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MACHINABILITY OF Cr-Mo BASED STEELS PRODUCED BY POWDER METALLURGY

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ABSTRACT: One of the main advantages of powder metallurgy over other processing methods is that it either eliminates or greatly reduces machining operation. However, many parts require machining afterwards because of intricate design. Thus, there is a renewed interest in machinability characteristics of sintered materials. This study deals with the evaluation of the machinability of Cr-Mo alloyed steels during turning operations. Cr-Mo alloyed steels having different microstructures, but an almost identical hardness value were produced by different sintering processes in powder metallurgy. As-sintered and sinter-hardened specimens were prepared with (MnS) and without additive for machinability evaluations. Turning tests were carried out by conventional CNC lathe in a dry condition. The turning operation was performed using two different cutting inserts (cemented carbide and cubic boron nitride). The cutting speeds and feed rates used were with different values while the depth of cut was kept constant. It was found that the MnS additive improved the machinability without having any detrimental effect on the sintered properties. Also, uses of cubic boron nitride insert improved the tool life. The results showed that the tool life and machinability of sinter-hardened steel is better than the as-sintered steels at identical cutting condition.

Keywords: Sintered steel, Powder metallurgy, Machinability, Turning, Cutting tool.

1. INTRODUCTION

Powder metallurgy (PM) is known for producing complex parts to very close tolerances without the necessity of machining operations. However, machinability is still important for some applications. Many components require surface-finish machining to reach final shape due to particular geometries. Investigation of the PM market reveals that about 60% of all components need some kind of machining operation [Höganäs, 2004a]. Turning operation is the most widely used cutting methods in machining of PM parts [Šalak et al., 2006]. Sintered parts do have some porosity and it is, therefore, necessary to differentiate their machining behaviour from those of fully dense wrought products. The major differences are, as follows: (i) When a porous metal is machined, the depth of work hardening is more important than for the wrought metal, as in case of former, pores create stress concentration. (ii) The temperature at the tool end causes oxidation of the pore surface. (iii) The surface porosity enhances tool vibration [Upadhyaya, 2002]. Many definitions of machinability as the metal cutting process presented in general prove that the machinability is extremely complex, and especially in machining of powder metallurgy materials [Šalak et al., 2005]. The term machinability is used to describe how easy a material is to machine [Sandvik, 1994]. Others describe it as the characteristics under which a cutting tool operates [Shaw, 1996]. However, the main goal of machining is to remove material to produce a component or product efficiently. The machinability of a PM component is dependent on the workpiece and tool material properties, cutting conditions, cutting tool and machine parameters like cutting speed, feed rate, and depth of cut [Wyatt and Trmal, 2006]. Chemical composition, porosity, free machining additives, and production process parameters such as compaction and sintering methods, also collectively influence machinability [Höganäs, 2004a].

The cost of machining can in many cases is a significant part of the total production cost. Additions of lubricating compounds cause enhancement of the machinability of PM materials without significantly influencing the mechanical properties of the component [Hultman et al., 1996]. It is well known that MnS is a very effective machinability enhancing additive for PM parts. Eugström [Engström, 1983] stated that MnS additive leads to improvement in machinability with limited effect on mechanical properties. During machining PM parts, the heat is generated due to friction between tool and work piece. The harder the material is the more heat will be generated. When the generated heat reaches a certain temperature level, it would cause premature tool failure. This is why conventional PVD/CVD coated tools are not able to cut the sinter-hardened materials, and high temperature resistant tools such as cBN are required [Hu et al., 2009]. The details of the machining properties should be further examined in order to use PM steel materials in a large scale. However, there are not enough studies on the machinability of PM parts in the literature. It is clear that wear data and tool life relationships in wrought can not be expected to be valid for porous material because of the porous structure mostly of the different composition [Šalak et al., 2005]. It was therefore necessary to study the effect of many machining parameters on the machinability of PM parts.

Astaloy CrM is a water-atomized iron powder pre-alloyed with Cr and Mo exhibiting an excellent hardenability. The low oxygen content gives a good compressibility. Very high strength and hardness can be achieved after sintering. The fully pre-alloyed composition results in a homogenous microstructure [Höganäs, 2004b]. The dimensional and mechanical properties are very satisfactory, and warm compaction combined with high temperature sintering has been outstandingly successful [Campos et al., 2000]. Thus it can be regarded as at least a match for the classical Ni-Cu-Mo steels. Machining of Cr and Mo prealloyed Astaloy CrM steels has been studied by a few researchers, and they emphasized the importance of Astaloy CrM steels in the PM industry. [Andersson and Berg 2005; Andersson and Larsson, 2009; Berg, 2005; Hu et al., 2009]. In order to widen the use of these steels a better understanding of the different factors influencing the machinability of these steels are required. This study describes the machinability of Cr-Mo based Astaloy CrM workpieces produced by different sintering processes. Turning tests have been carried out on a range of sintered steels. The tool life of insert and surface roughness has been determined using different cutting tools and machining parameters.

