Machining of Chromium Alloyed PM Steels

Olof Andersson, Sigurd Berg

Höganäs AB, SE-263 83 Höganäs, Sweden

ABSTRACT

Powder Metallurgy (PM) is a near net shape process. Since this process is "near net", secondary operations, e.g. machining, are often required for many applications, in order to create shapes not possible to achieve through compaction only, or to reach demanded tolerances.
The use of chromium alloyed PM steels, a high strength PM material, has increased in recent time. One of the features of the chromium alloyed PM steel material is the excellent hardenability. Machinability is related to the hardness of the component. To maintain the cost benefit for PM applications, machining of such parts is to be taken into account in material selection. Guidelines for tool choice, cutting data and the effect from additives are needed to improve the machining performance of chromium alloyed PM steels in their various applications. This paper describes the machinability of a high strength chromium alloyed PM steel. Optimal settings of inserts are established at which properties like life time and surface roughness are improved. The gains achieved when machining these PM steels by using machinability additives are also shown.

INTRODUCTION

Powder Metallurgy (PM) is a technique well-known as a means of mass production of complex parts with near-net shape. However, due to technical limitations, many PM components require some type of machining operation to reach final shape, e.g. a shape impossible to achieve through compaction only, or due to demands for very close shape tolerances.
PM materials are often considered to be difficult to machine, especially compared to conventional standard steels. However, by choosing a proper combination of tool material and insert geometry together with optimised cutting data, and additives if necessary, it is in many cases possible to achieve a productivity level of machining PM parts equal to that of machining standard steels [1][2].
In this study a turning operation has been performed on a relatively new PM material, the chromium and molybdenum prealloyed Astaloy® CrM [3][4], in a fully martensitic condition and with high strength properties. In this paper the influence of tool grades, insert geometries, additives and cutting data, when machining this type of PM material will be presented.

Presented at PM²TEC2005, in Montreal, on June 23, 2005

EXPERIMENTAL

The powder mixes used in this study are shown in Table 1. The specimens for the turning tests were manufactured by conventional compaction with cylindrical geometry OD = 64, ID = 35 and height 30 mm (OD = 2.5, ID = Ø1.4 and height 1.2 inch) at 700 MPa (50.4 tsi), reaching a green density of 7.0 g/cm³.

Table 1. Powder mixes based on Astaloy® CrM

PM material	Powder composition
Material 1	Astaloy® CrM + 0.47% Graphite + 0.8% Kenolube
Material 2	Astaloy® CrM + 0.47% Graphite + 0.8% Kenolube + 0.5% MnS
Material 3	Astaloy® CrM + 0.47% Graphite + 0.8% Kenolube + 0.3% MnX

The green specimens were sinter hardened in a laboratory belt furnace at 1120ºC (2048ºF) for 30 minutes in an atmosphere of 90%nitrogen/10% hydrogen, with methane addition. Immediately after sinter hardening all specimens were annealed at 200ºC in air for one hour. A martensitic structure, shown in Figure 1, was obtained in all three material compositions.

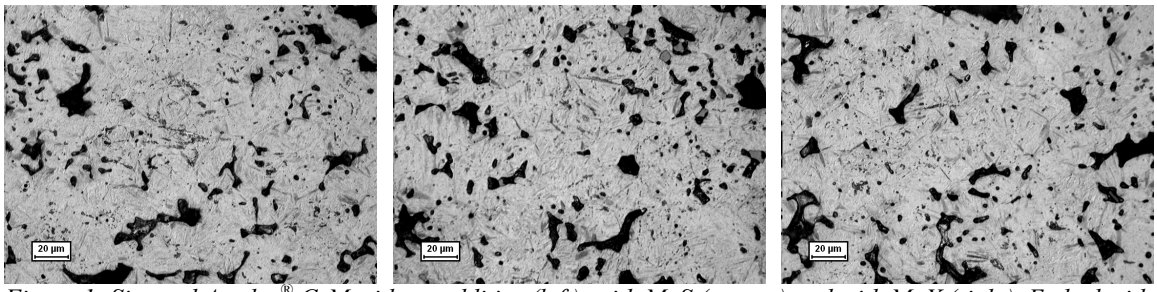


Figure 1: Sintered Astaloy® CrM without additive (left), with MnS (centre,) and with MnX (right). Etched with nital/picral.

The MnS additive influence can be observed in terms of a minor reduction in macro hardness as shown in Table 2. The micro hardness, on the other hand, of the martensitic matrix, is not influenced by the MnS additive at all.

