Hydrodynamic Mode of Bronze Sleeve Bearings Cast by Counter-Gravity in Calcite Investment Shell Moulds

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Abstract: High lead bronze alloys are found in applications for sleeve bearings. The counter-gravity pouring method was employed to cast C93800 bronze alloy in the investment shell moulds. The mechanical properties have decreased with temperature. The wear loss was very low under full-film operating conditions.

Keywords: Investment casting, C93800 bronze alloy, colloidal silica binder, calcite, counter-gravity pouring.

1. INTRODUCTION

Bronze bearings are the most extensively used sleeve bearing type, industry-wide. Even so, there seems to be a few misapprehensions about these multitalented products concerning their applicability, performance and most of all – their cost effectiveness [1-2]. Every bearing designer knows that spherical bearings are among the most complex to design, and they are unquestionably the most expensive to manufacture. In practical terms it is almost unaffordable to prototype a spherical rolling-element bearing because of the high costs involved. But making one, or two, or a hundred spherical bronze sleeve bearings is no more involved – or costly - than making a conventional bearing. So prototyping bronze sleeve bearings can be an economical part of the design process, and that alone gives the designer a lot more freedom. Sleeve bearings, and especially bronze sleeve bearings, operate efficiently over a wider range of pressure and velocity (PV) values than any other type, with allowable PV values up to 3,000,000+ with the proper lubrication. At the low end of the PV scale, the generous load distribution and favorable fatigue characteristics inherent to sleeve bearings make them the natural choice for oscillating, intermittent-motion or less-than 360-degree rotation jobs. Their inherently low friction characteristics make them natural choices for mixed film or boundary lubrication conditions, and those are the modes most bearings operate in most of the time. There are soft and ductile bronzes for jobs that require conformability and the ability to embed occasional dirt particles; there are hard bronzes for maximum strength and load-carrying capacity. The bronzes are well known for their inherently low frictional coefficients; all have outstanding corrosion resistance and excellent shelf life, and they are unsurpassed when it comes to handling shock loads or damping out noise and vibration. Bronze bearings operate at higher temperatures without losing ability to carry loads without creep and at sub-zero temperature without becoming hard and brittle. They have excellent heat dissipation for high loads and speeds.

Many millions of bearings operate successfully in the boundary and mixed-film modes for their entire service lives. The only penalty this entails is an increase in friction compared to hydrodynamically lubricated bearings and consequently higher energy expenditure. Bearing life, however, will depend very heavily on the choice of bearing material. Even hydrodynamic bearings pass through boundary and mixed-film modes during start-up, and shutdown, or when faced with transient upset conditions. This means that material selection is an important design consideration for all sleeve bearings, no matter what their operating mode. The general attributes of a good bearing material are:

- A low coefficient of friction versus hard shaft materials,
- Good wear behavior against steel journals,
- The ability to absorb and discard small contaminant particles,
- The ability to adapt and adjust to the shaft roughness and misalignment,
- High compressive strength,
- High fatigue strength,
- Corrosion resistance,
- Low shear strength at the bearing-to shaft interface,
- Structural uniformity, and
- Reasonable cost and ready availability.

A material's inherent frictional characteristics are extremely important during those periods when the bearing operates in the boundary mode. A low coefficient of friction is one factor in a material's resistance against welding to, and therefore scoring, steel shafts. Frictional coefficient for bronze alloys against steel range between 0.08 and 0.14. During wear, or when there is absolutely no lubricant present, the frictional coefficient may range from about 0.12 to as high as 0.18 to 0.30. By comparison, the frictional coefficient during wear for aluminum on steel is 0.32 and for steel on steel it is 1.00. While efforts are normally made to keep bearings and their lubricants clean, some degree of contamination is almost inevitable. A good bearing material should be able to compensate for this by embedding small dirt particles in its structure, keeping them away from the steel shaft, which might otherwise be scratched.

Likewise, there is always a danger that shafts can be misaligned, or not be perfectly smooth. A bearing alloy may therefore be called upon to conform, or wear-in slightly to compensate for the discrepancy. This property is called conformability: it is related to the material's hardness and compressive yield strength. High yield strength is also related to good fatigue resistance. Together, these properties largely define the material's load-carrying capacity. The need for adequate corrosion resistance is especially important in bearings that operate in aggressive environments, or for those bearings which stand idle for long periods of time. Good corrosion resistance therefore increases both service life and shelf life. A bearing material should have structural uniformity and its properties should not change as surface layers wear away. On the other hand, alloys such as the leaded bronzes are used because they provide a lubricating film of lead at the bearing/ journal interface. Lead has low shear strength, and is able to fill in irregularities in the shaft and act as an emergency lubricant if the oil supply is temporarily interrupted.

