MATERION

Tech Brief

Copper Beryllium Alloys

Shape Distortion of High-Strength Copper Beryllium During Precipitation Age Hardening

Alloy 25 copper beryllium is a high-strength, precipitation-hardenable alloy. The hardening process greatly improves the alloy's strength, hardness and other mechanical properties, although it can lead to distortion of the part unless care is used to prevent it.

+1.800.375.4205 | materion.com/copperberyllium

AGE HARDENING

Age hardening (also called aging, precipitation hardening, or simply heat treating) is the elevated temperature treatment required to fully develop the strength and hardness of copper-beryllium alloys. Age-hardenable tempers of copper beryllium are normally heat treated after the parts have been machined or stamped. Mill-hardened copper beryllium, which is not subject to distortion, is supplied in the age-hardened condition and requires no further heat treatment after forming. When age hardening is done after the part has been formed, dimensional or shape distortion can occur.

Age hardening of copper beryllium involves the metallurgical precipitation of a hard beryllide phase within the copper alloy matrix. This hard phase has a higher density than the matrix, and its formation at elevated temperature leads to a slight volume change during the aging cycle. The volume change is negative, which means that the density increases. For the high-strength copper-beryllium alloys (Alloys 25, M25 and 165), the volume change is about 0.6%. Correspondingly, the linear dimensional change for high-strength copper beryllium is 0.2%. These values are approximate since alloy temper, as well as the age hardening time and temperature, will exert a slight influence on volume change.

The high-conductivity copper-beryllium alloys (Alloys 3 and 10), because of their lower beryllium content, have almost zero percent volume change during age hardening.

Similarly, the spinodally-hardened BrushForm® 96 and BrushForm 158 copper-nickel-tin alloys experience less volume change during spinodal decomposition than Alloy 25 does during precipitation hardening. Distortion during heat treatment is less severe in these alloys than in Alloy 25, but is still a risk. Note that the copper-nickel-tin alloys do not readily respond to thermal stress relief, so you must take care to avoid introducing unnecessary residual stress.

If volume change occurs uniformly throughout the part during age hardening, density would increase uniformly and the overall shape of the part would not be affected. This uniform change could be included in dimensional design calculations and would not present major problems. However, if volume change is not uniform, shape distortion can occur.

Variation in temperature while aging large or long parts is a possible source of distortion. However, distortion problems are also encountered in small, stamped or machined parts where local temperature conditions during aging are uniform.

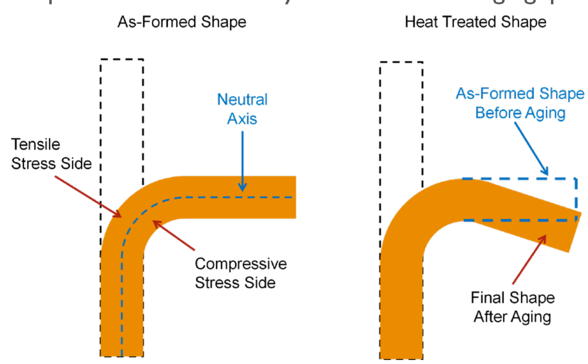
The most likely cause of aging distortion in small parts is non-uniform residual stresses resulting from mechanical forming operations such as machining, stamping, bending, coining, straightening, leveling, etc. For example, the flat strip formed into a simple bend in Figure 1 will be in compression on the inside of the bend and in tension on the outside.

Since age hardening copper-beryllium is accompanied by a volume contraction (increase in density), the presence of a compressive stress will, by LeChatelier's Principle, locally promote or intensify the aging response. Correspondingly, tensile stress will inhibit the aging process. When the part with the bend is age hardened, the aging response (and therefore, the volume contraction) will be greatest at the in-

continue

side of the bend radius and will decrease through the thickness of the strip toward the outside bend radius. The occurrence of greater volume contraction on the inside of the bend will cause the 90° bend angle in Figure 1 to increase during aging.

Figure 1: Compressive Stress in As-Formed and Heat-Treated Bends



A compressive stress locally intensifies the aging process, while a tensile stress effectively inhibits age hardening. The greater volume contraction on the inside of the bend can cause the 90° bend angle to increase during age hardening.

Flat parts exhibit aging distortion problems more readily than other shapes. This is because of the lack of stiffening features in the design and the tendency of distortion to be magnified by long dimensions. As well as changes in angles, aging distortion can lead to bending, twisting, buckling and waviness.

Part stiffness also plays a role. More flexible parts require less stress to move. As connectors are becoming smaller, there is also less material available to resist distortion, so additional planning is required for heat treatment of small, thin, and/or long parts. The following geometric features increase the potential for distortion and increase unpredictability:

- Long, thin, narrow beams
- Large bend radii
- Small bend angles
- Multiple bends along the same length

Although aging distortion occurs early in the aging cycle time, the heating rate does not affect distortion. The cooling rate, following age hardening, does not influence shape distortion.

