ENDURANCE LIMIT OF A FREE-CUTTING BRASS ROD

H. L. WALKER and M. BASKAL*
University of Illinois, Urbana

Free-cutting brass rod is the most important of all the leaded brasses. Each year millions of pounds are consumed in the manufacture of screws, nuts, bolts, door hinges, and general hardware of all kinds. This product has excellent plasticity within the temperature range of 1200° to 1450° F. and can be extruded into intricate shapes; however, it cannot be hot-rolled or forged because of its high lead content. It is usually fabricated by hot extruding and/or cold drawing to size and shape. For best machining properties the product is furnished in the cold drawn condition.

Lead is virtually insoluble in alloys of copper and zinc, and when present it occurs as finely divided and more or less evenly distributed globules of lead. The presence of lead in brass does not appreciably influence the mechanical strength or corrosion resistance of the parent alloy but it does drastically reduce the bending, cold-heading, and upsetting operations, which can be performed with comparative ease in most of the unleaded copper-zinc alloys. The one reason why lead is added to brass is to improve its machinability. The presence of lead uniformly distributed in a brass alloy causes chips to break off and, since the chips are practically undistorted and are only momentarily in contact with the tool face, very little heat is transmitted to the cutting tool.

Purpose of Investigation

Free-cutting brass rod is essentially common brass rod (63% Cu, 37% Zn) to which approximately 3% Pb has been added. The presence of lead does not appreciably influence the mechanical strength of the common brass rod as is shown by the following data: Common brass rod, 62.7% Cu; Pb 0.03%; Zn balance, grain size 0.045 mm. diameter ready-to-finish, cold drawn 30%, has a tensile strength of 70,000 psi. Free-cutting brass rod, 61.7% Cu; 3.35% Pb; 34.9% Zn, grain size 0.040 mm. diameter ready-to-finish, cold drawn approximately 30%, has a tensile strength of 67,000 psi.

Because of the presence of lead particles in the microstructure of free-cutting brass rod there is an excellent opportunity for the lead to act as stress-raisers and materially affect the endurance limit. There are only a limited number of references in the literature to the endurance limit of leaded brasses, therefore it was believed that such an investigation would be of value.

Apparatus

All tests were made on a Farmer machine of rotating simple beam type, in which the outermost fibers of a solid cylindrical specimen are subjected to cycles of completely reversed stress from tension to compression, under constant load.

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FIG. 1.—Brass rod, cold drawn approximately 30%. Structure shows grains of alpha and beta solid solution. The dark stringers are particles of undissolved lead. Average grain size 0.040 mm diameter. Etched with 1 part H_2O_2 plus 4 parts 50% NH_4OH. Magnification 100 diameters.

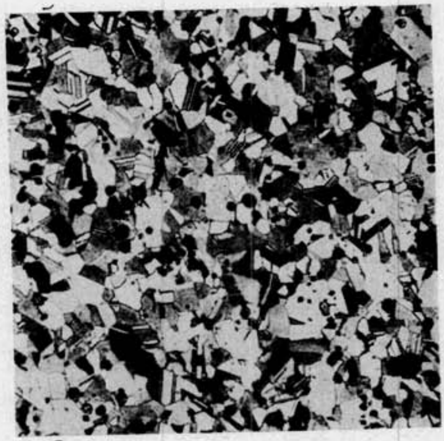

FIG. 2.—Brass rod annealed at 1050° F. for 2½ hours. Elongated grains of cold-drawn condition have been replaced by strain free equiaxed grains. Structure is essentially alpha solid solution grains with coalesced globules of lead. Grain size 0.040 mm diameter. Magnification 100 diameters. Etched in hydrogen peroxide plus ammonium hydroxide.

The specimens were of standard size: 4.0 inches long, 0.300 + 0.003 inch minimum diameter, and 5.0 inch radius. The ends of the specimens were threaded internally to facilitate a tight grip in the chucks. The surface was polished parallel to the axis with No. 00 metallographic paper.

MATERIAL AND PROCEDURE

The free-cutting brass rod was of ⅝ inch diameter, cold-drawn approximately 30%, with a ready-to-finish grain size of 0.040 mm. diameter.

