Powder Metallurgical Tool Steel Solutions for Powder Pressing and Other High-performance Cold Work Applications

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Abstract

In high-performance cold work applications, tool failure depends on the predominating loading conditions. Typical failure mechanisms are a combination of abrasive wear, adhesive wear, plastic deformation, cracking and edge crumbling.
In this paper we demonstrate how the microstructure of tool steels can be positively influenced by modifying the alloying system and the production route to meet the demands of the different loading situations which occur during operation. The investigation was focused on ductility, fatigue strength and wear resistance. Theoretical considerations were confirmed by practical tests.

Keywords : PM tool steel, Powder metallurgy, Powder pressing, Cold work applications, Damage mechanisms

1. Introduction

Traditional, conventionally-produced cold work tool steels, such as X155CrVMo12-1 (EN 1.2379) often do not fulfil the high requirements of high-performance cold work applications. The reason a tool fails early depends on the predominating loading conditions. Typical damage mechanisms are abrasive wear, adhesive wear, cyclic plastic deformation, fatigue cracking, and spalling of the surface and/or the edges [1]. To increase the abrasive wear resistance, tool steels with a high-strength matrix and a certain fraction of hard carbides are necessary [2]. To increase the adhesive wear, the mean free path between carbides in the high-strength matrix of the tool steel should be minimised [3]. To avoid plastic deformation and spalling of the edges as a result of cyclic loading, it is necessary to use a tool steel with both a high yield strength and a high ductility—a combination which can be achieved using a modified alloying system and a specific manufacturing technology. Mainly this involves minimising the quantity of internal defects, which means that only very homogeneous materials with a very fine microstructure and a high cleanliness can be used successfully [4, 5].

Each of these damage mechanisms can occur alone or in combination with one or more of the others. In general, to increase the tool life it is essential to use high-performance PM tool steels with a balanced chemical composition, high homogeneity, high purity, appropriate carbide size and carbide distribution, and optimal reproducibility to maximise toughness and fatigue properties tailored to the loading conditions.

In this paper it is shown how these relevant material properties can be influenced by varying the chemical composition of the tool steels and by modifying the production technology. Furthermore, the results of a test in practice are given.

2. Optimisation of Material Properties

State-of-the-art PM tool steel production using gas atomisation technology [6]. Tool steels and high-speed steels for highly demanding applications must have a high strength, high wear resistance, high fatigue strength, and good toughness for high safety against fracture. To increase the life of a tool material it is necessary to drastically reduce the quantity of crack initiating defects such as non-metallic inclusions and carbide clusters.
Böhler has therefore modified the melting-, slag- and atomisation technologies in the PM process, and is able to produce a comparatively fine powder with a mean particle size of around 60 µm. This is about half that of a traditional PM process. In addition, the fraction and size of the non-metallic inclusions are drastically reduced (Fig. 1).

Toughness and fatigue strength. This latest technology is used to produce the microclean® tool steels and microclean® high-speed steels with a very high cleanliness level, very fine carbide structure and a very homogeneous microstructure. These guarantee clearly advanced toughness properties and clearly advanced performance under cyclic loading [5], as shown in Fig. 2.

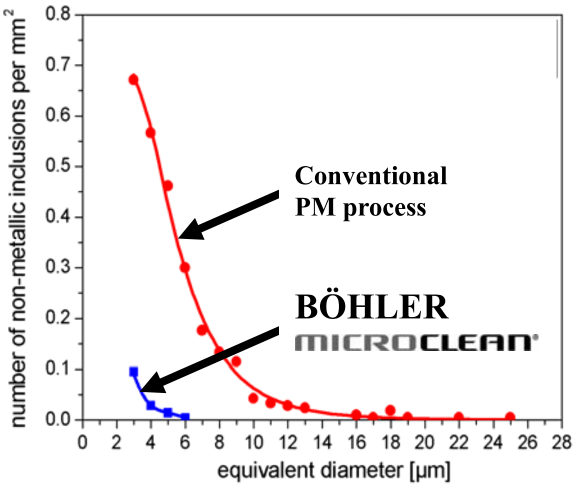

Fig. 1. Non-metallic inclusion size distribution [6].

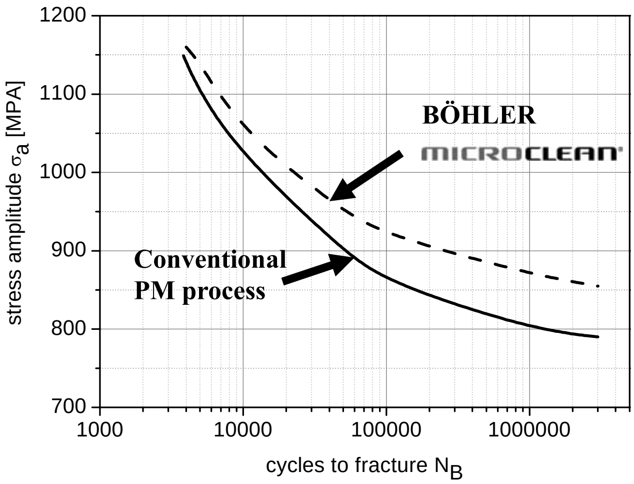

Fig. 2. Increase of the fatigue strength due to decreasing the fraction of non-metallic inclusions [5].

Influence of the chemical composition on the mechanical properties of high-performance PM tool steels. In this chapter five different high-performance PM tool steels for different predominate loading conditions are introduced. The combination of wear-resistance and toughness/ ductility for each of these five PM tool steels, S290 microclean®, K390 microclean®, S390 microclean®, S690 microclean® and K890 microclean®, is shown in Fig. 3. The corresponding chemical compositions of the steels are given in Fig. 4.