Finally, a bearing material should be cost-effective. No single bearing material excels in all these properties and that is one of the reasons bearing design always involves a compromise. However the bronze bearing alloys provide such a broad selection of material properties that one of them can almost always fit the needs of a particular design. The purpose of this investigation was characterization of C93800 bronze cast by counter-gravity in calcite investment shell moulds.

Table 1: Chemical composition of C93800 bronze alloy.

Element	Cu	Sn	Pb	Zn	Fe	Ni	Sb	P	S	Al	Si
%Wt.	76.00	7.00	14.20	0.80	0.10	1.00	0.80	0.04	0.05	0.005	0.005

2. MATERIALS METHODS

The chemical composition of C93800 bronze alloy is given Table 1. In the present work, the colloidal silica binder was used to fabricate the investment shell moulds from calcite as reinforced filler materials. The silica content in the colloidal silica binder was 30%. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation. Finer grade fused silica sand having AFS grain fineness number 140 was employed for primary coats. This is synthetic sand. This sand was used for first two coats, called prime coats to get good surface finish and every detail of the wax pattern. Coarser grade sand having AFS grain fineness number 60 was employed for back up coats. The backup sand was employed to develop more thickness to the shell walls with minimum coats [3-27]. The thickness of shell moulds were 10 mm. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made as shown in figure 1. The C93800 bronze alloy was melted in an induction furnace under vacuum.

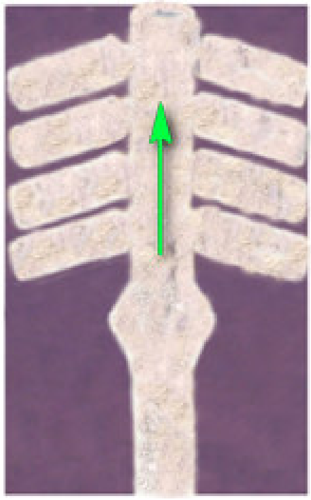

Figure 1: Counter-gravity poured investment shell mould.

The liquid alloy was counter-gravity poured under vacuum into the pre-heated investment shell moulds as soon as the molten alloy is ready to be cast, a preheated (750^{o}C) investment shell mould was placed on the bottom opening of a mould chamber. A preheated investment shell mould was transferred into the chamber and placed on top of the ceramic tube. Support media is packed around the preheated shell mould and the chamber containing the shell mould is transferred to the melting furnace. The shell mould at the bottom of the chamber is then inserted into the argon atmosphere above the molten alloy. Argon was drawn into to the shell mould chamber by creating a vacuum in the shell mould. This action essentially displaced air in the shell mold cavity through the semiporous mould with argon. The mould was then inserted deep into the molten alloy and the vacuum in the shell mould cavity was increased at a controlled rate, enabling the mould filling. The level of vacuum in the mould cavity was 1/3 of an atmosphere to fill the mold in 6 seconds. The shell moulds were knocked off by hand hammer after solidification of the molten. The castings were cleaned with soft brush and visually inspected for pins and projections.

The C93800 bronze alloy was tested for tensile strength, yield strength, compressive strength, fatigue strength, ductility and Brinell hardness at different temperatures. The sleeve bearing (figure 2) was tested for delineating Operation in the full-film condition.

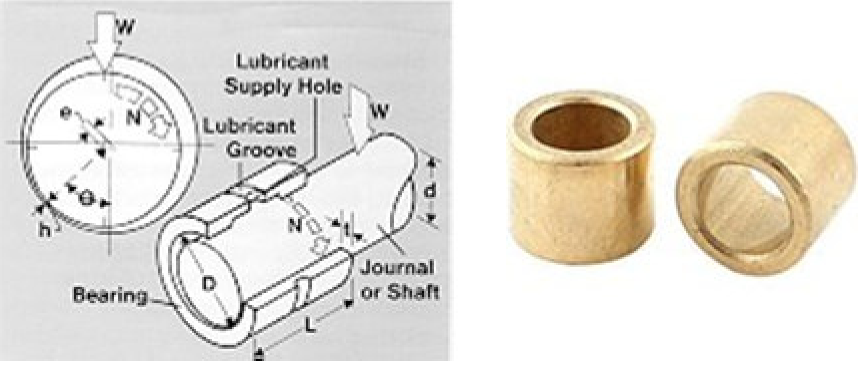

Figure 2: Sleeve bearing and cast C93800 bronze alloy by counter gravity pouring.