Table 2. Sintered density and hardness of the sintered specimens

Sinter hardened PM material	SD	HV10	MHV0.05
Material 1, without additive	7.0	380	740
Material 2, with 0.5% MnS	7.0	365	740
Material 3, with 0.3% MnX	7.0	380	740

SD: Sintered density [g/cm³]
HV10: Hardness measured on polished cross section of turning test specimens
MHV0.05: Micro hardness measured on polished cross section of turning test specimens

All sinter hardened cylindrical specimens have been machined in a CNC lathe (Mazak) using a face turning operation as shown in Figure 2.

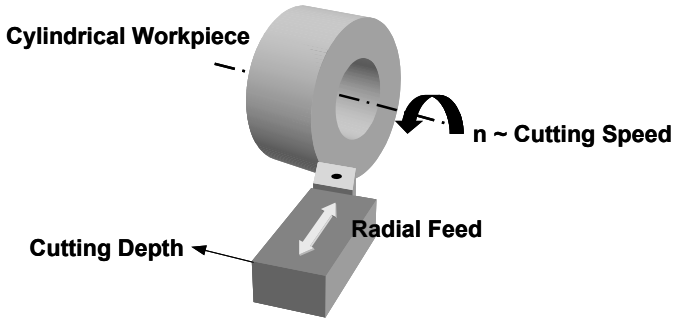


Figure 2: Face turning operation (schematic).

The inserts in the tests have the same basic ISO-geometry, CNGA120408, but consist of different insert material grades [5], shown in Table 3.

Table 3. Insert grades

Grade	Type, i.e. substrate and coating	Recommended application area* (ISO)
GC3215	Cemented carbide, coated with TiCN, Al_2O_3 and TiN	Grey or nodular cast iron (K15)
S05F	Cemented carbide, coated with TiCN, Al_2O_3 and TiN	High temperature alloys (S05)
CC6050	Ceramic, coated with TiN	Hardened steels (H)
CB7050	Cubic boron nitride, coated with TiN	Hardened steels and hardened cast irons (H05, K05)
CB7020	Cubic boron nitride with TiN binder, coated with TiN	Hardened steels (H01)

**Conventional wrought steel or cast iron/steel.*

RESULTS AND DISCUSSIONS

Turning tests without additives – Different insert materials

In a start-up test four inserts of different grades were tested; the cemented carbide grades GC3215 and S05F, the ceramic grade CC6050 and the cBN grade CB7050. The test was done dry, i.e. without cutting fluid, and with a cutting speed Vc = 150 m/min (492 ft/min), feed rate f = 0.20 mm/r (0.0078 in/r) and cutting depth ap = 0.15 mm (0.0059 in). This test was performed until flank wear (Vb) had reached 0.15 mm (0.0059 in), i.e. half of the normal (in machining tool life test) "standardized" value 0.3 mm (0.0118 in), to illustrate the large difference between the cBN grade with the others, as shown in Figure 3. The tool life with CB7050 is 583% longer compared with grade S05F.

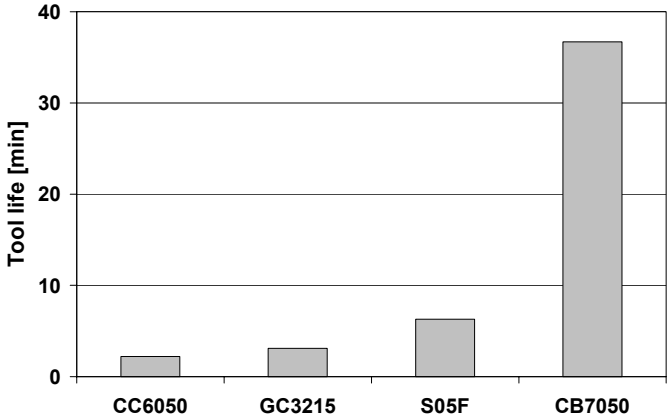


Figure 3: Tool life of different insert grades with the same tool geometry. CNGA120408, Vc=150 m/min (492 ft/min), f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), dry condition, Crit. Vb=0.15 mm (0.0059 in).

In an attempt to increase tool life, with the cemented carbide grades, the cutting speed was reduced from 150 m/min (492 ft/min) to 100 m/min (328 ft/min). The purpose of this is to lower the cutting heat and, consequently, to decrease tool wear. By reducing the cutting speed the tool life of grade S05F was increased by 138% and of grade GC32115 by 68%, as can be seen in Figure 4. Yet, even if tool life of the cemented carbides can be increased by reducing cutting speed, there still is a significant difference in favour of cBN grade CB7050.

