MATERION

TECH BRIEFS

Forging and Extruding Copper Beryllium

Elevated temperature forming operations, such as forging and extrusion, allow for efficient large scale shape and dimensional changes in the manufacture of metallic components. Copper beryllium alloys are readily hot worked to produce dimensionally accurate, sound parts that respond effectively to subsequent age hardening. The forgeability of copper beryllium is considered good. Preheating time and temperature, temperature control during processing, and deformation ratio are the variables important to obtain consistently high integrity products.

PROPERTIES OF COPPER BERYLLIUM

The material properties which most influence hot workability are provided in Table 1 for the two classes of copper beryllium alloys. Listed are high temperature yield strength, elongation, and deformation resistance values. Room temperature mechanical properties for copper beryllium alloys are provided in the publication, "Guide to Materion Brush Performance Alloys".

Alloy	Temperature		Yield Strength in Tension	Elongation	Deformation Resistance
	°F	°C	(ksi)	(%)	(ksi)
High Strength Copper Beryllium Alloys* (25 and 165)	1300	705	7	60	10-28
	1400	760	2	105	8-20
	1500	815	1	130	7-17
High Conductivity Copper Beryllium Alloys (3 and 10)	1300	705	11	35	16-33
	1400	760	8	45	12-27
	1500	815	5	55	10-23
	1600	870	3	70	6-20
	1700	925	2	85	5-16

* Alloy M25 (C17300) cannot be forged. Extrusion of M25 requires special conditions and processes.

Table 1. Elevated Temperature Properties of Copper Beryllium Alloys

The values in Table 1 should be used as a starting point to predicting press loads or in modeling deformation in hot forming operations. Process factors such as work piece geometry, friction, lubrication, adiabatic heating, as well as the condition and design of the dies, can exert significant influence on the validity of hot working models. These factors, as well as the material properties, must be considered. The yield strength and elongation values are from the simple uniaxial tensile test. They can be used to calculate approximate limits for the more complex forging and extrusion operations.

The deformation resistance, or K factor, is the yield strength of the material in pure shear. It is a material characteristic useful in predicting press loads, and it is a strong function of strain rate and temperature. For high strain rate (>10 sec-1) processes, such as impact forging, use values at the high end of the ranges. The lower values of deformation resistance define lower strain rate (<2 sec-1) operations such as press forging.

OPEN DIE FORGING

Open die forging provides an economical method to manufacture short run items or to produce large parts of relatively simple geometric design. Conventional forging equipment and processes, including rotary forging, ring rolling, and roll forging, are used with the copper beryllium alloys. During forging, the work must be maintained within a controlled temperature range to avoid forging defects: incipient melting on the high side and surface cracking on the low side. Table 2 provides standard forging temperature ranges for copper beryllium alloys. Alloy M25, a free machining copper beryllium containing lead, cannot be hot forged.

Alloy	Temperature	
25 and 165	1300-1425 °F	705-775 °C
3 and 10	1400-1700 °F	760-925 °C

Table 2. Forging Temperature Ranges for Copper Beryllium.

The forging temperature must be high enough to allow recrystallization without promoting excess microstructural grain growth. The actual temperature selected for forging depends on the amount and rate of deformation in the forging operation. Large reductions or high hammer rates, which generate significant adiabatic heat, should start with the work at the lower end of the temperature range to avoid overheating. Because of the tight temperature working range, reheating is usually necessary for large changes in dimension.

Reheating practice is a major issue in obtaining a sound forging. For some copper beryllium, the forging temperature range is limited and temperature lost at the surface through radiation and die contact demands close attention to the forging temperature limits. Although copper beryllium has high thermal conductivity, adiabatic heating from the forging operation may not make up for the heat lost at the surface. A cold surface will crack during forging. Knowing when to reheat, allowing sufficient time in the reheat furnace and good furnace temperature control are the key elements in avoiding many forging defects.