3. RESULTS AND DISCUSSION

The effect of temperature on mechanical properties is shown in figure 3. The tensile, yield strength, compressive strength and hardness were decreased with increase of temperature. The percent elongation was decreased with temperature; percent area of reduction was high at temperature 125^{o}C. The rate of decrease in fatigue decreases with increasing N as shown in figure 4.

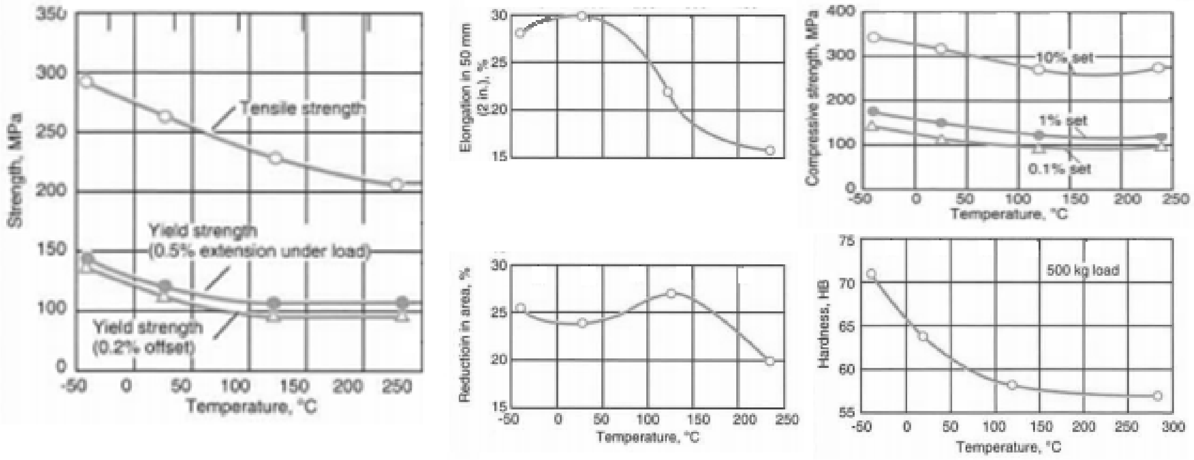

Figure 3: Mechanical properties of C93800 bronze alloy.

The ability of the lead particles in C93800 bronze alloy is to decrease the coefficient of friction between the bearing and the shaft. Lead particles are free to be sheared off the bearing surface by microscopic rough edges on the shaft surface. The steel shaft becomes covered with lead which is gradually redistributed to fill in the low spots on the shaft. Once this has been accomplished, the coefficient of friction rises only slightly again. This same phenomenon has a further advantage in that the temperature developed at the points of contact between the bearing and the mated part is limited by the fusion temperature of lead.

Obviously, this property of the leaded alloys is very valuable in the absence of lubrication or if the operating environment of the machine is itself subject to wide temperature extremes. The lead also absorbs dirt which finds its way into the interface. Since C93800 bronze alloy has lower strength than the non-leaded copper-tin alloys, and much lower strength than copper-aluminum or copper-zinc alloys, exhibits high degrees of conformability. The bearing adjusts its shape to allow for poor alignment or for vibration.