2. EXPERIMENTAL PROCEDURES

High strength PM materials were chosen as the workpiece material for this research. The specimens were produced by different sintering processes in powder metallurgy using Cr-Mo pre-alloyed, water atomized Astaloy CrM steel powders, which is a registered trademark of Höganäs Company, Sweden. The chemical composition of the powder was 3.0 wt.% Cr, 0.5 wt.% Mo, and balance-Fe. The powder premix consisted of 0.8 wt.% zinc stearate as lubricant, and 0.5 wt.% carbon was added as fine graphite

(UF4). The machibability of specimens was evaluated with and without additive, where 0.5 wt.% MnS was added in the premixes. The powder mixtures were prepared by weighing samples in Sartorious balance with 0.01 g sensitivity and then mixed homogeneously in a laboratory scale mixer for 30 min. Powder mixtures compacted uniaxially at 650 MPa in a steel die using a hydraulic press into cylindrical specimens that have about 7.0 g/cm^3 green density. Geometry for workpiece materials: inner diameter 30 mm, outer diameter 60 mm and height of about 60 mm. All the specimens were sintered at 1120 ºC for 30 minutes in an industrial continuous pusher furnace under 25% N_2-75% H_2 atmosphere and cooled with a cooling rate of 0.5 °C/sec for convectional sintering, and 2 °C/sec for sinter hardening. The powder mixes and the sintering processes use in this study, and designation of PM materials are shown in Table 1.

Table 1: Type of sintering and designation of the workpiece material.

PM material	Type of sintering	Designation
without additive	Sintering	S
with 0.5 % MnS	Sintering	MnS-S
without additive	Sinter hardening	SH
with 0.5 % MnS	Sinter hardening	MnS-SH

Turning tests were carried out by conventional CNC lathe using a face turning operation in a dry condition without any coolant. The turning operation was performed using two different types of inserts. The cutting inserts are presented in Table 2 according to Sandvic Coromant guide lines [Sandvik, 2003]. The inserts, from Sandvik Inc., were clamped on the same tool holder used for the tool life tests. The cutting speeds (V_c) and feed rates (f) used were with different values while the depth of cut (a_p) was kept constant in order to relevant setting and to meet tool life. The cutting conditions used in the experiments are listed in Table 3, and each treatment is replicated three times.

Table 2: The cutting tool properties.

Inserts	Type of insert grades
GC3215	Cemented carbide grade with a CVD coating of TiCN, Al_2O_3 and TiN
CB7050	Cubic boron nitride grade with a PVD coating of TiN

Table 3: The cutting conditions.

Inserts	V_c (m/mim)	f (mim/rev)	a_p (mm)
GC3215	200 - 400	0.1 - 0.30	0.5
CB7050	200 - 300	0.1 - 0.30	0.5

The as-sintered and sinter-hardened specimens were grinded and polished in cloths with alumina and pure water then etched in 4% Nital solution for optical examination. Olympus PME3 optical microscope was used for microstructural examination. Rockwell B (HRB) scale was used to measure the macrohardness of the specimens in Zwick hardness testing machine. The microhardness measurements were taken on Vickers scale with a Tukon microhardness machine. Three different locations were selected on the surface of the specimens and the average of those values was used as the hardness measure of samples. The surface roughness value on each of the workpieces was measured with a Mitutoyo SJ-210 surface roughness tester. The measurements were taken on the same day of the experiment in order to prevent oxide films from depositing on the machined surface.

