-11.0	1.5-3.5	4.0-7.0	0.5-2.0		Plate
CA106	CuAl8Fe3	6.5-8.0	2.0-3.5				Rods, sections, forgings plate
CA107	CuAl6Si2	6.0-6.4	0.5-0.7		0.5 max	2.0-2.4	Rods, sections, forgings, plate

* Alloying elements only, impurities also specified in BS1400

Standards

Ministry of Defence (PE) Naval Engineering Standards

For Aluminium Bronzes for naval requirements, 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, rod and sections (replaces DGS 1043)

NES 834 - Silicon-Aluminium-Bronze

Pt I - Sheet, strip and plate (replacing DGS 8453)

Pt 2 - Forgings, forging stock, rods and sections (replacing DGS 1044)

Pt 3 - Ingots and castings (replacing DGS 128A)

Properties

Properties of Aluminium Bronzes

The aluminium bronzes are generally as strong as the low alloy steels and better than many stainless steels. They are tough and ductile at all temperatures and retain their strength well at elevated temperatures.

Cast Aluminium Bronzes

The values shown are typical of the range of properties possible, these being dependent on casting process and section thickness. For more accurate guidance on the actual properties possible for any particular design, consult experienced foundries.

Mechanical Properties of Cast Aluminium Bronzes

Designation		0.2% Proof Stress N/mm^2	Tensile Strength N/mm^2	Elongation (%)	Hardness (HB)	Impact Strength (J)
BS	ISO					
AB1	G-CuAll0Fe3	170-270	500-650	40-18	90-160	38-42
AB2	G-CuAll0Fe5Ni5	250-360	640-740	20-13	140-180	22-24
AB3	G-CuA16Si2Fe	180-190	460-500	30-20		25-30

Wrought Aluminium Bronzes

The very wide spread of these values indicates the variations possible dependent on the wrought form, such as plate, sheet, tube, rod, bar, section or forging, the section thickness and the temper specified. For more acurate guidance on the properties available to suit your requirements, consult the appropriate British Standards, the manufacturers or specialist stockists.

Mechanical Properties of Wrought Aluminium Bronzes

Designation		0.2% Proof Stress N/mm^2	Tensile Strength N/mm^2	Elongation (%)	Hardness (HV)	Impact Strength (J)
BS	**ISO**					
CA102	CuAl7	140-660	420-720	55-10	100-230	68-108
CA104	CuAll0Ni5Fe4	320-500	650-820	25-10	200-240	14-27
CA105	CuAll0Fe3	300-500	550-650	25-18	185-240	18-20
CA106	CuAl8Fe3	230-450	500-600	40-20	140-190	45-55
CA107	CuAl6Si2	280-400	550-650	45-30	160-210	30-35
Shear strength can be estimated at 2/3rds of the tensile strength						

The relative magnetic susceptibilty of the silicon-aluminium bronzes (AB3 and CA107) is low, typically less than 1.05.

Data on machinability can be found in the MACHINING section of this publication and in CDA Publication No 83 Aluminium Bronze Alloys for Industry.

More details of these properties and other data such as fatigue strength, design stresses, elevated temperature strength, creep rates, low temperature strength and impact properties are contained in CDA publication No 82 Aluminium Bronze Alloys - Technical Data.

Typical Physical Properties of Aluminium Bronzes

Designation		Young's Modulus N/mm^2 x 10^3	Density Kg/m^3	Coeff. Lin.Expansion °C-1 x 10-^{6}	Electrical Cond. % IACS	Thermal Conductivity W/m°C
BS	**ISO**					
AB1	G-CuAll0Fe3	100	7600	17.0	13	61
AB2	G-CuAll0Fe5Ni5	120	7600	17.1	8	42
AB3	G-CuAl6Si2Fe	100	7600	18.0	9	44
CA102	CuAl7	108	7860	17.1	15	71
CA104	CuAll0Ni5Fe4	125	7590	17.1	8	46
CA105	CuAll0Fe3	135	7600	16.0	8	42
CA106	CuAl8Fe3	123	7800	16.0	13	65
CA107	CuAl6Si2	105	7700	18.0	9	44

Welding

All Aluminium Bronzes can be welded, whether in cast or wrought form. This means that it is possible to manufacture components by the most economic production techniques. In the event of damage, it is also possible to repair aluminium bronze components by welding, frequently while still in place.

Naturally, there are recommendations that can be made to help ensure success.

Welding Processes

For best results, inert gas shielded arc welding is generally recommended. This helps to overcome possible problems caused by the otherwise beneficial aluminium oxide films. 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 Tungsten Inert Gas (TIG) and Metal wire Inert Gas (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.

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 approaching the best manual TIG practice.

