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# Crystallography and metallography of carbides in high alloy steels

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## ABSTRACT

The carbides in high carbon, high chromium bearing steels, high chromium carburizing steels, newly developed easily carburizable low carbon, low chromium high speed steels and M62 high speed steel fabricated by powder metal processing were studied. The particular steels evaluated include 440C, BG42. M50-Nil, CHS1, CHS50, Pyrowear 675®, CSS-42L™ and M62. The morphology and structure of the carbides were evaluated by means of metallography, X-ray diffraction and electron beam backscattered diffraction. The combination of these three techniques has provided new insight into how different carbide morphologies form during processing and the carbide structures that can be expected to be present in components fabricated from these steels by various types of heat treating.

## 1. Introduction

Heat treated steels have been used for manufacturing antifriction bearings almost since their invention. Steels are used for these types of applications, because in the hardened and tempered condition the material has a very high yield strength and good resistance to wear and debris. Plain carbon steel containing over 0.80% carbon is an inexpensive material that can be used for low cost commodity bearings. The material is hardened by first heating it into the austenite phase for a moderate length of time. After austenitizing, the steel is generally oil quenched, and the resulting brittle constituent termed martensite is formed. In the as-quenched condition martensite has a body centered tetragonal crystallographic structure and is supersaturated with carbon. Subsequent tempering at temperatures in the range of 500 °C improves the toughness of the steel. After tempering, the microstructure of the steel is composed of body centered cubic martensite and intermediate carbide originally reported to be $Fe_2C$ [1], then believed to be $Fe_{20}C_9$ [2]. The carbide was reported to have a hexagonal structure and designated as $\varepsilon$ carbide [3], and recently reported to be orthorhombic $F_2C$ [4]. The use of high austenitizing temperatures can often lead to high amounts of retained austenite in the quenched and tempered microstructures of bearing steels, Fig. 1. To minimize the amount of retained austenite, for hypereutectoid steels, intermediate austenitizing treatments between the $A_1$ and $A_{cm}$ temperatures are used.

One of the first alloys developed for commercial use as a bearing material was 52100 steel. This alloy is primarily composed of 1% carbon and 1.5% chromium, Table 1. When austenitized at intermediate temperatures, quenched and tempered, the microstructure is found to primarily consist of tempered martensite and small spherical $(Cr,Fe)_3C$ carbides [5], Fig. 2. Generally the iron–chromium cementite is designated as $M_3C$. In this and all similar examples to follow, the capital letter M refers to metallic elements that can form carbides. Typical carbide forming elements include, but are not limited to Cr, Fe, Mo, V, W, Nb, Ti and Zr.

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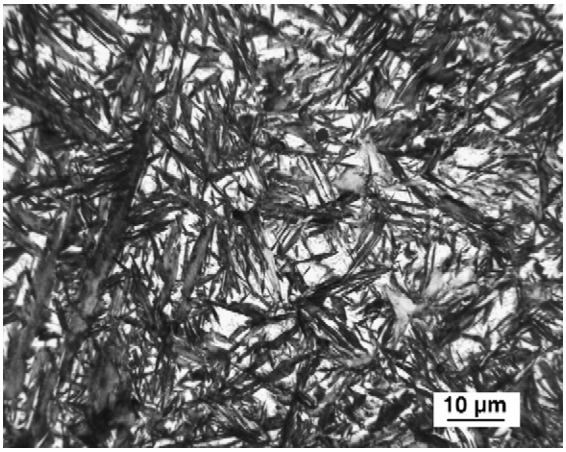

**Fig. 1 – The microstructure of carburized 4620 steel is composed of tempered martensite, retained austenite and small spherical carbides.**

While 52100 steel is used in numerous bearing applications, this and all high carbon steels have one major deficiency; they have poor impact toughness.

To enhance fracture toughness, many bearings are manufactured by using carburizable alloy steels. One of the first carburizable alloy steels used for bearing manufacturing was 4620. In addition to the low carbon level of 0.20%, this steel contains approximately 0.55% Mn, 1.8% Ni and 0.25% Mo, Table 1. After carburizing at 950 °C and then heat treating at an intermediate temperature of approximately 830 °C, the near surface microstructure of carburized components consists of tempered martensite, some retained austenite and small round alloy carbides, Fig. 1. Early studies on the carbides in the high carbon surface region of carburized bearings manufactured from this alloy were performed by electrolytically extracting the carbides from the steel matrix and analyzing them by X-ray diffraction. This work revealed the carbides to be face centered cubic (FCC) with a unit cell dimension of approximately 1.06 nm [6,7]. Chemically, these carbides were determined to be $M_{23}C_6$.

