Easily Carburizable High-Speed Steel Bearing Alloys

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Most bearings for piston-driven aircraft engines and early jet engines were made of through-hardening AISI 52100 steel or carburizing grades of alloy steels. However, as power requirements rose, operating temperatures increased, and alloys with more heat resistance became necessary. Minor improvements in the performance of AISI 52100 were achieved by extra alloying additions, but these incremental changes were not enough to keep pace with the higher operating temperatures.

In the 1950’s in Europe, T-1 and M-2 high-speed steel (HSS) were used for some jet engine applications. T1, also known as 18-4-1, contains tungsten, chromium, and vanadium as the primary alloy elements. M-2, known as 6-6-2, contains chromium, tungsten, vanadium, and molybdenum (see table).

In the United States, M50 HSS, containing chromium, vanadium and molybdenum, was selected for bearing applications. The reason for selecting M50 was that the major sources of supply of tungsten are the former Soviet Union and other unstable countries.

T-1, M-2, and M50 tool steels exhibit similar metallurgical properties. In particular, tool steels display the phenomenon known as secondary hardening. Standard alloy steels display what is termed Class 1 tempering behavior: they soften as the tempering temperature is raised.

However, tool steels exhibit Class 3 tempering behavior: As the tempering temperature is increased, the hardness remains constant or only slightly decreases. As the tempering temperature approaches approximately 500°C (930°F), hardness increases slightly.

Then, as the tempering temperature increases beyond 600°C (1110°F), the hardness rapidly decreases, Fig. 1. The increase in hardness between 500°C and 600°C (930 and 1110°F) is called secondary hardening. The hardness increase is caused by the transformation of retained austenite to martensite, and the precipitation of very small alloy carbides. Generally, HSS alloys are double tempered to re-temper the martensite that forms during the first tempering cycle.

This article discusses current tool steels, the laser glazing process, and the residual stress developed through carburizing. It then describes the development of a new family of HSS bearing steels called CHS (carburizable high-speed) steels. CHS steels contain about 1% chromium, rather than the conventional 4%. They are easy to manufacture and easy to carburize to high hardness.

M50 tool steel

One advantage of M50 HSS is that the melting point and the range of hot working temperatures are lower than for the other grades of high-speed steels. Microstructural banding is evident after processing, due to the relatively large percentage of alloy carbides in these grades.

Another difference between the microstructure of M50 HSS and other grades is the presence of large carbide plates. The plates appear as “rods” or “sticks” on a polished cross section, Fig. 2. Since these types of microstructural features can be detrimental to performance, one of the challenges in manufacturing is to minimize banding and to have enough mechanical deformation in the forging and rolling practices to break up the large carbides.

At the Timken Company in the 1990’s, a patented Laser Glazing process was developed to simultaneously remove the effects of microstructural banding and greatly reduce the size of carbides in wrought M50 and other grades of high-speed steels. Bearings manufactured by the Laser Glazing process exhibited an L10% fatigue life approximately ten times longer than that of bearings made using conventional processes, Fig. 3.
times greater than identical bearings manufactured from wrought M50 HSS.

The fatigue spalls in the wrought alloy bearings are numerous, extend over almost the entire length of the raceway, and appear to be related to the microstructural banding. However, the spalls on the Laser Glazed bearings are much smaller in number and size.

The Laser Glazing process greatly changes the microstructure of the M50 alloy, Fig. 3. The tempered martensitic matrix, which contains banding and large carbides, is replaced by a very small cellular dendritic solidification structure. The removal of the plate-like carbides and banding greatly reduces material factors that can initiate cracks and promote crack propagation, resulting in a large increase in fatigue life.

Residual stress
In all applications, carburized bearings possess one beneficial factor not realized by through-hardened bearings: the carburized bearings have a compressive residual stress on and near the surfaces of the races. To utilize this beneficial property, a carburizable version of M50 was developed in the early 1980’s and patented by General Electric. The alloy, known as M50-Nil, contained nickel and only about 0.10% carbon, but otherwise was nearly identical to wrought M50.

While this steel addressed the detrimental effects of carbide banding and the presence of large carbides found in wrought M50, it is difficult to process. Generally, prior to carburizing, a preoxidation treatment is necessary. If the material is not properly oxidized, a nonuniform carburized case often results. Thus, numerous quality control processes are required to assure the uniformity of bearings manufactured from this alloy.

