Tech Briefs

Heat Treating Copper Beryllium

by Technical Service Department
Brush Wellman Inc.

Heat treating is key to the versatility of the copper beryllium alloy system. Unlike other copper base alloys which acquire their strength through cold work alone, wrought copper beryllium obtains its high strength, conductivity, and hardness through a combination of cold work and a thermal process called age hardening. Age hardening is often referred to as precipitation hardening or heat treating. The ability of these alloys to accept this heat treatment results in forming and mechanical property advantages not available in other alloys. For example, intricate shapes can be fabricated when the material is in its ductile, as-rolled state and subsequently age hardened to the highest strength and hardness levels of any copper base alloy.

Heat treating the copper beryllium alloys is a two-step process which consists of solution annealing and age hardening. Because Brush Wellman performs the required solution anneal on all wrought products prior to shipping, most fabricators' primary concern is the age hardening process. The following text details this process and overviews the available copper beryllium alloys. Specific heat treating procedures for Wrought and Cast products, recommended heat treating equipment, surface oxidation information, and general solution annealing practices are also included.

Copper Beryllium Alloys

Copper beryllium alloys are available in two basic classes (Table 1): *High Strength Copper Beryllium* offers high strength with moderate to good conductivity; and *High Conductivity Copper Beryllium* features maximum conductivity and slightly lower strength levels.

High Strength Copper Beryllium		High Conductivity Copper Beryllium	
Wrought	Cast	Wrought	Cast
25 (C17200) 190 (C17200)* M25 (C17300) 165 (C17000)	275C (C82800) 245C (C82600) 20C (C82500) 21C (C82510 165C (C82400)	3 (C17510) 10 (C17500) 174 (C17410)* 171 (C17450)*	3C (C82200) 10C (C82000)

Table 1. Copper Beryllium Alloys, Brush Wellman Designations and UNS Numbers.

* These alloys are supplied only in the mill hardened condition and require no further heat treatment.

Both the *High Strength* and *High Conductivity Copper Beryllium* are available as strip in the heat treatable and mill hardened tempers. Mill hardened tempers are supplied in the heat treated condition and require no further heat treatment.

Copper beryllium is produced in tempers ranging from solution annealed (A) to an as-rolled condition (H). Heat treating maximizes the strength and conductivity of these alloys. The temper designations of the standard age hardenable copper beryllium tempers are shown in Table 2.

Brush Wellman Designation	ASTM Designation	Description
A	TB00	Solution annealed
1/4 H	TD01	Cold worked, Quarter hard
1/2 H	TD02	Cold worked, Half hard
3/4 H	TD03	Cold worked, Three-quarter hard
H	TD04	Cold worked, hard
AT 1/4 HT 1/2 HT 3/4 HT HT	TF00 TH01 TH02 TH03 TH04	The suffix "T" added to Brush Wellman temper designations indicates that the material has been age hardened by the standard heat treatment.

Table 2. Temper Designations, Alloys 25 and 165 Strip

Age Hardening Copper Beryllium Alloys

Copper beryllium achieves its maximum levels of strength, hardness, and conductivity through age hardening. During the age hardening process, microscopic, beryllium-rich particles are formed in the metal matrix. This is a diffusion controlled reaction, and the strength will vary with aging time and temperature.

Recommended or standard age hardening time and temperature combinations have been determined for each copper beryllium alloy. These standard times and temperatures allow parts to reach peak strength in two to three hours, without the risk of strength decrease due to extended temperature exposure. As an example, the Brush Alloy 25 response curves in Figure 1 indicate how low, standard, and high aging temperatures affect both peak properties and the time required for the alloy to reach peak strength.

In Figure 1, at the low temperature of 550°F (290°C), the strength of Brush Alloy 25 increases slowly, and peak strength is not reached until approximately 30 hours. At the standard temperature of 600°F (315°C), Brush Alloy 25 exhibits virtually no change in strength after three hours of exposure. At 700°F (370°C), peak strength is reached in 30 minutes and declines almost immediately. In short, as aging temperature increases, the time necessary to reach peak strength decreases, as does maximum obtainable strength. This response is similar for all copper beryllium alloys, but at different standard temperatures.

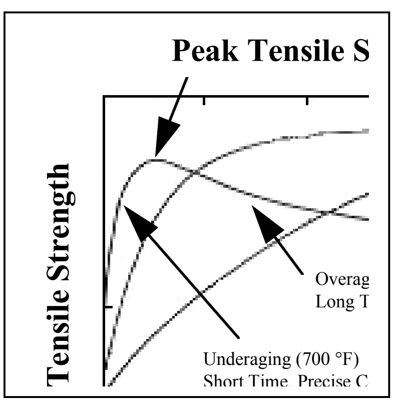


Figure 1. Response to age-hardening heat treatment for three treating temperatures - Brush Alloy 25.