Generally, the filler metal should match the composition of the material being welded but other considerations also apply, for example hot ductility and corrosion resistance.

Post weld heat treatment, to relieve stresses or improve corrosion resistance, is recommended for the most critical of applications.

Many more detailed recommendations on choice of welding process, shielding gas, filler metal, joint design, welding conditions, post weld heat treatment and inspection requirements are contained in CDA Publication No 85 'Welding Aluminium Bronzes'.

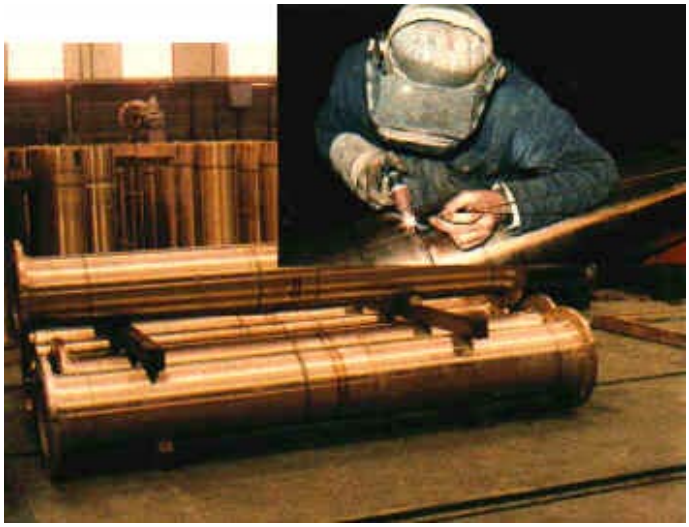


Figure 14 – Spuncast aluminium bronze pipes for offshore platform. Cast with a flange on one end, after proof machining and joint preparation, welded, stress relieved and non-destructively tested.

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. Below are listed the relevant filler metals from British Standard Specification 2901: Pt3. These are generally available in straight rod form for TIG welding and as wire on reels for MIG welding, in ranges of appropriate diameters. Besides these BS designations, fillers are available under a variety of trade names.

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 total - 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	

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

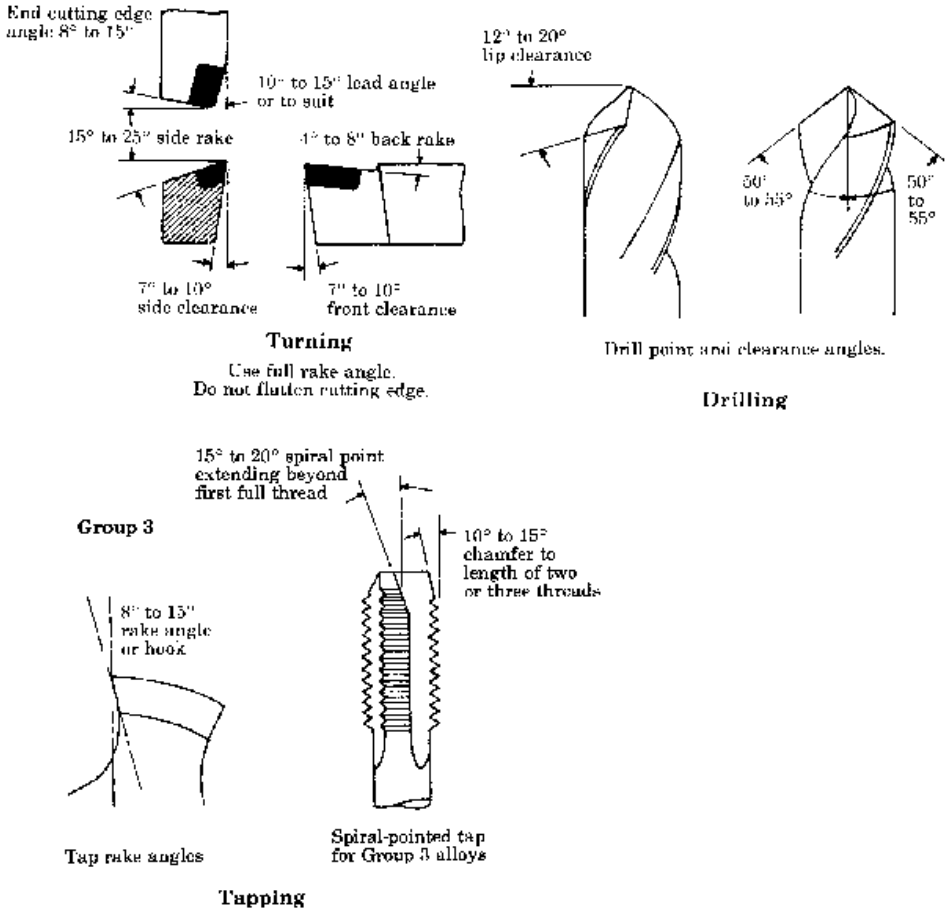
Machining

The handling of aluminium bronze need present no difficulty to the average machine shop. The material can readily be machined using modern tooling and correct workshop techniques.