To insure temperature uniformity in preheating, the parts should be soaked at temperature for 1 hour per inch of section on charging a room temperature blank into a hot furnace; 0.5 hour per inch for reheating during forging. Furnace uniformity and control should be within ±10°F (5°C). Billets exiting the furnace should be checked with a probe pyrometer or, if the billets are not heavily scaled, a radiation pyrometer (emissivity of copper beryllium is about 0.85). To prevent hot shortness in forging, gas fired furnaces using high sulfur fuel should not be used to heat copper beryllium. The furnace atmosphere should be neutral to slightly oxidizing to avoid excess oxidation of the forging blank.

The forgeability of copper beryllium alloys is considered good, approximately equivalent to aluminum bronze. Copper beryllium is rated 40 50, with forging brass (C37700) equal to 100. Copper beryllium tends to barrel relatively little during upsetting; the face contacting the die will spread. Forging copper beryllium does not require the use of special die alloys. Any conventional material suitable for copper beryllium's forging temperatures can be used. As with the forging of any copper alloy, the thermal conductivity of the work piece is relatively high, and hot dies will reduce die chilling of the work piece.

The reduction ratio for copper beryllium should be large enough to allow the deformation to penetrate the entire work section. Partial penetration resulting from light hammer blows, particularly on the final passes, will not produce the desired uniform dynamic recrystallization in the work piece. This will cause nonuniformity in the microstructure and mechanical properties after age hardening. Forging reduction ratios of 3:1 5:1 are desirable, although in some cases copper beryllium will allow total reduction ratios of 3:1 10:1. Of course, deformation should not exceed the high temperature ductility limit of the material (Table 1).

CLOSED DIE FORGINGS

Closed die forging is usually selected for longer run jobs or for more complex and precision designs. In general, no lubricant is required although, if desired, it can be used (avoid sulfur containing lubricants). The acceptable processing parameters and material properties for the closed die forging are the same as those listed in the section on open die forging.

There may be one or more roughing dies before the final finishing die. As with open die forging, sufficient deformation must be provided in each die (particularly, the finishing die) to avoid dead zones and the formation of a duplex grain microstructure which may lead to nonuniform properties after age hardening. As with open die forging, adiabatic heating on large reductions must be controlled to avoid processing defects.

Where metal flow in the die is difficult, flash formation may be limited, requiring close attention to maintaining consistent input blank weights. Flash trimming is done hot or cold. In die design, the minimum corner radius is 1/32 inch (1 mm). The minimum draft angle is 1°, although properly designed minimum draft forging dies can be designed with as little as 1/8° draft angle for small to medium sized parts. Typical dimensional tolerances for closed die forgings are ±0.01 inch (0.25 mm).

EXTRUSION

Because of copper beryllium's high resistance to flow at low temperatures, extrusion is always performed hot. Consistent with equipment capacity, the objective is to extrude at the lowest temperature and the highest speed. Table 3 provides typical extrusion temperatures. Alloy M25, a leaded, free machining version of Alloy 25 is more difficult to extrude than the other copper beryllium alloys. Because of the requirements for special process and equipment, some of the parameters provided in this report do not apply to M25.

Alloy	Temperature	
	°F	°C
25 and 165	1300-1425	705-775
3 and 10	1500-1650	815-900

Table 3. Extrusion Temperature Ranges for Copper Beryllium.

Die materials, die design, speed, dummy block configuration, friction, and extrusion ratio, in addition to temperature, all play important roles in the production of sound extrusions. If the temperature is too high, the extruded material may exhibit excess oxidation, crack¬ing, coarse grains, or incipient melting. Alloys 3 and 10 are less susceptible to heat checking because of the larger hot working range. A low billet temperature will cause high press loads and may lead to nonuniform deformation. The preheat furnace atmosphere should be approximately neutral to reduce oxidation which can cause excess extrusion die wear. Alternatively, induction heating provides an efficient method to preheat billets with minimum oxide formation.

The reduction ratio and speed depend upon die design and the ability of the operation to deal with the adiabatic heat generated during extrusion. Reduction ratios of up to 100:1 are possible. Flat dummy blocks are used for most reduction ratios, and a 35° half die angle works well for high strength copper beryllium.