Copper beryllium can be age hardened to varying degrees of strength. The term *peak aged* refers to copper beryllium aged to maximum strength. Alloys not aged to maximum strength are *underaged*, and alloys aged beyond maximum strength are *overaged*. Underaging copper beryllium increases toughness, uniform elongation, and fatigue strength. Overaging increases the alloy's electrical and thermal conductivity's and dimensional stability. Copper beryllium never ages at room temperature, even if material is stored for significant lengths of time.

Allowable variances in age hardening time are dependent on furnace temperature and final property requirements. To peak age at the standard temperature, furnace time is typically controlled to ±30 minutes. For high temperature aging, however, more precise time control is required to avoid overaging. For example, the aging time of Alloy 25 at 700°F (370°C) must be controlled to ±3 minutes to hold peak properties. Similarly, underaging requires tight control of the process variables because of the sharp initial increase of the aging response curve. In the standard age hardening cycle, heating and cooling rates are not critical.

However, to assure that aging time does not begin until parts reach temperature, a thermocouple can be placed on the parts to determine when desired temperature has been achieved.

Standard age hardening times and temperatures for the *High Strength Copper Beryllium* alloys and the *High Conductivity Copper Beryllium* alloys are detailed in the following sections.

<u>High Strength Wrought Copper Beryllium (Alloys 25, M25, and 165</u>)
Age hardening temperatures for high strength wrought copper beryllium varies from 500°F (260°C) to 700°F (370°C). The time required to reach peak properties at the lower temperature is longer than at the higher temperature. The standard age hardening treatment is 600°F (315°C) for two to three hours; two hours for cold-worked alloys and three hours for annealed alloys. Figure 2 shows the effect of time and temperature on the mechanical properties of Alloy 25 1/2H temper.

A complete set of aging response curves and mechanical properties can be found in Brush Wellman's "Guide to Beryllium Copper".

<u>High Strength Cast Beryllium Copper Alloys (Alloys 275C, 245C, 20C, 21C, and 165C)</u>
The standard age hardening cycle for the high strength casting alloys, both annealed and as-cast, is three hours at 625-650°F (320-340°C). However, to develop the highest strength for the as-cast products, a separate solution anneal should precede the age hardening.

<u>High Conductivity Wrought Alloys (Alloys 3 and 10) and High Conductivity Cast Alloys (Alloys 3C and 10C)</u>
The standard age hardening cycle for both the wrought and cast high conductivity alloys is 900°F (480°C) for two to three hours; two hours for the cold-rolled alloys and three hours for the cast and annealed wrought alloys.

The high conductivity alloys are noted for their excellent electrical and thermal conductivity's. They obtain their moderate strength through age hardening, but at a higher temperature than the high strength alloys.

Because their mechanical properties change only slightly with time, few high conductivity applications benefit from either underaging or overaging. As an example, the heat treating curves for Brush Alloys 3 and 10 demonstrate the affects of aging on the mechanical properties (see Figure 3).

Age Hardening Equipment

There are a number of effective procedures and equipment available to age harden copper beryllium.

<u>Recirculating Air Furnaces</u>
Recirculating air furnaces, with temperature controlled to ±15°F (±10°C), are recommended for the standard age hardening of copper beryllium parts. These furnaces are designed to accommodate both large and small batches of parts, and are ideal for reels of stamped parts aged on carrier strips. However, care must be exercised when aging large batches of parts. Because of their sheer thermal mass, large batches of parts will not have all parts at temperature for the same length of time. As a result, underaging or short aging cycles of large batches of parts should be avoided.

<u>Strand Aging Furnaces</u>
Strand aging furnaces, using a protective atmosphere as the heating medium, are suitable for processing large quantities of material in coil form. This process is generally used by metal producers, and performed in long furnaces where material can be uncoiled into the furnace, passed through heating and cooling zones, and upcoiled upon exiting the furnace. The advantages of this type of furnace include good time and temperature control, better part-to-part uniformity and the ability to control special cycles for underaging or high temperature/short time aging and selectively hardening a portion of a part.

<u>Salt Baths</u>
Also recommended for age hardening wrought products are salt baths. Salt baths offer rapid and uniform heating, and are recommended at any temperature in the hardening range. They are particularly advantageous for short-time, high temperature aging.

<u>Vacuum Furnaces</u>
Vacuum aging of copper beryllium parts can be done successfully, but caution must be exercised. Because vacuum furnace heating is by radiation only, it is difficult to uniformly heat large loads of parts. Parts on the outside of the load are subject to more direct radiation than those on the inside, as a result, the temperature gradient produces a variation in properties after heat treatment. To assure uniform heating, load size should be limited and parts must be shielded from the heating coils.