CONTROLLING PART DISTORTION

Alloy and temper selection, fixturing, age hardening conditions and stamping adjustments can be used to control part distortion.

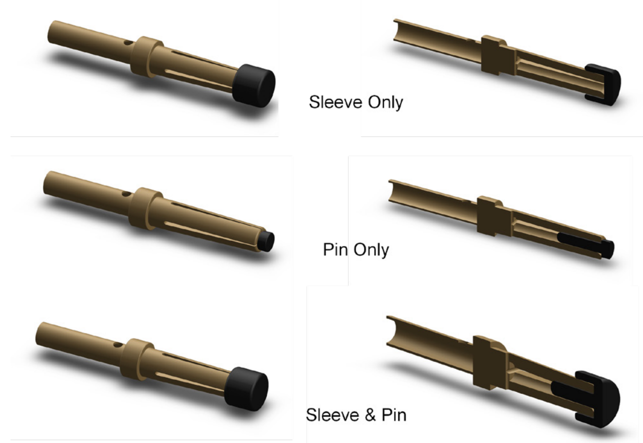
Selecting a mill hardened copper-beryllium alloy, which is already age hardened, eliminates aging distortion problems all together. After stamping or machining, no additional heat treatment is required. Mill-hardened tempers are available in a range of formability and strength. The mill-hardened versions of copper-beryllium Alloy 25 are known as Alloy 190 and 290.

CONTROLLING DISTORTION WITH FIXTURES AND STIFFENING FEATURES

Most aging distortion problems arise from non-uniform distribution of stresses. Techniques used to control these problems vary widely with the shape of the part. Large parts, including long rod and tube, can be fixtured to prevent metal movement by securing them to stiff beams or between flat plates during aging. Other parts may be fixtured by tightly packing in sand. Smaller, cup-shaped, stamped parts can be fixtured by nesting.

For slotted cylindrical connectors machined from rod, you may need to insert a pin between the tines to prevent them from closing and/or place a cap or sleeve over the end to prevent them from opening. See Figure 2, below.

Figure 2: Potential Fixtures to Prevent Distortion in Machined Slotted Cylindrical Connectors

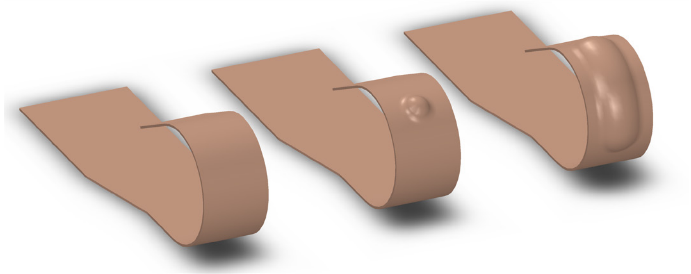


You can create a fixture for loose parts by machining a conformal space in a block of steel or other metal into which the parts will fit exactly. However, because of part design complexity, fixturing is not a universal option.

Thin, flat parts can sometimes be self-fixtured by including in-plane stiffening features such as bosses or ribs in the design. See Figure 3 on the next page.

continue

Figure 3: Bosses and Ribs on Stamped Parts to Increase Stiffness and Minimize Distortion



CONTROLLING DISTORTION WITH TEMPER SELECTION

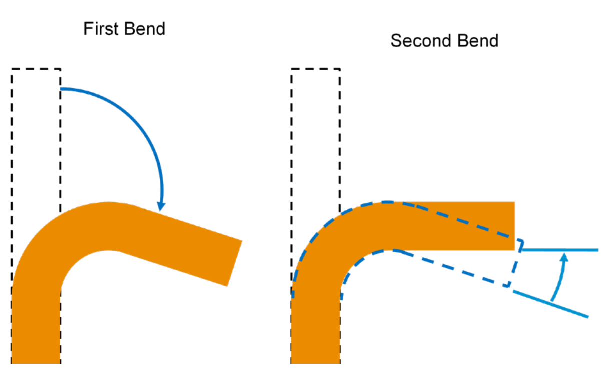
Temper selection provides another means of controlling distortion; however, changing temper can also mean a different set of properties after aging. For distortion of large diameter rod in the cold-worked temper, annealed temper rod can often be substituted with good results. In this case, residual stresses from cold work are totally eliminated. At other times, distortion can be resolved by increasing the uniformity of the residual stresses through temper selection. For example, the non-uniformity of the residual stresses from bends will be less significant in strip that has been more heavily worked during manufacturing.