The highly ductile tool steel solution. The alloying concept of Böhler K890 microclean® was designed to give a highly ductile, high-strength martensitic matrix with a very small fraction of hard carbides. Because of this specific alloying system, K890 microclean® has a hardness of up to 65 HRc and a property profile including a high yield strength, high tensile strength, high compressive strength, highest ductility and highest fatigue strength. K890 microclean® is therefore particularly suitable for cold work tools with the highest demands on ductility and fatigue.

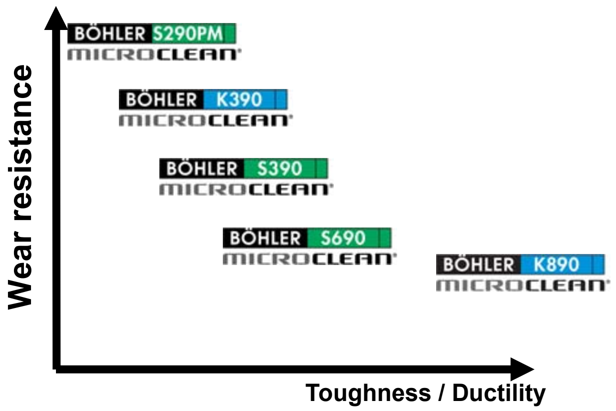

Fig. 3. Positioning of PM microclean® tool steels.

Böhler Tool Steel	% C	% Cr	% Mo	% W	% V	% Co
K890 microclean®	0.8	4	2	2.5	3	4.5
S690 microclean®	1.3	4.1	4.9	5.9	4.1	0
S390 microclean®	1.6	4.8	2	10.5	5	8
K390 microclean®	2.5	4	4	1	9	2
S290 microclean®	2	4	2	14	5	11

Fig. 4. Chemical compositions of PM microclean® tool steels.

The highly wear-resistant tool steel solutions. Both K390 microclean® and S290 microclean® feature highest strength, highest compressive strength and highest wear resistance. These PM tool steel grades are therefore a serious alternative to cemented carbides with the big advantages of a comparatively low price and comparatively high toughness or ductility.

Böhler K390 microclean® is a highly alloyed PM cold work tool steel. Its microstructure is composed of a high-strength, modified matrix and a volume fraction of about 18 percent hard primary carbides. Böhler K390 microclean® therefore has a high abrasive wear resistance, high compressive strength and a very good ductility for highly demanding applications.

Böhler S290 microclean® is another alloy which fills the gap between state-of-the-art PM tool steels and cemented carbides. On the basis of a specifically designed very high-strength matrix and a total fraction of about 30 percent carbides it is possible to obtain a hardness of up to 69 HRc.

The all-purpose tool steel solution.

Böhler S390 microclean®

Because of its extraordinary property profile consisting, in detail, of a high-strength, very ductile matrix in combination with high compressive strength, high fatigue strength and very good abrasive and adhesive wear resistance, Böhler S390 microclean® represents the universal solution for highly demanding cold work applications such as blanking, fine blanking, cold forming, cutting and powder pressing.

Böhler S690 microclean® is suitable for applications with even higher toughness and ductility requirements.

3. Result of a Practical Test

Powder Pressing. For the pressing of highly demanding constructional elements, for example complex automotive gear parts, the main requirements for a tool steel are highest compressive stress and highest abrasive wear resistance in combination with good ductility.
Fig. 5 shows an example of a powder pressing die where the die insert was made of cemented carbide. The die insert broke after 50 000 parts. After changing the dies material to S290microclean, the tool has pressed more than 500 000 parts and is still in use.

Die insert made of BÖHLER S290PM MICROCLEAN

Fig. 5. Powder pressing tool.

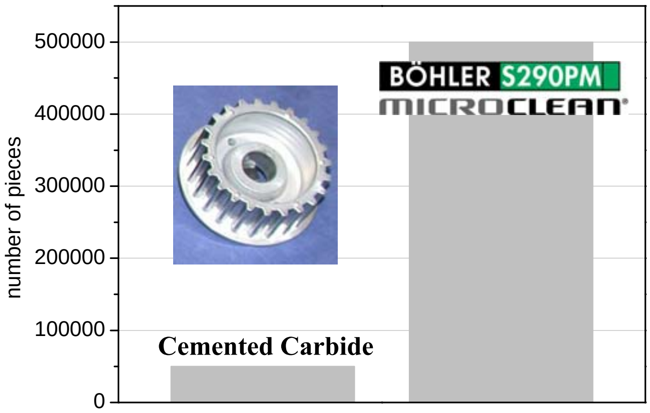

Fig. 6. Drastic increase in the tool life achieved by using the high-performance PM tool steel, Böhler S290 microclean®.

4. Summary

Common PM cold work tool steels often do not fulfil the high requirements for tools in high-performance cold work applications such as cold forming, blanking or powder pressing, resulting in wear, cyclic plastic deformation or fatigue cracking.
To increase or optimise the lifetime of such highly demanding tools it is essential to modify the microstructure of the tool steels. In this paper we have shown that there are two important ways in which the main material properties like wear resistance, toughness, ductility, strength, and fatigue strength can be optimised. PM tool steels have been introduced which each have a very well-balanced chemical analysis of the matrix and a precisely designed fraction of hard primary carbides according to the specific complex loads acting on the tooling for which they are intended. Furthermore, we have shown that the tool life can be influenced drastically by the manufacturing process. Böhler has modified the PM production route to obtain PM tool steels with a very homogeneous microstructure, very fine and homogeneously distributed carbides, and best cleanliness. The benefits of these considerations are demonstrated by the result of a test in practice, which show the advantages of PM tool steels produced via the microclean® production process.

5. References

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