One disadvantage possessed by these alloy steels was that they displayed poor corrosion resistance. In order to passivate steel, it has been shown that a minimum chromium content of 12% by weight is necessary. Using this principle, a 1% carbon bearing steel containing 17% chromium and up to 0.75% molybdenum, named 440C, was developed. Due to the higher alloy content of this steel when compared to 52100 or a standard carburizing grade many more primary carbides are present in both the annealed and the quenched and tempered microstructures. Based on the Fe–Cr–C phase diagram [8], and X-ray diffraction work performed on extracted carbides, the very large carbides in this alloy are $M_7C_3$ and the smaller carbides are $M_{23}C_6$. While the $M_{23}C_6$ is FCC, the $M_7C_3$ can be represented by either a hexagonal or an orthorhombic unit cell [6,7].

In most low and intermediate temperature applications, bearings made from alloy steels perform satisfactorily. However, at elevated temperatures, the performance of alloy steels begins to degrade. Thus alloys with more heat resistance were found to be necessary. While minor improvements in the performance of 52100 were achieved by using extra alloying additions such as silicon, these incremental changes were not enough to keep pace with the increased operating temperatures of advanced applications. In the 1950's in Europe, T1 and M2 high speed steels (HSS) were used for some jet engine applications. T1, referred to in Europe as 18-4-1, contains tungsten, chromium and vanadium as the primary alloy elements, while M2, referred to as 6-6-2, contains chromium, tungsten, vanadium and molybdenum, Table 1. In the United States, M50 HSS, containing chromium, vanadium and molybdenum, was selected for bearing applications. The reason for selecting M50 was because the major sources of tungsten were the former Soviet Union and other unstable countries.

**Table 1 – Nominal bearing steel compositions**

| Alloy | Element (wt.%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Cr | Mo | V | W | Co | Ni | Nb |
| 52100 | 1.00 | 0.35 | 1.5 | | | | | | |
| 4620 | 0.20 | 0.55 | | 0.25 | | | | 1.8 | |
| 440C | 1.00 | 1.00 | 17.0 | 0.75 | | | | | |
| BG 42 | 1.15 | | 14.0 | 4.0 | 1.2 | | | | |
| M50 | 0.80 | 0.35 | 4.0 | 4.25 | 1.00 | | | | |
| M 1 | 0.83 | 0.30 | 3.75 | 8.5 | 1.15 | 1.75 | | | |
| M 2 | 0.85 | | 4.2 | 5.1 | 1.85 | 6.3 | | | |
| M 62 | 1.30 | | 3.75 | 10.5 | 2.0 | 6.25 | | | |
| T 1 | 0.75 | | 4.1 | | 1.1 | 18.0 | | | |
| M50 Nil | 0.13 | 0.20 | 4.1 | 4.25 | 1.25 | | | 3.40 | |
| CHS 50 | 0.10 | 0.25 | 1.2 | 5.75 | 1.20 | | | 2.80 | 0.20 |
| CHS 1 | 0.28 | 0.25 | 1.5 | 9.0 | 1.25 | 1.00 | | 2.00 | 0.20 |
| P 675 | 0.07 | 0.65 | 13.0 | 1.8 | 0.6 | | 5.4 | 2.6 | |
| CSS 42L | 0.13 | | 14.0 | 4.75 | 0.6 | | 12.5 | 2.0 | |

These three grades of tool steels exhibited 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; i.e., 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

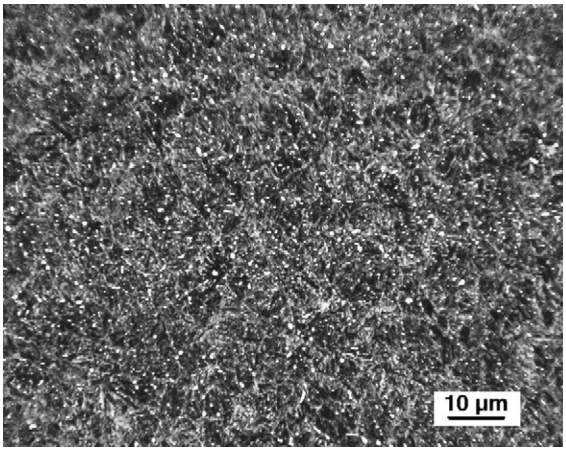

**Fig. 2 – Hardened and tempered 52100 steel primarily consists of tempered martensite and small spherical $(Cr,Fe)_3C$ particles.**