3. RESULTS AND DISCUSSION

The machinability of a PM component is dependent on the microstructure properties of the workpieces [Höganäs,

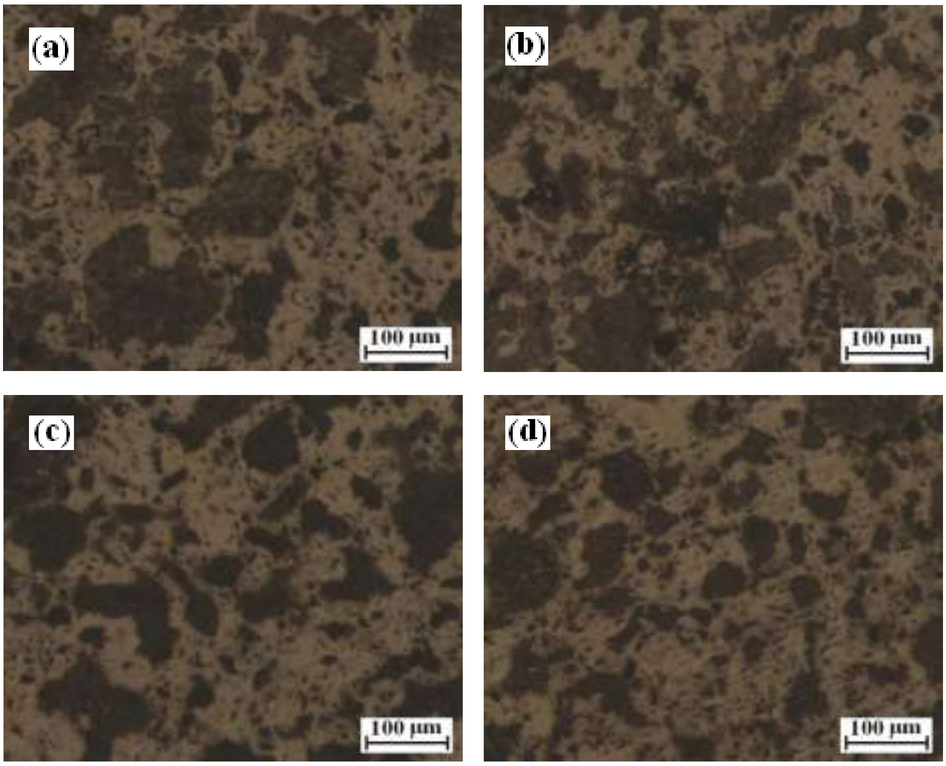

Figure 1: Microstructure of the specimens: (a) S, (b) MnS-S, (c) SH and (d) MnS-SH

2004a]. The microstructures of as-sintered and sinter-hardened specimens with or without MnS are shown in Figure 1. The as-sintered specimens consist of an almost martensitic structure with a very small amount bainite structure (Figure 1 a-b). The sinter-hardened specimens are full martensite phases as a result of rapid cooling (Figure 1 c-d). In the micrograph, bright regions are martensite, darker regions are bainite, and black regions are micropores between the steel particles. Sinterhardening process changed the microstructure and properties of this high strength steel. There is no effect on the microstructure when the MnS additive is added.

The macro and the microhardness values of as-sintered and sinter-hardened specimens with or without MnS are given in Table 4 according to sintering processes. The microhardness is less influenced with MnS additive, but the macrohardness is not. The increase in macrohardness and microhardness values were achieved with sinter hardening. Sinter hardening led to increase in hardness due to formation of full martensite [Andersson and Berg, 2005].

Table 4: The macro and microhardness of the specimens.

Sintering groups	Macrohardness (HRB)	Microhardness (HV0.1)
S	121 ±7	351 ±42
MnS-S	128 ±9	352 ±38
SH	146 ±8	392 ±48
MnS-SH	158 ±10	397 ±36

In a start-up test two inserts of different grades were tested; the cemented carbide grade GC3215 and cubic boron nitride grade CB7050. The tool life of insert grades when turning as-sintered and sinter-hardened workpieces with or without additives is shown in Figure 2. The cutting speed and feed rate of grades were 300 m/min and 0.15 min/rev, respectively. The tool life with grade CB7050 is bigger compared with grade GC3215 for all workpieces. According to

Hu and Shah [Hu and Shah, 2008], the PM materials are basically not able to be cut with cemented carbide grades and, high performance cubic boron nitride grades are generally used for machining this type of material with long tool life. Both MnS addition and sinterhardening process strongly improved machinability, as can be seen in Figure 2. Hu et al. [Hu et al., 2009] explained that the machining on the sinter-hardened materials with MnS additive achieved at least 5 times longer tool life than the machining on the materials without additive.

