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Machining and Microstructural Characterisation of Sintered Valve Seat Inserts

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Abstract: This article shows some fabrication aspects related to the obtention of sintered valve seat insert. This insert was made of a mixture of high-speed steel powders and iron powders. The physical properties, mechanical properties and machining behaviour are discussed. The machining characteristics of the insert were compared to available commercial insert. The results indicate that the material under development has potential for commercial application and shows good machining evidences. However, the machining tests point out the necessity for a microstructure homogenisation of the obtained material.

Introduction

The valve seat inserts, for intake and exhaustion of gases in the combustion chamber operate under severe work conditions. Due to their good properties of thermal stability at high temperatures, the high-speed steels have been considered as an alternative material for this application. Others additional and important characteristics are good corrosion resistance (oxidation), high thermal conductivity and machining [1]. Therefore, the use of the powder metallurgy technique (PM) in this segment has growing constantly. The powder metallurgy process allows the production of parts and metallic components at low costs, high flexibility in the production of the alloys and improvement of the microstructure control [2,3]. The present project is focused in the obtention of new materials by less complex processes and application of cheaper and less aggressive metals. This is the case of cobalt substitution due its high cost and the replacement of lead by other less toxic element [4-6].

One of the objectives of this work was to find alternatives for the cobalt alloys and to reduce the sintering temperature [4]. The decrease of the sintering temperature of the present alloy allowed the use of traditional sintering equipment. This equipment is commonly found in the PM industries and operates continually at 1150 °C maximum temperatures. The substitution of the cobalt in the alloy allowed a reduction of the part cost already in the feedstock acquisition phase.

The other objective appeared along this work development. It was very important to know the machining properties of the obtained alloy. Although the associated operation (machining) it is limited only to the execution of the insert contact area with the valve (once PM techniques makes possible the obtention of near-net-shape components), it can represent a substantial production cost, given the great number of engines produced.

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Experimental

Material

The nominal chemical composition of the powders mixture used for obtention of the insert here denominated MD series- "material under development", is presented in table 1. It were measured and evaluated some properties and characteristics of the obtained insert which are compared to the properties of commercials inserts of Fe-Co (CM – commercial material), see table 2.

Table 1. Used nominal chemical composition of the powders mixture (weight %) for the insert under development.

Material	Fe	AISI M 3/2	C	Cu (infiltration)	NbC
MD	40-44	40-44	0.5-1.0	10-15	1-3

Table 2. Mechanical and physical properties of the insert under development in comparison to the commercial material (CM).

Materials	Green density (g/cm^3)	Density after sintering (g/cm^3)	Hardness (HRC)	Radial strength (MPa)
MD	6.50	7.11	38-45	1230-1350
CM	...	7.30	25-30	1280-1370

... Not available.

Machining

For the machining tests it was prepared three assemblies of inserts made with the CM and MD materials. Each assembly consisted of 10 inserts stack-pilled in a special device, making possible a machining length of 60 mm with external diameter of 31.4 mm. The machining was executed between bearing points holding the mentioned device that was especially projected and built for the tests (fig. 1).

Ceramic and coated hard-metal tools were used for the machining tests. The tools (interchangeable inserts) had triangular form and they were mounted in a support whose group characteristics (support + interchangeable insert) are the followings: side-rake angle (γ) = 0 °, side-relief angle (α) = 11 ° and position angle (χ) = 90 °, see fig. 2.

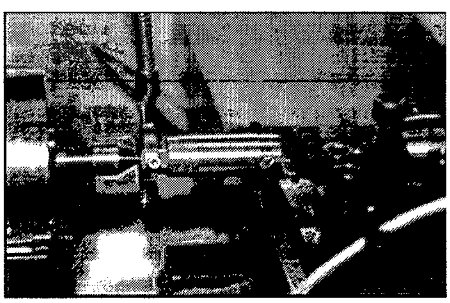


Fig. 1. Picture showing the device between bearing points with the inserts being worked by the machining tool.

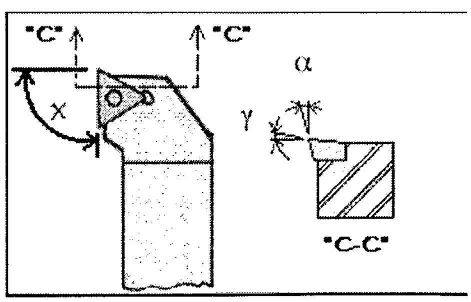


Fig. 2. Illustration of geometric details of inserts and tool holders.