Work at that time clearly demonstrated that the removal of carbide banding and refinement of size distribution could both be beneficial in creating enhanced-performance alloys. What was required was an alloy that was easy to manufacture and easy to carburize.

Grades with 1% chromium
Most of the standard grades of HSS alloys were developed in the 1930’s through the early 1950’s. In reviewing the development of different HSS grades, one factor stands out: Almost all the HSS grades contain approximately 4% chromium.

A comprehensive literature review indicated that one of the most important reasons for 4% chromium was that at this particular level, oxidation at austenitizing temperatures of approximately 1200°C (2200°F) was minimized. Although high-temperature oxidation was a problem 50 years ago, today this problem has been eliminated by vacuum heat treating and rectified salt-bath austenitizing systems.

Thus, although 4% chromium served a useful function for the wrought alloys, it is the main factor that causes M50-Nil to be difficult to carburize. The next logical question is: What happens if the chromium content of these alloys is reduced to 1%?

Serendipitously, this led to the development of an entirely new family of easily carburizable high-speed steels. An additional literature search led to work in the late 1940’s showing the effect of chromium, molybdenum, vanadium, and tungsten on the Vickers hardness of HSS, Fig. 4. Based on this data, the following equations were developed to model the change in hardness as a function of carbide content:

Vickers Increment (Cr) = 550 [%C0.60]
Vickers Increment (Mo) = 764 [%C0.60]
Vickers Increment (V) = 678 [%C0.60]
Vickers Increment (W) = 584 [%C0.60]

In conjunction with this information, not only could an easily carburizable grade of HSS similar to M50 be developed, but also an alloy with higher hardness could be created. After testing preliminary lab heats, a 3000-pound heat of steel containing 1% chromium and increased levels of...
Molybdenum and vanadium was air melted and a VAR ingot was remelted. This steel, called CHS-50 (see table), was then forged and rolled into bars. Material from this heat was used to make tapered roller bearings identical in size to those previously tested for laser glazing.

The most remarkable aspect of these alloys is the ease and simplicity of the heat treating process. The bearing components were carburized via conventional processing cycles for alloy steels such as 4320 and 8620. In particular, the components were carburized at 955°C (1750°F) for approximately eight hours in a furnace having a carburizing potential of approximately 1.30%. After carburizing, the parts were oil quenched and tempered at 175°C (350°F) for two hours.

The components were then vacuum heat treated in thermal cycles typical of those for high-speed steels. The bearings were preheated at 870°C (1600°F) for one hour. The furnace temperature was then ramped to 1120°C (2050°F) and held for ten minutes. The components were then gas quenched and double tempered at 550°C (1020°F) for two + two hours. After machining and grinding, the hardness profile of the cups and cones was evaluated, Fig. 5. As indicated, the near surface hardness was approximately 65 HRC. No post heat treatment refrigeration was required.

As a result of the carburizing and heat treating process, very high residual stresses are formed on and near the surface of the bearings, Fig. 6. The near-surface microstructure of the bearings consisted of tempered martensite and very fine carbides. Essentially no retained austenite was seen in the case material, Fig. 7.

The three factors of high hardness, high surface residual compressive stresses, and the absence of banding and large carbides, combined to produce a material with outstanding rolling contact fatigue performance. As indicated, the L10% life of the CHS-50 bearings was over 20 times that of conventional M50 HSS, and more than twice the life of laser glazed M50 HSS.

Additional alloy development is being conducted on variations of other HSS alloys. A carburized version of M-1 was found to have a surface hardness higher than that possible with CHS-50. The carburized microstructure of this alloy contains many small, well-distributed carbides that should provide enhanced wear resistance to components fabricated from these types of steels.

The examples described here reveal how the size and distribution of carbides in high-speed steel alloys have a very significant effect on the performance of bearings. The Laser Glazing process removed microstructural banding and refined the size distribution of the carbides. The result was an order-of-magnitude increase in performance.

The compositionally modified M50 carburizable grade of high speed steel provides enhanced bearing performance when compared with current alloys. Of utmost importance for this new family of alloys is that standard carburizing processes are utilized. The subsequent heat treating processes are identical to those suitable for HSS alloys. No refrigeration treatments are required after austenitizing and tempering.

Other carburizable grades of HSS alloys being developed, such as the carburizable version of M1, are anticipated to show similar performance enhancements in other applications. It is expected that these alloys will be useful in applications such as cutting tools, thread rolling dies, and possibly in injection molding dies.

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