Machining of bainitic and martensitic Chromium pre-alloyed PM steel

Author: Sigurd Berg
Höganäs AB
SE-26383 Höganäs

P/M is a net or near net shape process. Machining operations are used for many applications in order to reach final tolerances or shapes not possible to achieve in the compaction step. Chromium pre-alloyed high strength PM steels in sinter-hardening condition or in heat treat conditions have increased in recent time. Guidelines for insert choice and effect from additives are needed to improve the performance in the machining operation for these application areas.

This paper describes the influence of material structure and selection of machining tool for bainitic and martensitic chromium pre-alloyed PM steels. Guidelines for cost effective machining of banitic and martensitic chromium pre-alloyed PM steels are presented.

INTRODUCTION

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 PM material, prealloyed with chromium and molybdenum, Astaloy® CrM [3][4], in fully bainitic and also in fully martensitic condition.

EXPERIMENTAL

The powder mixes use 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

PM material	Composition
Material 1	Astaloy CrM® + 0.37% Graphite + 0.8% Kenolube
Material 2	Astaloy CrM® + 0.37% Graphite + 0.8% Kenolube + 0.5% MnS
Material 3	Astaloy CrM® + 0.37% Graphite + 0.8% Kenolube + 0.3% MnX
Material 4	Astaloy CrM® + 0.47% Graphite + 0.8% Kenolube
Material 5	Astaloy CrM® + 0.47% Graphite + 0.8% Kenolube + 0.5% MnS
Material 6	Astaloy CrM® + 0.47% Graphite + 0.8% Kenolube + 0.3% MnX

MnX is a patented product of Höganäs AB that has been found effective as a pre-mix additive in the machining of PM steels.

Green specimens were sintered in a laboratory belt furnace at 1120ºC for 30 minutes in an atmosphere of 90% nitrogen/10% hydrogen, and with additional 0.2% methane to maintain a good carbon control. The cooling rate in the end of the sintering cycle was 0.8ºC/s (denoted as sintered) for material 1 to 3 and 1.5°C/s (denoted as sinterhardened) for material 4 to 6.

All cylindrical specimens have been machined in a CNC lathe (Mazak) using a face turning operation.

RESULTS AND DISCUSSIONS

Metallographic

All specimens at a cooling rate of 0.8°C/s have a bainitic microstructure. Specimens after cooling rate of 1.5°C/s have a martensitic microstructure.

Turning tests as sintered without additives – wear mechanism.

One of the first attempts to machine Astaloy CrM® was carried out with a CVD coated cemented carbide insert, CNMG120408-WF [4]. With start-up cutting data (Vc = 150 m/min, f = 0.1 mm/r, ap = 0.5 mm) and dry machining the insert was inspected every tenth pass, up to 50 passes. The dominating wear mechanism was found to be adhesion in terms of severe built up edge (BUE), Fig. 1 and a heavily smearing effect, i.e. pressure-welded specimen material, on clearance flank.

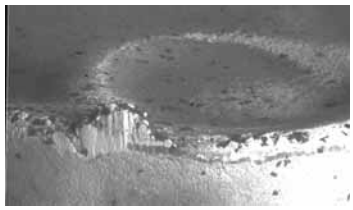


Figure 1: BUE and smearing on insert CNMG120408-WF

As sintered - Insert selection

Two measurements have proven to minimize or eliminate the smearing tendencies; cutting speed but especially the addition of cutting fluid with significant result. To make further optimizations, with regards to an increased tool life, different insert grades [4], i.e. substrates and coatings, applied on insert CCMT09T308 [4], a positive design compared with the negative CNMG, were tested. All tests were performed until flank wear on tool insert had reached the standardized length of 0.3 mm. The two most successful grades were grade CT5015 (uncoated WC-Co cermet) and GC3215 (solid carbide, coated with TiCN, Al_2O_3 and TiN), fig. 2.