Tool steel and high temperature cobalt and nickel base alloy dies can be used with copper beryllium. Ceramic (zirconia, alumina) dies are also used. The advantages of ceramics are the lower coefficient of friction with copper beryllium and lower die wear rates. Mandrels for tube extrusion are fabricated from high strength alloys such as Inconel 718.

Die wear rate is influenced by lubrication practice. For copper beryllium, graphite/based lubricants are effective; sulfur containing lubricants should be avoided. Glass lubricants are not usually used. Final tolerances, which depend upon extrusion temperature, speed, reduction ratio and die design can be held to ±0.005 inch (0.15 mm) for high reduction ratios.

To avoid a separate solution annealing and quenching step after extrusion, the product can be quenched directly from the extrusion press. However, to effectively quench, immediate immersion in a well agitated medium is required; a spray quench is usually not adequate.

CLEANING COPPER BERYLLIUM

The oxide on copper beryllium, formed during hot working, should be removed before age hardening the parts. Depending upon the amount of oxide formed, it may also be necessary to clean the parts during the forging sequence. Extrusion billets should have a clean surface to minimize die wear. The high conductivity copper beryllium alloys (3 and 10), because of their lower beryllium content and higher processing temperature, will oxidize more than the high strength alloys (165 and 25). If the finished, age hardened parts are to be plated, soldered, or brazed, the thinner, transparent oxide formed during the lower temperature age hardening process must also be removed.

Copper beryllium can be chemically cleaned and, when required, treated to a bright, lustrous surface. The cleaning process is described fully in another TechBrief by Materion Brush Performance Alloys titled, “Cleaning Copper Beryllium”.

MACHINING COPPER BERYLLIUM

Copper beryllium is readily machined using con¬ventional processes and tooling. Machining is some¬times done with the alloy in the soft or solution an¬nealed condition. The machined part is then hardened by a simple heat treatment. Precision machining is best with the part in the final age hardened temper. Machining should be performed wet. Information on machining, including speeds, feeds, lubricants, and tool design are available in Materion Brush Performance Alloys’s publication, “Machining Copper Beryllium”.

HEAT TREATING COPPER BERYLLIUM

Heat treatment is required to develop the strength and conductivity of copper beryllium alloy products which have been hot worked. To develop maximum properties, the parts must be solution annealed, quenched, and age hardened by uncomplicated thermal treatments. More detailed processing informa¬tion is provided in another Materion Brush Performance Alloys TechBrief titled, “Heat

Treating Copper Beryllium Parts". The ranges for mechanical and physical properties of age hardened parts are listed in the publication, "Guide to Materion Brush Performance Alloys".

INSPECTION AND TESTING

Standard techniques can be used for ultrasonic, eddy current, radiographic, and liquid penetrant inspection of copper beryllium forgings and extrusions. Metal flow patterns and forging defects can be made visible by macroetching cross sections in concentrated nitric acid. On a smaller scale, standard metallographic examination is used to measure grain size and for examination of microstructural features.

For optimum properties in the high strength copper beryllium alloys, the hot working and annealing processes should be controlled to generate a uniformly fine grain product. A grain size in the range of 0.003 .01 inch (0.08 0.25 mm), ASTM grain size #1 5, is desirable for most applications.

ORDERING COPPER BERYLLIUM

When placing an order for copper beryllium to be used for forging, specify "forging grade billet". This will insure the product you receive is best suited for your application.

SAFE HANDLING OF COPPER BERYLLIUM

Handling copper beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Materion Brush Performance Alloys, Technical Service Department at 1-800-375-4205.

In hot working operations, the relevant safety concern with copper beryllium is spalling of the surface oxide during processing or handling steps. Although the oxide is composed mostly of copper oxides, it contains beryllium in proportion to the beryllium content of the alloy. Billet preheating and reheating should be done in a manner which minimizes oxide formation. Oxide particles, when present, should be prevented from entering the breathing zones of unprotected workers. Please refer to the Materion Corporation publication "Safety Facts 105 - Processing Copper Beryllium Alloys."