Aluminium Bronze must not be confused with free-machining brass. In mechanical properties and machinability it is similar to low alloy steels and better than most stainless steels.

In the costing of machining, some advantage can be taken of the value obtained by the resale of swarf, provided that it is completely free of contamination, a good price can be expected.

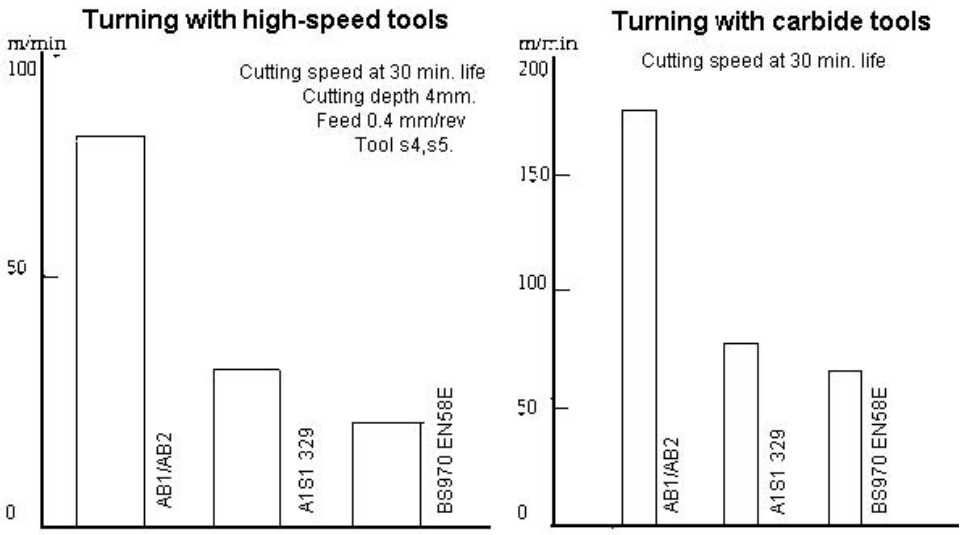
When ordering some types of castings, especially those centrifugally cast, it may advantageous to procure them proof-machined by the suppliers in order to remove the as-cast surface where required. Their great experience in machining and facilities for recycling swarf give useful economies. The following figures give initial guidance on tool geometry, speeds and feeds for roughing and finishing. They represent a reliable starting point but it will be found that production rates will improve with experience. The use of a good lubricant will help to keep the work cool during machining. For turning, the use of tungsten carbide or similar tipped tools is advisable.



Recommended machining rates for aluminium bronze

		Turning		Drilling	Tapping
		Roughing	**Finishing**		
Cut	mm	3-6	0.12-0.25		
	in	0.125-0.25	0.005-0.010		
Speed	m/min	30-60	120-180	15-40	10-20
	ft/min	100-200	400-600	50-130	30-60
Feed	mm/rev	0.25	0.12	0.075-0.5	
	in/rev	0.010	0.005	0.003-0.02	

Comparative data based on machining tests carried out by Johnson Metall



	AB1/2	A1S1 329	BS970EN58E
Carbide ISO-range	K20, M20	P20, K20	K10, M10
Cutting Depth mm	8	8	8
Feed mm/rev	0.75	0.75	0.50

Further information on machinability is available in CDA Publication No 83. 'Aluminium Bronze Alloys for Industry' and in CDA Technical Note TN 44 ‘Machining Brass, Copper and its Alloys’.

Further Information

Available Publications on Aluminium Bronzes

Much more information on the Aluminium Bronzes is contained in a series of publications available free of charge from Copper Development Association at www.cda.org.uk/enquiry-form.htm. The main titles are:

- Aluminium Bronze Alloys for Industry, Publication No 83, a useful 16 page introduction to the alloys, their applications, properties and machinability.
- Aluminium Bronze Alloys - Corrosion Resistance Guide, Publication No 80, 26 pages of invaluable data on recommended service environments.
- Aluminium Bronze Alloys - Technical Data, Publication No 82, 90 pages of tabulated mechanical and physical properties.
- Welding Aluminium Bronzes, Publication No 85, 8 pages of useful guidance.
- Designing Aluminium Bronze Castings, a 7-page reprint of data from an article by H. J. Meigh.

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

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