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Mechanical and Microstructural Characterisation of P/M High-Speed Steel Valve Seat Inserts

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ABSTRACT. This work presents the use of high-speed steels, for valve seat inserts application. Two types of materials were evaluated, one made on purpose high speed steel M3/2 mixed with iron powder and niobium carbide and another valve seat insert made of Fe-Co alloy used for comparison. The microstructure of the valve seat insert was evaluated by scanning electron microscopy. The physical and mechanical properties of the inserts studied are presented in terms of densification, hardness, radial mechanical strength and machining. The results showed that the made on purpose material is a potential candidate for the fabrication of valve seat inserts, with additional economic advantage over traditionally used Fe-Co alloys.

INTRODUCTION

The exhaust valve seat inserts operate under severe conditions. Due to their high temperature properties, the high-speed steels are being considered as alternative material for this application. Other additional and important characteristics are good corrosion (oxidation) resistance, high thermal conductivity, and good machining [1]. Taking into account this scenario, the use of powder metallurgy - P/M - is growing steadily. The P/M process allows the production of parts at low cost, high alloying flexibility, and improved microstructure control [2,3]. The present research and development is focused on new materials obtained by less complex processes and less expensive stock material. This is the case of cobalt substitution due to its high cost, or lead substitution for ecological reasons [4,5].

One of the main targets of this work was to find alternatives to the costly cobalt-steel alloys and to reduce sintering temperature [4]. The decrease in high-speed steel sintering temperature allowed the use customary sintering equipment found in the P/M industry, i.e., that which operates continuously at maximum temperature of 1150 °C. Substituting the more often used cobalt alloys by high-speed steels reduces feed stock costs.

EXPERIMENTAL

A selected nominal composition of the powder mix is given in Table 1. The base powders used were, atomised M3 class 2 HSS powder (median particle size of 45 μm) and pure iron powder. Niobium carbide was added to the mixture. Copper infiltration was made to improve sintering and consequently the material density. This material is named here as ME series. Green compacts, 31.8 mm external diameter, 24.7 mm internal diameter and 7 mm thick rings were compacted at 700 MPa to 900 MPa to attain approximately 80 % of the theoretical density. Sintering was carried out in a pusher furnace in hydrogen atmosphere. Sintering temperature was in the range of 1130 °C to 1170 °C. Fig. 1 shows P/M high-speed steels valve seat inserts under development at the Powder Processing Centre - CPP [6]. The specimens rings were characterised by hydrostatic density, hardness, radial crushing strength and machining. The microstructure was evaluated by scanning electron microscopy.

Table 1. Powders mix nominal composition (wt. %).

Material	Fe	M3/2	C	Cu (infiltration)	NbC
ME	40.0-44.0	40.0-44.0	0.5-1.0	10.0-15.0	1.0-3.0

For the machining test, two specimens 60 mm long and 31.75 mm in diameter were prepared by stacking 10 valve seat inserts. Alumina based ceramic with addition of titanium carbide tool was used. The inserts and tool-holders had the following characteristics: side rake angle (γ) = 0°; side-relief angle (α) = 11°; and position angle (X) = 90°, as shown in Fig. 2. A computerised numeric command (CNC) lathe was used. A programming routine in the language of the numeric command lathe was developed to carry out the tests. The routine considered an initial block of roughing, for removing a layer of material. Once this layer was removed, the routine program considered regular stops for tool wear evaluation [7].

Fig. 1. High-speed steels valve seat inserts made by P/M at the Powder Processing Centre - CPP [6].

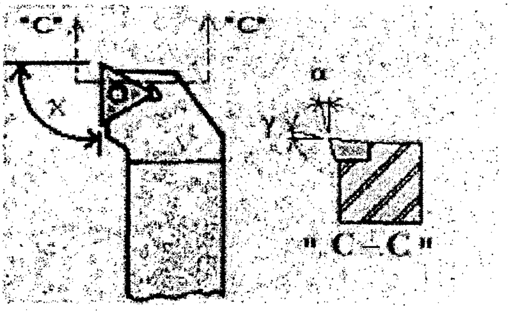


Fig. 2. Illustration shows the geometric details of inserts and tool holders.

The specimens were machined at cut depth (p), feed (f) and nose radius (r) of 0.65 mm, 0.09 mm/rot and 0.4 mm, respectively. The constant cutting speed used was 100 m/min. The principal tangential cutting force was measured by means of strain gauges attached to the tool holder. Several stops were made for wear analysis.

RESULTS AND DISCUSSION

The M3 class 2 powders are normally sintered at high temperatures, near 1240 °C depending on their chemical composition. The target was to develop a process where the sintering temperature was around 1150 °C, the practical limit for commercial belt furnaces. The experimental results are summarised in Table 2 for ME series material. For comparison purposes, this table also shows results from a valve seat insert made of Fe-Co alloy.

Table 2. Mechanical and physical properties of ME series material obtained in this study, in comparison to results typical of Fe-Co alloys valve seat inserts.