Therefore, to minimize aging distortion, the hardest copper-beryllium temper meeting the formability requirements should be selected.

CONTROLLING DISTORTION IN THE STAMPING DIE

The forming operation itself can be used to promote more uniform stress patterns. As shown in Figure 1, a simple right angle bend was produced by plastically deforming the metal in tension on the outside of the bend and in compression on the inside. Alternatively, to obtain the same bend configuration, the part could be initially bent beyond the desired angle and then bent back to the desired angle, as shown in the two-step process in Figure 4.

Figure 4: Uniform Stress Pattern Created by Using a Two-Step Bend Process



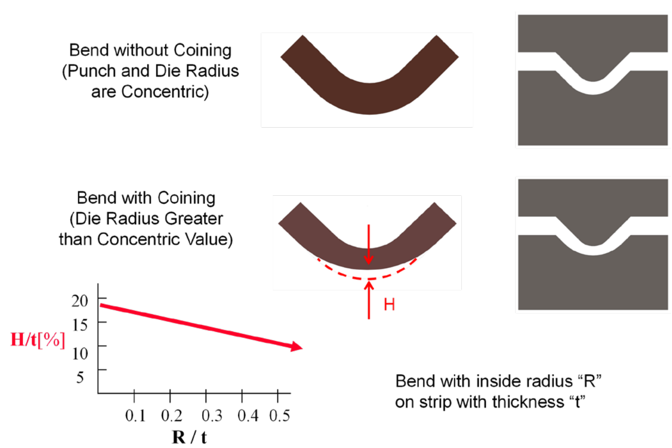
The reverse (second) bending operation will impose compression on the outside of the bend (which was initially formed in tension) and conversely, tension on the inside. The opposing stress states from the two sequential bends will, to some degree, "cancel" each other, or reduce total non-uniformity. Typically, an overbend of 10-20% is sufficient for most bends.

Larger radius bends will minimize stress non-uniformity. However, with larger bend radii, the elastic spring-back after stamping may cause the residual stresses on the inside and outside of the bend to reverse signs. In this case, the aging distortion will be in the opposite direction as seen in tighter radius bends.

Stamping tools can also be a source of residual stress leading to distortion problems. Dull tooling or excessive die clearances can promote high residual stress at the stamped edge leading to distortion particularly in very narrow and/or thin parts. It is important to keep the tooling sharp and maintain the appropriate clearances within the die.

Coining of the outside diameter (Figure 5) is a common technique to control spring-back during stamping. This is another means of reducing non-uniformity of residual stress, so it can also help to reduce distortion.

Figure 5: Coining Process of Outside Diameter



A coining process that is used to control spring-back during stamping is also effective at controlling distortion. However, it may make the bend more susceptible to cracking, so exercise care if you choose this option.

If the stress, or more importantly, the non-uniformity in stress cannot be eliminated, the age hardening conditions may be adjusted to lessen distortion.

continue

CONTROLLING DISTORTION IN THE FURNACE

Age hardening at a higher temperature (for a correspondingly shorter time) will decrease distortion. High-temperature aging will also decrease the peak strength or hardness the alloy can attain. As an example, if the aging temperature for Alloy 25 was increased from the standard 600°F (315°C) to an alternate temperature of 700°F (370°C), the aging time would decrease from 2 ± 1 hours to about 30 ± 3 minutes. Peak strength would decrease by about 15 ksi (10 kg/mm^2, 100 MPa). The level of decrease in aging distortion at 700°F (370°C) can be significant, but its magnitude would depend on the initial stress state of the part.

Stress relief treatments before age hardening may reduce some residual stress, but are not always effective in eliminating aging distortion. The residual stress level may be reduced by stress relieving; however, the non-uniformity in residual stress persists.

CONCLUSION

Distortion during the age hardening of copper-beryllium parts is usually caused by non-uniform residual stress. Distortion can be reduced or eliminated by the following:

- Changing to a mill-hardened temper
- Selecting the hardest temper that will meet formability requirements
- Fixturing during the age-hardening process
- Including stiffening features such as bosses and ribs in the parts
- Eliminating or reducing residual stress in the parts
- Providing more uniformity in the stress state
- Increasing the age-hardening temperature with decreased time at temperature.

SAFE HANDLING OF COPPER BERYLLIUM

Please refer to the Materion Corporation publications "Safety Facts 6 - Safety Practices for Heat Treating Copper Beryllium Parts", and "Safety Facts 105 - Processing Copper Beryllium Alloys."

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 Safety Data Sheet (SDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact the Materion Technical Service Department at +1.800.375.4205.

MATERION Global Headquarters
6070 Parkland Boulevard
Mayfield Heights, OH 44124 USA

Contact Us:
materion.com/ContactPAC
+1.800.375.4205