The equipment used in the tests (fig. 3) was a computerised numeric command (CNC) lathe. It was developed a specific program in the machine language for the machining tests. In order to collect data it was used strain gauges connected to the tool holder whose microstrains were converted into milivolts by a Wheatstone bridge. The values were send to a microcomputer through a multimeter using a communication interface RS232 (fig. 4).

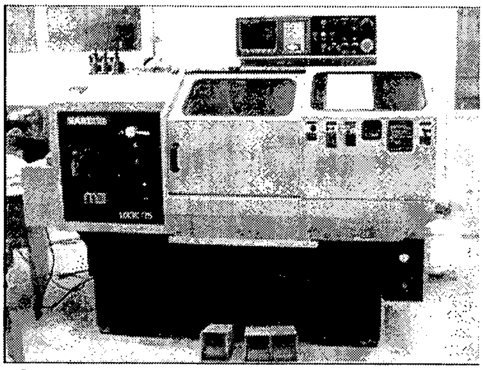


Fig. 3. Details of the CNC lathe used for the experiments.

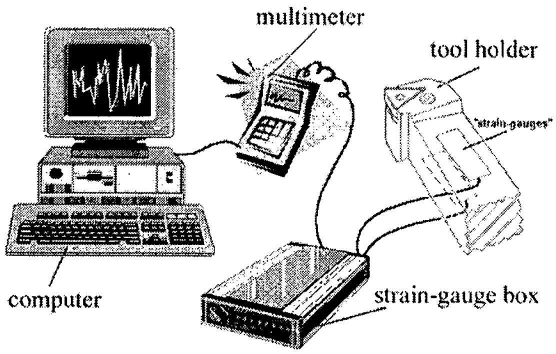


Fig. 4. Schematic representation of the apparatus used for forces measurement [8].

The tests consisted of the machining of the specimens at cut depth (p), feed (f), nose radius (r) and constant cutting speed (Vc) and equal to 0.65 mm, 0.09 mm/rot, 0.4 mm and 100 m/min respectively (fig. 5). It was executed cuts of depth 0.65 mm in each group of inserts and for each cut one stop was programmed for evaluation and photographic registration by optical microscope of the tool wear.

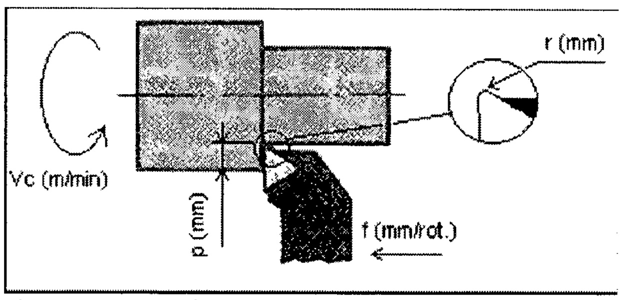


Fig. 5. Illustrative representation of the machining parameters used in the tests.

Results and discussion

The results obtained during the machining tests for series MD and MC with ceramic tool, showed that, in spite of the inherent fragility of the ceramic, this was capable to absorb better the hardness differences present in the structure of MD material as will be seen later. Differently to that occurred with the hard metal tool. The results of cut force (fig. 6) presented values of the same order for series MD as for series MC, showing that the addition of the high-speed steel and NbC did not affect considerably the machining characteristics of the obtained material.

Even with the occurrence of a small chipping of the tool flank during the machining of the MD series, it was not noticed an increase of the cutting force for this condition, showing that the developed material presents reasonable machining characteristics. The chips produced during the MD series machining presented geometric characteristics and visual aspect of the type connected arc chips [9], typical of an easy machinable material. Regarding the chips obtained during the MC series machining (loose arc chips), that presented aspects of a more fragile material and therefore with worse machining characteristics (figs. 7 and 8).