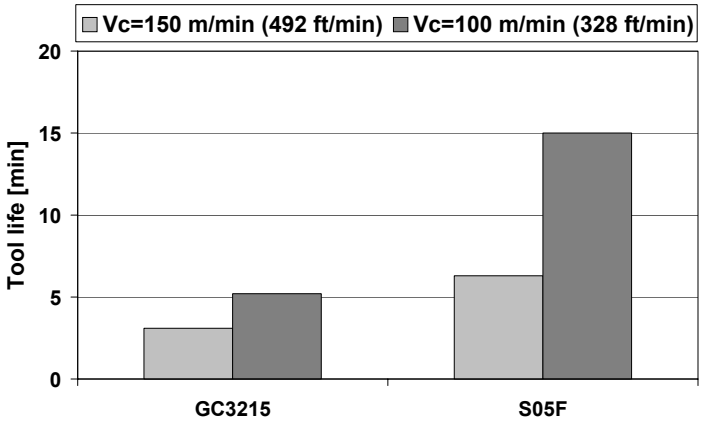


Figure 4: Tool life of cemented carbides at different cutting speeds. CNGA120408, f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), dry condition, Crit. Vb=0.15 mm (0.0059 in).

Turning tests without additives – Different cBN grades

The CB7050 is a so called "high content cBN" grade with high toughness compared to CB7020, which is a harder grade that consists of cBN and titanium nitride in the substrate, a so called "low content cBN" grade. In the tool life test the difference between the CB7050 and the CB7020 shows to be remarkably high, as can be seen in Figure 5. The test includes two flank wear

criteria, 0.15 and 0.20 mm (0.0059 and 0.0078 in), but criterion Vb = 0.2 mm (0.0078 in) was never fulfilled with the grade CB7050 due to the very long tool life.

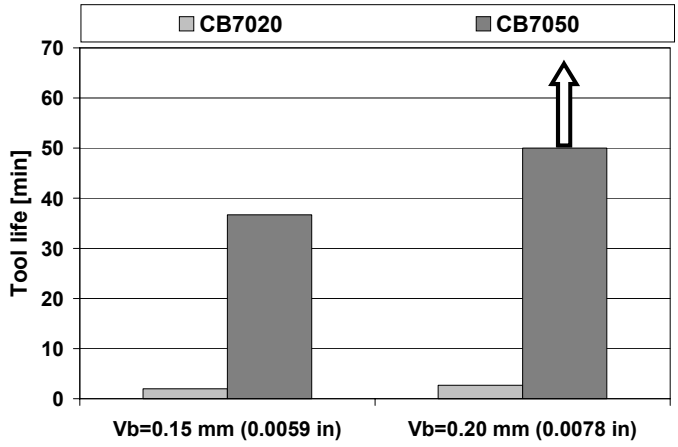


Figure 5: Tool life of two different cBN grades. CNGA120408, Vc=150 m/min (492 ft/min), f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), dry condition.

This test result exhibits the importance of toughness, rather than of hardness, of the insert material grade when turning the Astaloy® CrM in martensitic condition.

Turning tests without additives – Wet or dry turning

The environment is often favoured when machining can be performed without cutting fluids or coolant aids, i.e. in dry condition. On the other hand, the use of cutting fluid may have a beneficial influence on the tool life. However, turning tests with grade CB7050 strongly indicates how the machinability is influenced by the use of cutting fluid or coolant aid, shown in Figure 6.

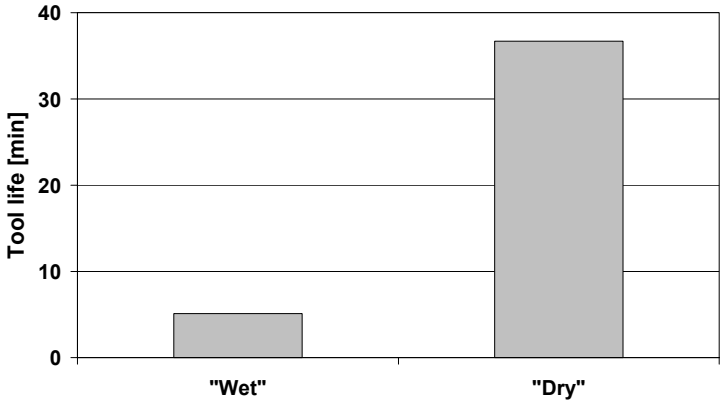


Figure 6: Tool life when turning with or without cutting fluid. CNGA120408, CB7050, Vc=150 m/min (492 ft/min), f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), Crit. Vb=0.15 mm (0.0059 in).