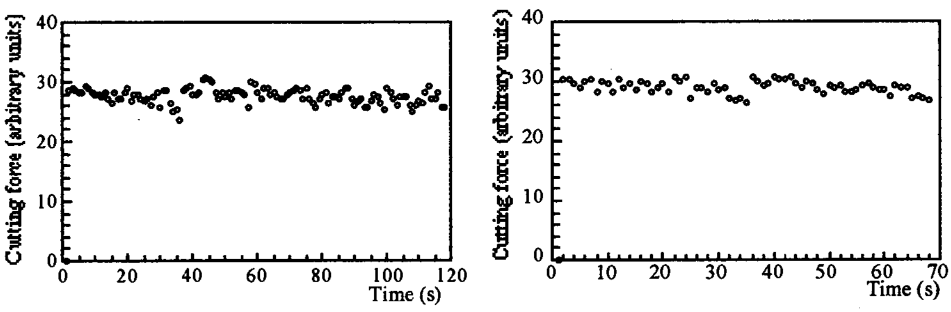
Materials	Green density g/cm^3	Sintered density g/cm^3	Hardness HRC	Radial crushing strength N/mm^2
ME	6.50	7.11	38-40	270-295
Fe-Co	...	7.30	25-30	280-300

... Not available

Niobium carbide was added to improve the mechanical strength, see ME series material in Table 2. Fig. 3 shows the obtained microstructure for the as sintered material. This microstructure shows a non-uniform carbide distribution, ferritic-perlitic areas, isolated copper rich areas and porosity. This microstructure was dependent on the particle size distribution of the powders, since no further homogenising heat treatment was performed. In addition, it is possible to attain an optimisation of the overall microstructure, thus reinforcing the potential use of the proposed new material for exhaust valve seat inserts.

Fig. 3. Scanning electron micrograph of ME series material (HSS mixed with iron and NbC) showing HSS microstructure, ferritic-perlitic areas, isolated copper rich areas, NbC particles (white contrast) and porosity (dark contrast).

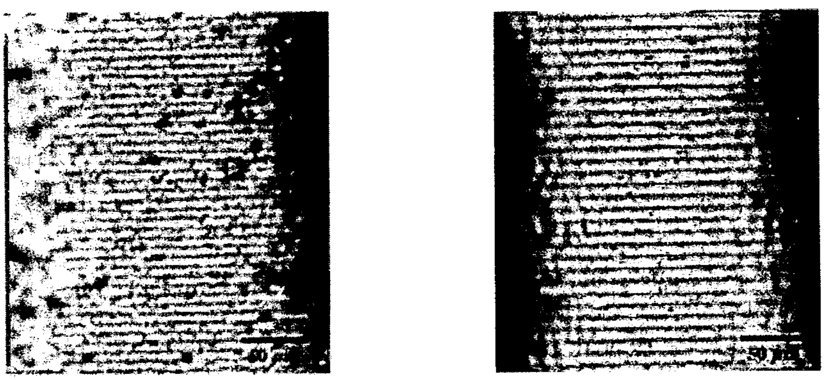
According to the used machining condition, the tests showed that the addition of high-speed steel particles and NbC does not affect considerably the machining characteristics of the material, when compared to the inserts made of Fe-Co alloy. The extent of the ceramic tool wear was negligible. This preliminary machining tests showed that the cutting force was similar for both materials, ME series material and Fe-Co alloy, see Fig. 4. However, more extensive experiments with other types of tool material and higher machined lengths must be carried out to attain more conclusive data on the ME series material machining.



(a) (b)

Fig. 4. Ceramic tool cutting force expressed in arbitrary units, for the machining test. (a) ME material. (b) Fe-Co alloy.

The machined surface of ME series material showed more irregularities than the Fe-Co alloy, see Fig. 5. These irregularities are of the same size as the porosity showed in Fig. 3. After machining the ME series material, connected arc chips were originated, according to ISO 3685 [8]. The Fe-Co alloy presented extremely fragile chips, loose arc chips type. ME series material is more porous and harder than Fe-Co alloy, see Table 2. Besides, it presented machined chips with a more ductile characteristic. This can be attributed to the mixture of harder phase high-speed steel, to a ductile phase, pure Fe.



(a) (b)

Fig. 5. Optical macrographs of the specimens surface after machining with ceramic tool. (a) ME series material. (b) Fe-Co alloy.

CONCLUSIONS

The addition of NbC has improved the mechanical strength, allowing equivalent properties between ME series and Fe-Co alloy, to be attained.

Preliminary machining tests showed that ME series material presented equivalent-machining characteristics as the Fe-Co alloy when machined with ceramic tools. The shape of the machined chips for ME series suggests a more ductile material than the Fe-Co alloy, from the machining point of view.

The ME series material (Fe-HSS-NbC mixture, copper infiltrated) is a potential candidate for the fabrication of valve seat inserts. Furthermore, it may represent an economic alternative to the sintered Fe-Co alloys used for manufacturing exhaust valve seats.

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