The chemical analysis was:

Copper	61.70%
Lead	3.35%
Zinc	34.90%
Total	99.95%

The structure of the bar in the as-received condition consisted of alpha and beta brass, plus particles of lead; and the structure is illustrated in figure 1.

A series of as-received brass specimens was given a heat treatment to eliminate beta brass and produce a grain size equal to the ready-to-finish grain size. The treatment consisted of heating to 1050° F., holding for 2½ hours at that temperature in an electrical resistance furnace, followed by quenching in water. The grain size produced averaged 0.040 mm. diameter. The structure showed complete recrystallization but no appreciable beta phase, and is illustrated in figure 2. Another series of brass specimens was heat treated to produce a grain size twice as large as the ready-to-finish grain size and to eliminate the presence of beta phase. The heat treatment consisted of heating to 1500° F., holding for 3½ hours at that temperature, cooling to 1050° F. and holding at 1050° F. for 7½ hours, followed by quenching in water. The grain size produced averaged 0.080 mm. diameter. The structure showed complete recrystallization and coalescence of the grains but no beta phase, and is illustrated in figure 3.

FIG. 3.—Brass rod annealed at 1500° F. for 3½ hours. Structure consists of alpha solid solution and globules of lead. Grain size 0.080 mm diameter. Magnification 100 diameters. Etched in hydrogen peroxide and ammonium hydroxide.

The specimens were rough machined, heat treated, finish machined, and polished. An initial load of approximately 0.6 times the tensile strength was used. The load was continuously reduced until failure did not take place in 50 million cycles of reversed stressing. The specimens annealed at the higher temperature, to produce a large grain size, could not be loaded with a load greater than 25,000 psi without causing plastic deformation when the load was applied.

TABLE 1.—FATIGUE AND MECHANICAL PROPERTIES OF FREE-CUTTING BRASS ROD

Material	Rockwell B hardness	Ultimate strength psi	% Elongation in 1.2 inch gage length	% Reduction of area	Endurance limit psi	Cycles of stress
Brass, cold drawn approx. 30%. Av. grain dia. 0.040 mm.	73	67,000	22.4	51.1	16,500	$50x10^6$
Brass annealed 2½ hrs. at 1050° F. Av. grain dia. 0.040 mm.....	17	52,000	64.1	51.6	18,000	$50x10^6$
Brass annealed 3½ hrs. at 1500° F., cooled to 1050° F., held 7½ hrs. Av. grain dia. 0.080 mm.	13	45,300	65.2	58.5	17,500	$50x10^6$