Turning tests – The effect of additives

When the martensitic Astaloy® CrM is machined using the cBN grade CB7050, the influence by the additives goes in two directions, shown in Figure 7. On the one hand the impact from MnS is remarkably positive and enables extended tool life (the test had to be terminated before critical flank wear was obtained). On the other hand the additive MnX actually decreases the machinability with reduced tool life as a consequence.

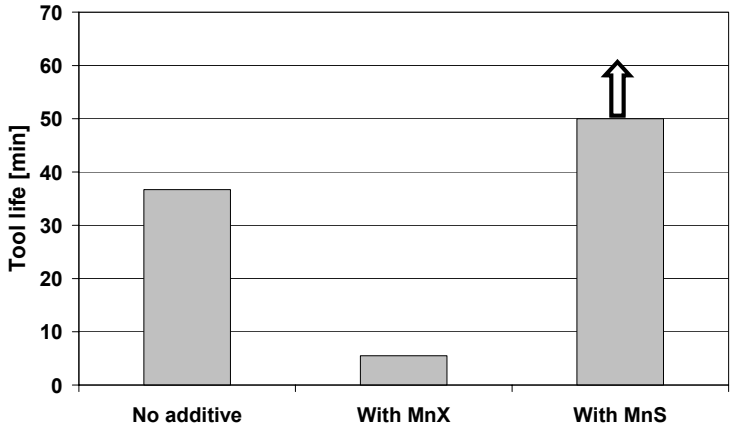


Figure 7: Tool life when turning Astaloy® CrM with or without additive. CNGA120408, CB7050, Vc=150 m/min (492 ft/min), f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), dry condition, Crit. Vb=0.15 mm (0.0059 in).

The effect from MnS is also valid when the martensitic Astaloy® CrM is turned using the cBN grade CB7020 as shown in Figure 8. This test also had to be terminated before critical flank wear was obtained due to very low tool wear. The influence by MnX was, as opposed to the test with grade CB7050, in fact somewhat better than when no additive was used.

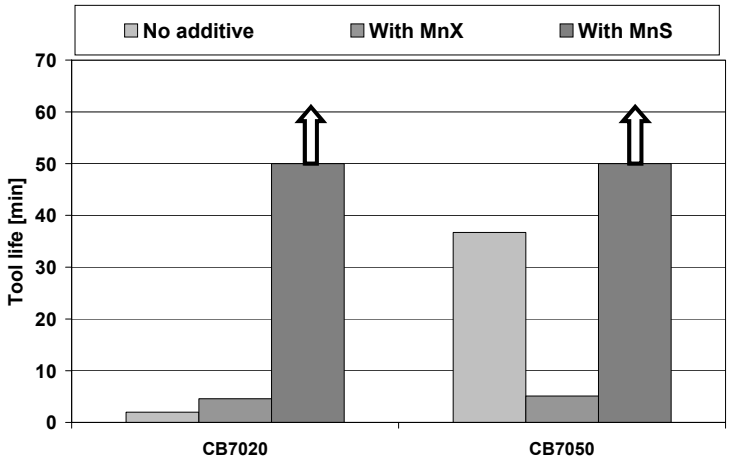


Figure 8: Tool life when turning Astaloy® CrM with or without additive and with two different cBN grades. CNGA120408, Vc=150 m/min (492 ft/min), f=0.20 mm/r (0.0078 in/r), ap=0.15 mm (0.0059 in), dry condition, Crit. Vb=0.15 mm (0.0059 in).

Turning tests – Surface roughness

By natural causes will both feed rate and insert nose geometry influence the machined surface topography, i.e. the surface roughness. By using a cBN insert with Wiper technology, the CB7050 with geometry CNGA120408 T01020 AWG [5], at feed rates equal to or lower than 0.3 mm/r (0.0118 in/r), high surface quality can be obtained independent of cutting depth, in this case between 0.05 – 0.15 mm (0.0020 – 0.0059 in), shown in Figure 9.