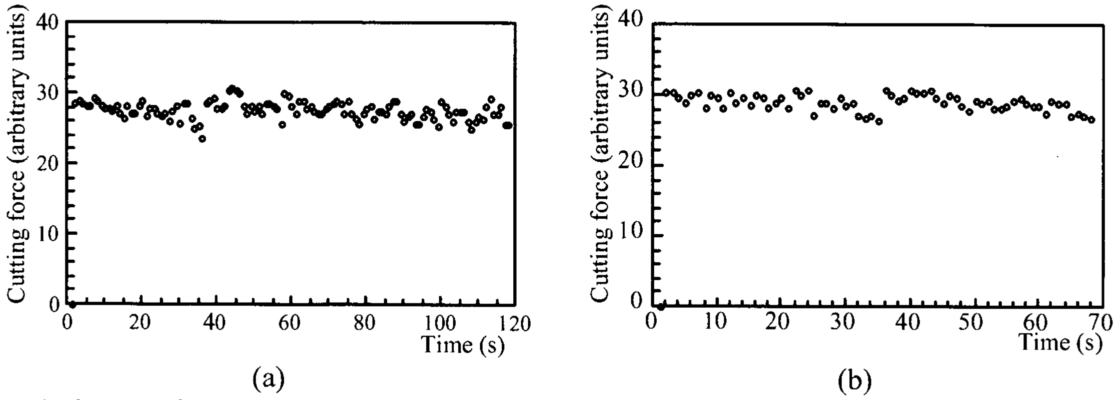


Fig. 6. Cutting forces in arbitrary units measured during the machining with ceramic tool. a) Material under development (MD). b) Commercial material (CM).

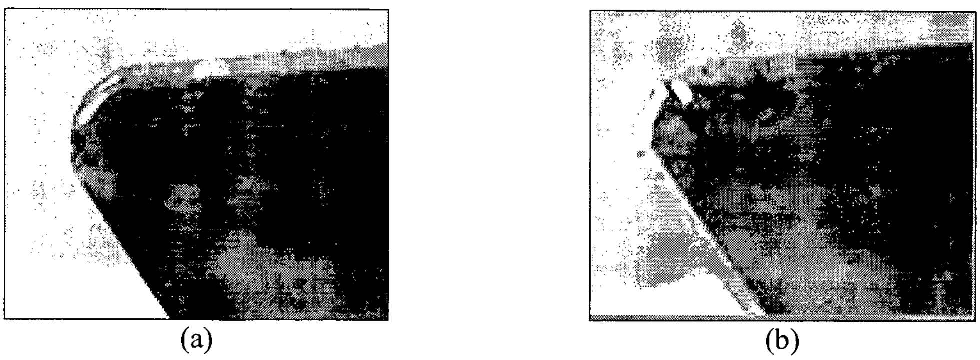


Fig. 7. Aspects of the ceramic tool surface submitted to flank wear. a) Ceramic tool aspect after machining the material under development (MD). b) Ceramic tool after machining the commercial material (CM).

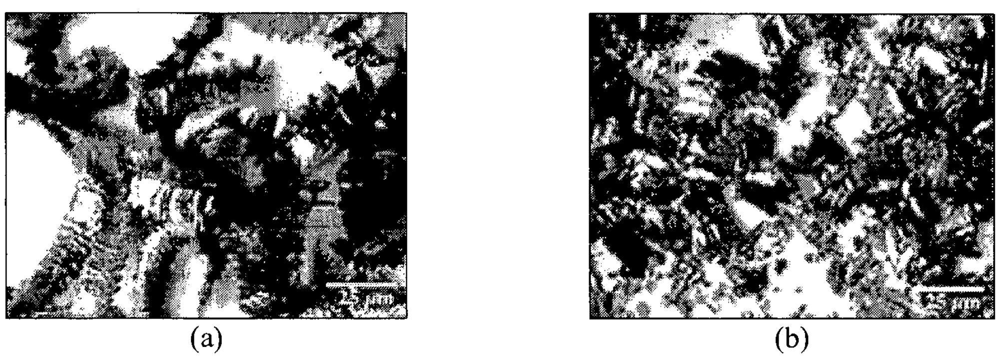


Fig. 8. Optical macrography of the machining chips. a) Connected arcs chips originated from the material under development (MD). b) Loose arcs chips originated from the commercial material (CM).