Alternatively, vacuum furnaces, backfilled with an inert gas such as argon or nitrogen, can be used. Again, parts must be shielded unless the furnace is equipped with a recirculating fan.

Surface Oxide

During aging, the copper beryllium alloys develop a surface oxide composed of beryllium and, depending on the alloy and furnace atmosphere, copper oxides. These oxide films vary in thickness and composition and are often transparent.

Surface oxidation of beryllium during age hardening cannot be suppressed, even in a pure hydrogen atmosphere or a hard vacuum. However, some atmospheres can minimize the copper oxidation. For instance, a low dew point (-40°F) atmosphere of approximately 5 percent hydrogen in nitrogen will minimize oxidation and economically aid in heat transfer. Air atmospheres contribute the most to surface oxide and reducing atmospheres the least.

Although oxide films are not detrimental to the base alloy, they should be removed if parts are to be plated, brazed, or soldered. For specific information on cleaning copper beryllium, consult the Brush Wellman TechBrief, "Cleaning Copper Beryllium".

Solution Annealing

To elicit an effective age hardening response, copper beryllium must be solution annealed and quenched prior to aging. In addition to preparing the alloy for age hardening, annealing softens the alloy for further cold work and regulates grain size. Brush Wellman performs this required anneal on all wrought products at the mill. Therefore, customers usually do not need to anneal prior to age hardening.

If solution annealing is required, it is a high temperature soak: 1450°F (790°C) for the high strength alloys and

1650°F (900°C) for the high conductivity alloys. Annealing must be carefully controlled as excess time or temperature may cause grain growth. Solution annealing should be immediately followed by a water quench. As a precaution, large quantities of metal should not be annealed without first conducting a furnace simulation test. Thin sections, such as fine wire, require an annealing time of about 3-5 minutes. Fifteen minutes to one hour is required for thin walled tube and small castings. Heavy sections (above about one inch) usually require 1-3 hours. A heat-up time of one hour per inch-of-thickness must be added to the soak time. If you need assistance in establishing an annealing cycle, call Brush Wellman's Customer Technical Service Department.

Because most salts will attack copper beryllium at temperatures in the solution annealing range, solution annealing should not be performed in a salt bath.

When peak aging copper beryllium castings and weldments, the customer must always solution anneal prior to age hardening. However, if peak properties are not required, castings can be age hardened from the as-cast condition without the solution anneal.

Mill Hardened Alloys

In applications not requiring severe forming, fabricators can eliminate the heat treating and cleaning of the heat treatable alloys by specifying mill hardened copper beryllium. Brush Wellman performs a special heat treatment on mill hardened product which delivers maximum formability at desired strength levels.

<u>High Strength Mill Hardened Alloys</u>
The high strength copper beryllium mill hardened alloys are Brush Alloy 190 and Brushform 290. Both alloys fall within the C17200 designation and are available in several tempers. Brushform 290 provides improved formability at a given strength level.

<u>High Conductivity Mill Hardened Alloys</u>
The high conductivity mill hardened copper beryllium alloys are Brush Alloys 3, 10, 171, and 174. The mechanical properties of mill hardened Alloys 3 and 10 are equivalent to the peak aged properties of the AT or HT age hardenable tempers. Alloys 3 and 10 can also be ordered with either enhanced strength (HTR temper) or enhanced conductivity (HTC temper). High conductivity Brush Alloys 171 and 174 are available only in mill hardened tempers. Consult Brush Wellman's "Guide to Beryllium Copper" for additional data on all mill hardened tempers.

Safety

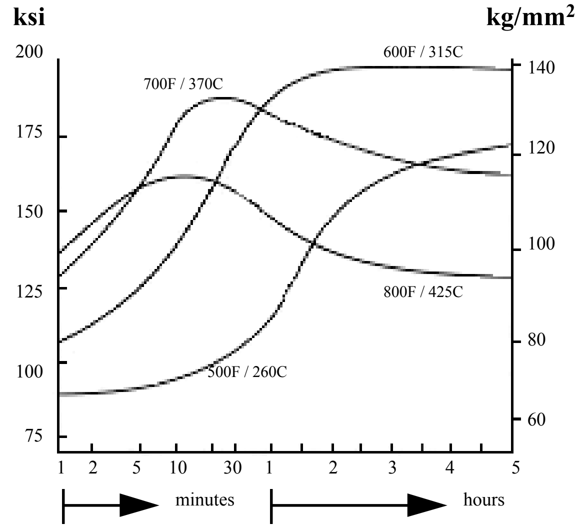
Inhalation of finely sized particulate material containing beryllium may cause health problems in some workers. While copper beryllium heat treating operations do not generate any beryllium containing fume or particulate, the relevant safety concern is spalling of the surface oxide during subsequent 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. The furnace atmosphere should be controlled to minimize oxide formation. Heat treated parts should be chemically cleaned before processing.