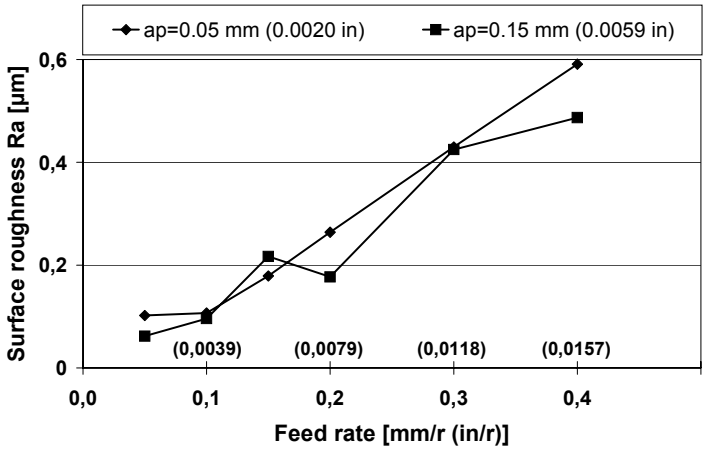


Figure 9: Surface roughness at different cutting depths vs. feed rate.
CNGA120408 T01020 AWG,CB7050, Vc=150 m/min (492 ft/min),dry condition.

In this case the increased cutting depth is proportional to increased cutting capacity, i.e. a higher productivity is possible without loss of quality.

CONCLUSIONS

Turning tests have been performed to find how machinability of the sintered hardened PM material Astaloy® CrM is influenced by the choice of insert tool material grade, additives and cutting conditions.

Turning tests of Astaloy® CrM without additive

With a cutting speed of 150 m/min (492 ft/min) and a feed rate of 0.20 mm/r (0.0078 in/r) the cBN grade CB7050 is superior, with respect to tool life, compared to cemented carbide or ceramic grades. With the cemented carbide grades, the S05F and GC3215, tool life can be increased if the cutting speed is reduced. This was shown in the test with a cutting speed of 100 m/min (328 ft/min), where tool life was increased by 138% with grade S05F, and by 68% with grade GC3215.

To find an optimal cBN grade the CB7050 and the CB7020 were compared. Even if both grades are recommended to machine hardened wrought steel, the difference in tool life was found to be dramatically high. In this case the toughness of the CB7050 shows to be extremely favourable and outperforms the result with the harder grade CB7020.

The overall best performance was obtained by the grade CB7050, without cutting liquid, i.e. dry.

Turning tests with Astaloy® CrM with additive MnS and MnX

The machinability of the investigated material is highly enhanced when MnS is added, shown by the dramatically increased tool life of the insert grade CB7050, but also of the grade CB7020. The influence of the additive MnX, however, shows no improvement with respect to tool life and machinability, when the cBN insert grades are used.
The overall best performance was obtained with grade CB7050 without cutting liquid, i.e. dry. The recommended cutting speed is 150 m/min (492 ft/min), the feed rate 0.20 mm/r (0.0078 in/r) and the cutting depth equal to or below 0.15 mm (0.0059 in).

Turning tests with Astaloy® CrM – Surface roughness

Insert geometry and feed rate will both, by natural causes, influence the machined surface. Tests with insert grade CB7050 and with geometry including Wiper technology (CNGA120408 T01020 AWG), shows how a high surface quality can be obtained independent from cutting depths up to 0.15 mm (0.0059 in), i.e. a higher productivity is possible without loss of quality.

ACKNOWLEDGEMENTS

The authors would like to thank Hans Thordenberg, AB Sandvik Coromant Sweden, for cooperation and for his support of this paper.

REFERENCES:

1 Berg, S. ”*Cutting data Recommendations for Turning of Various P/M Materials Using Different Tool Grade and Geometry Selections*”. Paper presented at 1998 Powder Metallurgy World Congress, Granada, Spain October 1998.

2 Berg, S., Mårs, O. ”*Investigating the Relationship Between Machinability Additives and Machining Parameters*”. Paper presented at PM^{2}Tec2001, New Orleans, USA, May 2001.

3 Lindberg, C. ”*Mechanical Properties of a Water Atomized Fe-Cr-Mo Powder and How to Sinter it*”. Paper presented at PM^{2}Tec1999, Vancouver, Canada, June 1999.

4 Maroli, B., Berg S.; Lewenhagen, J. ”*Properties and Microstructure of PM Materials Pre-Alloyed with Nickel, Molybdenum and Chromium*”. Paper presented at EURO PM2001 Congress & Exhibition, Nice, France, October 22-24, 2001.

5 AB Sandvik Coromant. Catalogue: “*Metal Working Products – Turning Tools 2003*”