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GEAR BRONZE AND THE EFFECT OF TIN CONTENT

Copper alloy (bronze) gears have unique properties that contribute to minimal wear in bronze to steel contact. Bronze gears are used in gear reducers and are mated against steel worm gears. Bronze spur gears are used in other devices where they are required to mate with steel spur gears.
In all cases, the steel surfaces are harder than the bronze surfaces. The selection of the bronze to steel combination is based on the same principle relating to bronze sleeve bearings mated with harder steel shafts.

- Bronze to steel results in sacrificial wear of the bronze and little or no wear of the steel.
- Bronze to steel results in much lower friction forces than with steel to steel.
- At high relative surface speeds, full film or hydrodynamic lubrication will separate the steel to steel pair, but at lower speeds, the asperities (surface roughness) of the mating parts contact each other. This results in severe wear of both steel parts. With the bronze to steel pair, the stronger steel asperities shear of the weaker bronze asperities.

As a result of these considerations, metallurgical and mechanical engineers have developed a series of bronze alloys that minimize wear of the bronze while providing all the benefits of the bronze to steel pair.

The desired bronze would have the following properties:

- Strength to withstand the required loads.
- Low coefficient of friction against steel.
- Minimum wear of the bronze.

Many bearing bronzes contain lead to lower the coefficient of friction, However, lead separates out of the freezing castings to reside between the crystals of copper alloy. This weakens the material and, while helpful to sleeve bearings, lead must be kept to a minimum for the casting of strong gear bronze. Some gear bronzes include a small amount of this inter-crystalline lead to enhance machinability.
The best combination of wear properties is found in two copper alloy groups:

Aluminum and Manganese Bronzes are strong and wear sacrificially against steel mating parts. These alloys have strong matrix, embedded with very hard phases.

Steel mating parts must be very hard and both parts must have very fine surface finishes. These bronzes do not develop a low friction layer of bronze on the steel.

Tin Bronzes are strengthened by the solid solution of tin in the copper up to about 10% tin. Additional tin will result in strong, hard inter-crystalline phase rich in tin. The tin atoms distort the copper matrix enough to help inhibit slip of crystal layers and the inter-crystalline phase contributes to hardness. The tin bronzes do develop a low friction deposit of bronze on the mating steel parts. For this reason, tin bronze is the alloy of choice for nonferrous gears.

Asperities from the aluminum and manganese bronzes, deposited on the steel, are not as beneficial as with tin bronze. The aluminum bronze asperities eventually develop aluminum oxide content, which is very abrasive. Manganese bronzes contain both aluminum and (high) amounts of zinc. Zinc oxide is abrasive and zinc in the copper matrix promotes galling when mated with steel. Tin has a much lower affinity for oxygen than either aluminum or zinc.

The "wearing in" and the resulting boundary conditions are what make tin bronze so desirable in mating against steel. When a sufficient amount of the bronze asperities become embedded on the surface, wear decreases and friction forces decrease.

The basic copper - tin alloy, used for gears, has developed into a series of five popular gear bronzes. These alloys are specified in specification ASTM B 427-93A. Variations are not large. The 12% tin alloys have more of the hard phase. Copper alloy C92900 is the most diverse, as it has 2.5% lead content. This allows for good machinability and the lead particles will embed any abrasive media during the wearing in period. The nickel content (3.5%) in this alloy is very beneficial. It increases corrosion resistance and promotes a smaller crystal size in the castings. Smaller crystals result in less chemical segregation and higher mass physical properties.

These gear bronzes cannot be produced by wrought processing such as extrusion, drawing, rolling or forging. They must be used as cast. The high tin content will cause extrusion billets to fracture. Tin content of 8% can be continuously cast and drawn in small diameters. Lower tin contents can be extruded and drawn into small diameters. The (cold) drawing does increase the physical properties above those of the cast material. No improvement of frictional properties takes place.

The true gear bronze can only be cast by certain methods. Sand casting and chill casting both allow for shrinkage cavities and nonmetallic (abrasive) inclusions. Continuous casting has eliminated those problems. The continuous cast rod or tube is extracted from a die attached to a furnace filled with liquid metal. The inlet to the die is submerged far beneath the top surface of the liquid metal. No slag can reach that area and the liquid metal acts as a reservoir to feed the casting, thus avoiding any shrinkage cavities.

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Continuous casting of gear bronzes has progressed from the onset in the early 1950's to included many refinements. Advances in continuous casting technology yield cast bar and tube products with small, uniform crystal sizes. This results in more homogeneous and stronger continuous cast material. Gear bronzes produced by this method are superior to those produced by any other means. Yield strength, impact strength and hardness are all largely increased. Wear properties are also enhanced.