To assure a safe working environment, air samples should be analyzed during operations which can generate airborne particulate. OSHA has established beryllium exposure limits which, when met, assure worker safety. Before heat treating copper beryllium, information on the most effective methods of safely handling copper beryllium should be obtained by contacting Brush Wellman Inc. Material Safety Data Sheets and other information for your application will be furnished.

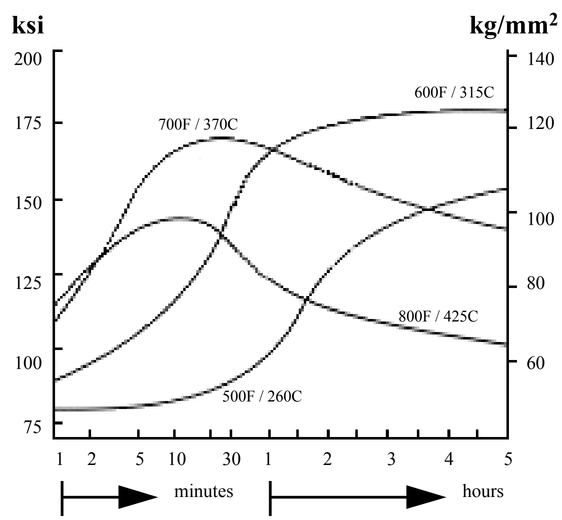
If you need further information or technical assistance, call Brush Wellman's Customer Technical Service Department at (800) 375-4205.

Alloy 25 1/2 H

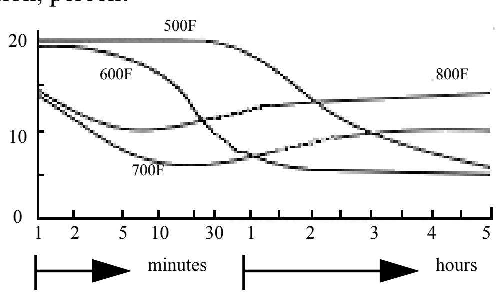
Tensile Strength



Yield Strength



Elongation, percent

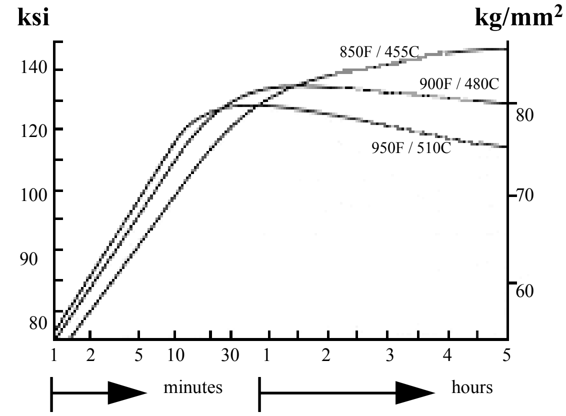


Time at temperature

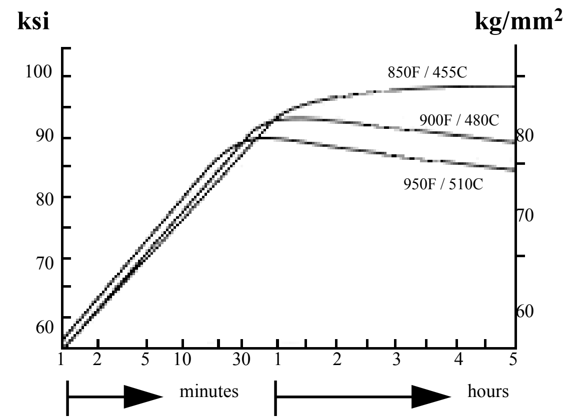
Figure 2.

Alloy 3 and 10 A

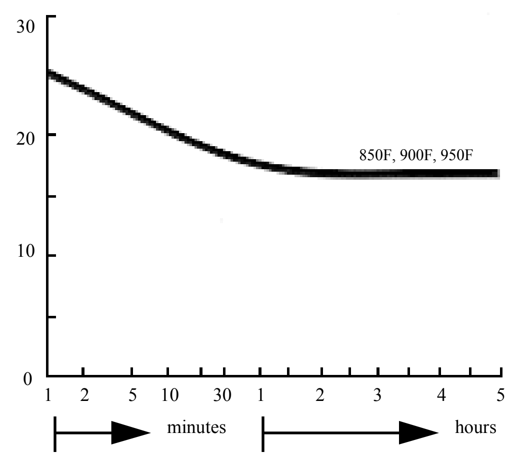
Tensile Strength



Yield Strength



Elongation, percent



Time at temperature

Figure 3.