An analysis of the hardness profile of stack-pilled inserts using the material under development – MD series (fig. 9) shows a significant dispersion of values along its length. This variation of hardness along the inserts thickness is comprehensible since the material was tested in the condition as sintered. However, this is not probably a suitable condition for the final product and it should be pointed out the need for an appropriate study of heat treatment effect on the hardness homogeneity this component.

Conversely from what occurred during machining using ceramic tool, the hard-metal tool was more susceptible to the hardness variations along the machined length of the MD series material. This was due to a more ductile nature that produced an elastic effect in the system and consequently a higher dispersion of points (between 19 and 49 machining force arbitrary units), fig. 10a. The more homogeneous commercial material (CM) produced a narrower dispersion of the values of machining forces (fig. 10b). Therefore, more beneficial from the point of view of process optimisation and even useful tool life.

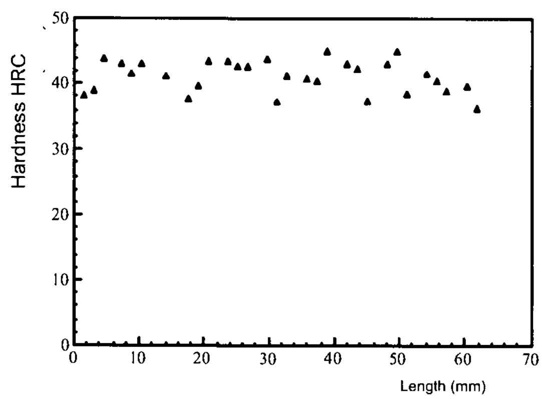
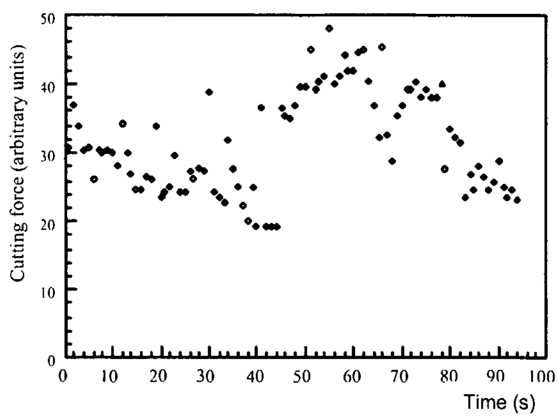
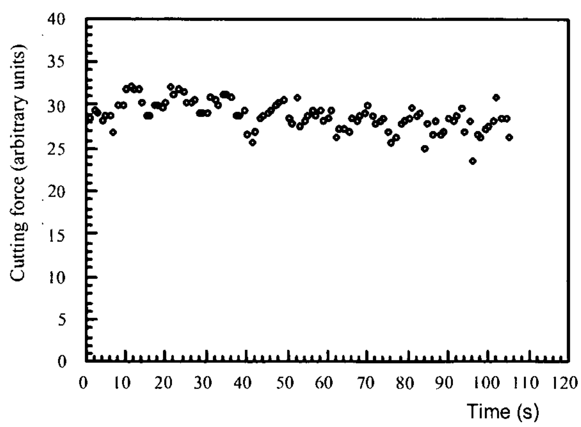


Fig. 9. Rockwell C hardness profile of 10 stack-pilled valve seat inserts (MD series).

Considering that the forces obtained during machining the CM series using ceramic and hard-metal tools were practically of the same order of magnitude (figs. 6b and 10b). The wear of the hard-metal tool in this first evaluation may be considered acceptable. It can be said that, if the material under development undergoes a heat treatment in order to homogenise the hardness (see discussion of fig. 9), it is possible to obtain a better condition for machining with hard-metal tools. The hard-metal tools are cheaper in relation to the ceramic tools as well as diamond. However, this aspect should be better addressed through a careful cost against benefit study.



(a)



(b)

Fig. 10. Cut forces in arbitrary units measured during the machining test using hard-metal tool. (a) Material under development (MD). (b) Commercial material (CM).

Conclusions

The results showed that the machining the material under development in the condition as sintered could be more efficient using tools with substrate or harder characteristics (ceramic or even diamond).

The machining results using hard-metal tool and the hardness profile of the material under development (series MD), point out to the need of making a thermal treatment to homogenise the hardness of the material as sintered.

Although the mean hardness of the material under development (MD) is higher than the commercial material (CM), the chips produced during the machining tests are evidences that this material presents better machining characteristics.

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