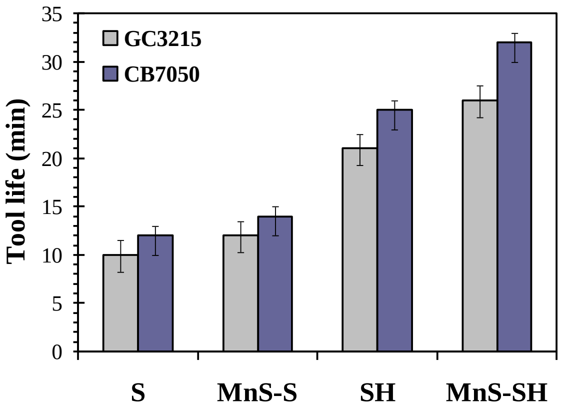

Figure 2: The tool life of insert grades for all workpieces.

In an attempt to increase tool life, the cutting speed was reduced from 300 m/min to 200 m/min for grades GC3215 and CB7050. The tool life of insert grades at different cutting speed of MnS-SH groups is shown in Figure 3. The feed rate of grades was 0.15 min/rev. With decreasing the cutting speed the tool life of grade GC3215 was increased by 18% and of grade CB7050 by 11%. The cause of this is lower the cutting heat at low cutting speed, and decrease tool wear. All obtained tool wear was formed by normal abrasion.

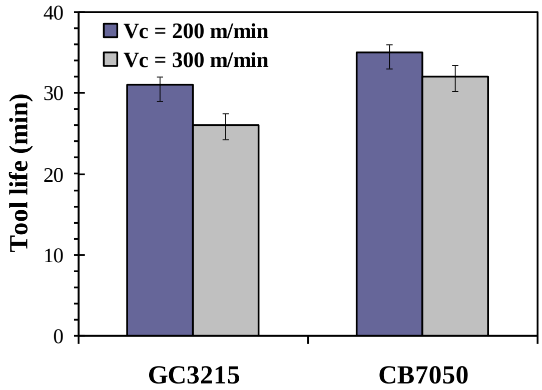

Figure 3: The tool life of insert grades at different cutting speeds.

In the tool life test the difference between the grades GC3215 and CB7050 show to be considerably high. The CB7050 is grade with high toughness compared the grades GC3215. Surface quality may be considered to be one of the vital factors in metal cutting as it is directly related to a fatigue life for most materials. By natural causes will both feed rate and insert material influence the machined surface roughness [Andersson and Berg, 2005]. Figure 4 shows the surface roughness at different feed rates of SH groups. The cutting speeds of grades GC3215 and CB7050 were 300 m/min and 200 m/min, respectively. The results indicated that the investigated insert type used in this study has no a significant effect on the machined surface. For both cutting inserts, surface roughness linearly increased. The increase of feed rate results in an increase in the surface roughness and similar trends were obtained for the investigated range.

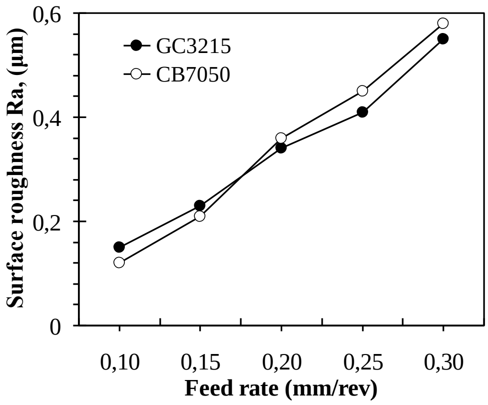

Figure 4: Surface roughness at different feed rates as function of grades.

Porosity affects chip formation and chip continuity. In generally, chips tend to produced in PM machining are discontinuous, especially at intermediate and low densities [Šalak et al., 2005]. The results showed that tool wear decreased and chip formation improved with the use of sinter-hardened specimens. Also, MnS additive facilitates the chip removal. These results are also supported by the data obtained from surface roughness.

4. CONCLUSIONS

Turning tests were performed to find how machinability of as-sintered and sinter-hardened Cr-Mo based workpieces was influenced by choice of insert type, MnS additive and cutting conditions. The following conclusions can be drawn:

- The machinability of PM steels can be explained partially by their microstructure.
- Improvements to tool materials and tool design improve the machining of PM steels.
- MnS additive increases the tool life remarkably. Sinterhardening process strongly improved the machinability due to martensitic formation.
- Tool life can be increased when the cutting speed is reduced.
- The best machining performance is achieved by the grade CB7050.
- The feed rate has a significant effect on the machined surface, but the surface quality can be obtained independent from the investigated insert.
- The different behaviours of machinability improvement observed in PM workpieces used in this study are manageable during production.

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