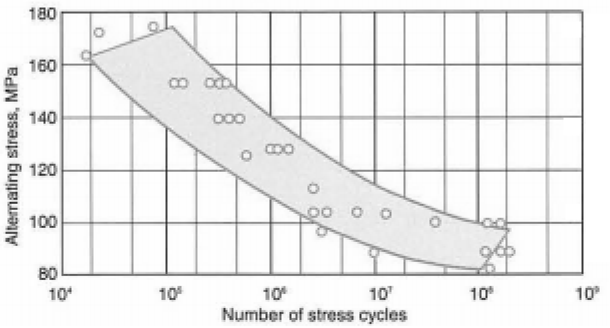

Figure 4: Fatigue test results

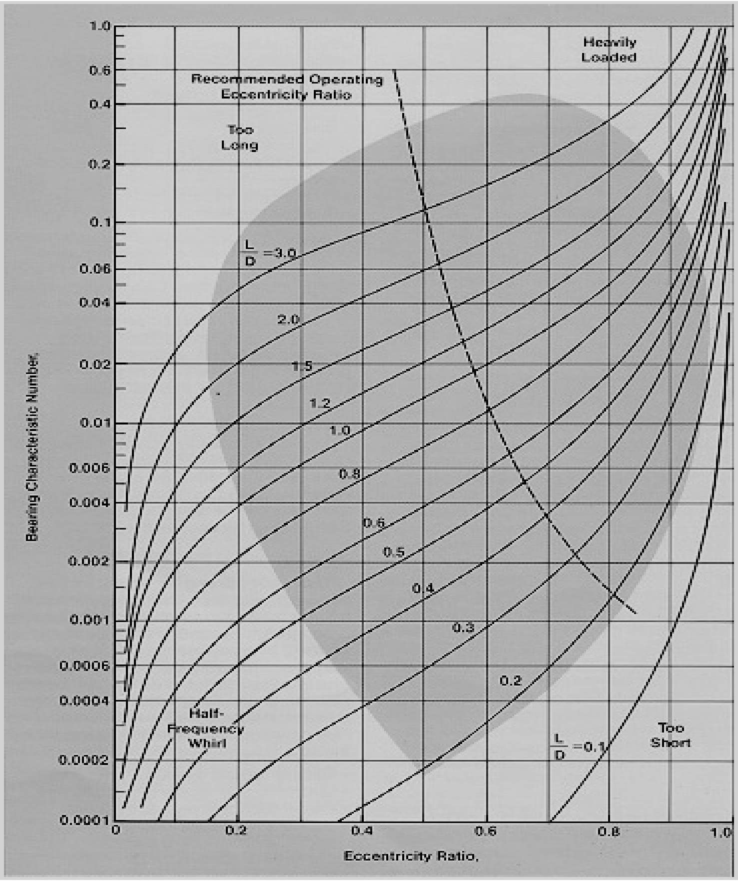

Figure 5: Full-film characteristics of sleeve bearings.

The mode offering the lowest friction and least wear is called hydrodynamic or full-film operation. In this mode the bearing is completely separated from the shaft by a continuous film of oil in the eccentric space between shaft and bearing as shown in figute 2. The oil is under hydrodynamic pressure created by the relative motion between bearing and journal. A sleeve bearing's operating mode is described in terms of a bearing characteristic number. A. The value of A, in relation to other factors, determines whether or not the bearing will operate hydrodynamically. The characteristic number is calculated by means of the equation:

$$A = \frac{m^2 W}{D^2 Z N} \qquad (1)$$

where, D is the shaft diameter; W is the steady load; Z is the absolute viscosity of lubricant; Clearance factor, $m = 2C/D$; C is the radial clearance; and N is the rotational speed.

If load, speed and other factors can be adjusted such that A falls between 0.0005 and 0.50 the bearing should operate in the full-film mode. A bearing and its journal operate in practice with a given eccentricity, i.e., with the shaft positioned slightly off the bearing's true center by a distance, e, (Figure 1). We can then define an eccentricity ratio, E, as:

$$E = \frac{e}{C} \qquad (2)$$

where, e is the eccentricity or radial journal displacement.

A diagram in terms of A, E and the bearing's L/D (bearing length/shaft diameter) ratio is shown in figure 5. It describes different operating modes based on A, E and the L/D ratio. Bearings, which fall inside the heart-shaped area, operate in the full-film or hydrodynamic mode. Since the bearing and journal are not in contact in the hydrodynamic mode, frictional coefficients can be as low as 0.001. Also, since there is no metal-to-metal contact there can be no wear and bearing life should be indefinite. Theoretically, the only important material property consideration for full-film bearings is that the bearing alloy be strong enough to support the applied load. Hydrodynamic bearings normally can sustain changes in load or shock loads up to ten times the design load for limited periods of time.

4. CONCLUSIONS

All mechanical properties of C39800 bronze alloy was decreased with temperature. As there is no metal-to-metal contact, the wear loss of sleeve bearing was very low.

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