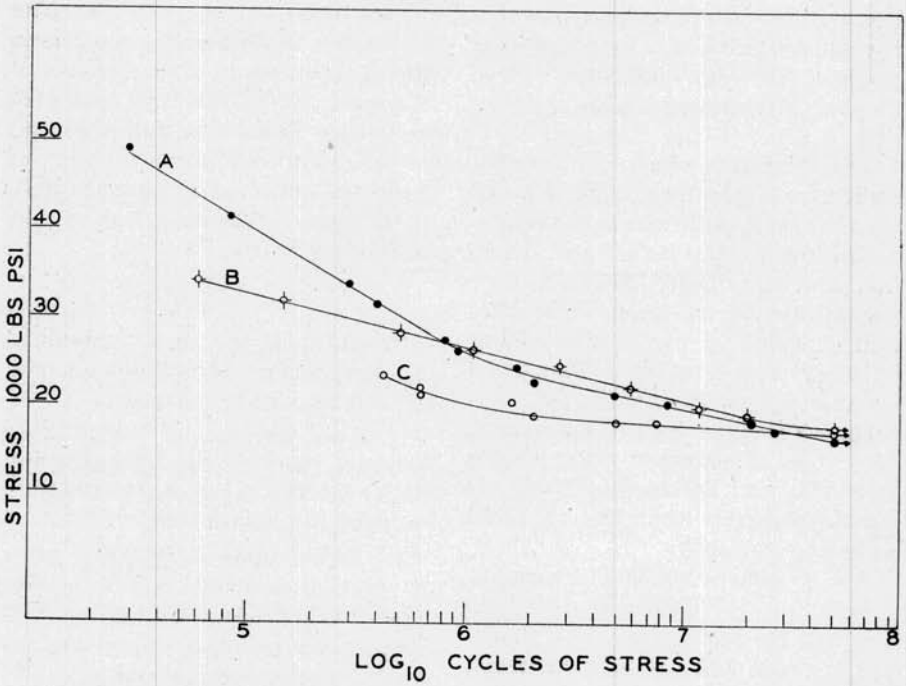

FIG. 4.—Stress versus cycles of stressing to produce failure in a free-cutting brass rod.

Curve A. Cold-drawn approximately 30% reduction in area.
Curve B. Annealed at 1050° F.
Curve C. Annealed at 1500° F.
Arrows indicate no failure for conditions of stress and cycles of stressing.

DISCUSSION OF RESULTS

The mechanical properties of the free-cutting brass rod in the three conditions of testing are shown in table 1. The loss in hardness and strength, and increase in elongation with the first heat treatment, shows recrystallization was complete and coalescence of grains had taken place. When the grain size was doubled by coalescence, in the second heat treatment, a further loss in strength and hardness was found, but the ductility was less affected.

The stress in pounds per square inch and the number of cycles of reversed stressing, to produce failure, are tabulated in table 1; and the data are plotted in figure 4 in the conventional manner of stress vs. cycles of stressing on a semi-logarithmic plot.

The rod in the as-received condition with approximately 30% cold deformation showed a continuously lowered stress for cycles of stressing up to 50,000,000 cycles. The slope of the curve for failure decreases at stresses of less than 25,000 psi. However, with cycles of stressing up to 50,000,000 cycles the S-N curve had not become horizontal, and a stress had not yet been reached in which it could be said a safe load had been reached for an infinitely large number of repeated cycles of stressing.

The specimens which had been annealed for 2½ hours at 1050° F., and with the same grain size as the ready-to-finish grain size before cold drawing, show an initially lower stress for a small number of cycles. The relation of stress vs. cycles of stressing is linear from 200,000 to 10,000,000 cycles of stress. Curiously, the load-carrying ability of these specimens, for cycles of stressing greater than 1,000,000 and up to 50,000,000, is somewhat better than for the cold drawn specimens.

The specimens which had been annealed for 3½ hours at 1500° F., followed by holding at 1050° F. for 7½ hours, would not take an initial load in excess of 25,000 psi without plastically deforming under the load. The load-carrying ability of these specimens of large grain size was materially lower than for the cold drawn specimens, or for the specimens annealed at the lower temperature and with a grain size only half as large. The relation of stress vs. cycles of stressing is linear and parallel to the specimens of smaller grain size with cycles of stressing up to 5,000,000 cycles. At 5,000,000 cycles the slope of the curve decreases and the curve is practically horizontal from 5,000,000 to 50,000,000 cycles.

The three curves, for the three specimens in different conditions, practically meet at a constant value of stress for 50,000,000 cycles of stressing. Thus, it is indicated that for an infinitely large number of cycles the annealed rod has the ability to carry as large a load as the cold drawn rod.

Conclusions

Based upon the results obtained in this experiment the following conclusions may be summarized:

1. Cold drawing of leaded-brass does not increase the load-carrying ability of the metal for 50,000,000 cycles of reversed stress.

2. Based upon 50,000,000 cycles of reversed stressing there is no indicated safe load for an infinite number of reversals of stressing, such as is exhibited by ferrous alloys.

3. Cold drawing a leaded-brass does increase the load-carrying ability, under complete reversal of stressing, for cycles of stressing less than 1,000,000 cycles.

4. The endurance limit of leaded-brass is not affected by increasing the grain size from 0.040 to 0.080 mm. diameter, for a large number of stress cycles.

5. It may be safely concluded that the globules of insoluble lead found in leaded-brass tend to act as localized stress raisers and thus prevent the homogeneous distribution of stress across the matrix of the alloy.