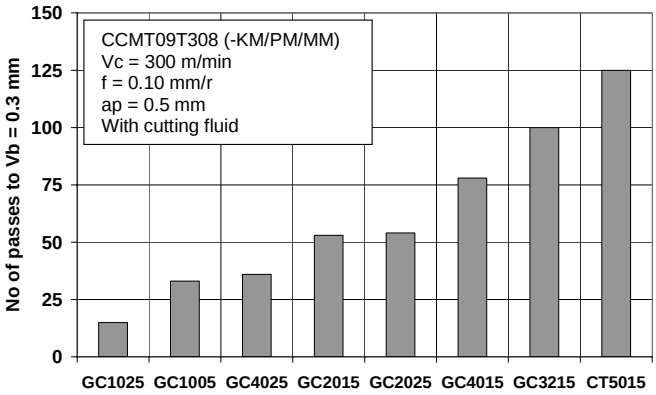


Figure 2: Tool life with different insert grades and same tool geometry.

With the cermet grade CT5015 the influence of geometry was tested by choosing different cutting edge designs (-WF, -PF and -PM). In this test an insert with a more improved tolerance by grinding, CCGT09T308-UM was also tested. The result shows an increase by 35% for –PF, 54% for –PM and 114% for UM cutting edge design. A well-defined edge radius and sharpness affects the tool life.

Sinterhardened - Insert selection

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, feed rate f = 0.20 mm/r and cutting depth ap = 0.15 mm. This test was performed until flank wear (Vb) had reached 0.15 mm, i.e. half of the normal (in machining tool life test) "standardized" value 0.3 mm, 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.

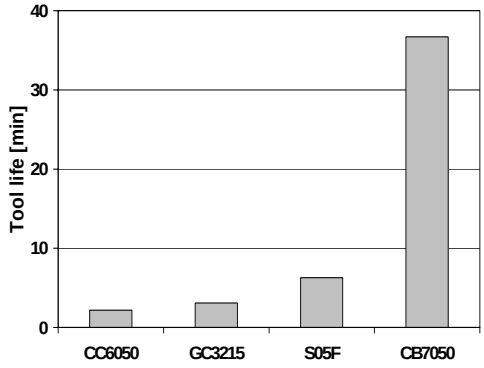


Figure 3: Tool life of different insert grades

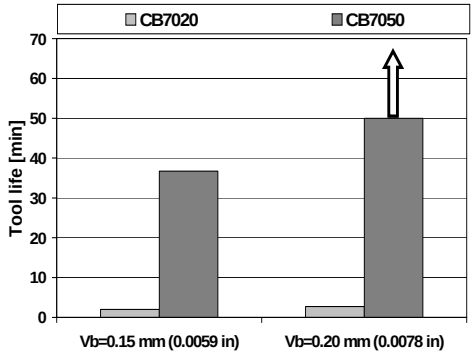


Figure 4: Tool life of two different cBN grades.

Hard or tough insert?

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 4. The test includes two flank wear criteria, 0.15 and 0.20 mm, but criterion Vb = 0.2 mm was never fulfilled with the grade CB7050 due to the very long tool life.

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.

Wet or dry turning.

A sintered

In a next step to reduce BUE and smeared material on tool insert, cutting fluid (emulsion of water and 5% Castrol Syntilo XPS) was applied. The use of cutting fluid was found to be of significant importance [Fig. 5] since BUE and a large amount of the smearing could be eliminated.

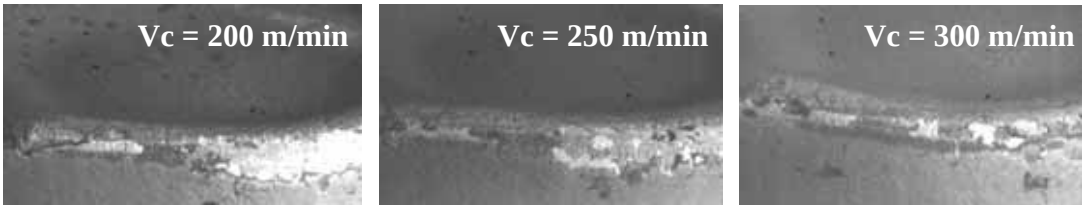


Figure 4: CNMG120408-WF. Turning with increased cutting speeds and applied cutting fluid.

Sinterhardened

Turning tests with grade CB7050 strongly indicates how the machinability is influenced by the use of cutting fluid or coolant aid figure 5. Complete contra dictionary to machining of as sintered – bainitic microstructure.

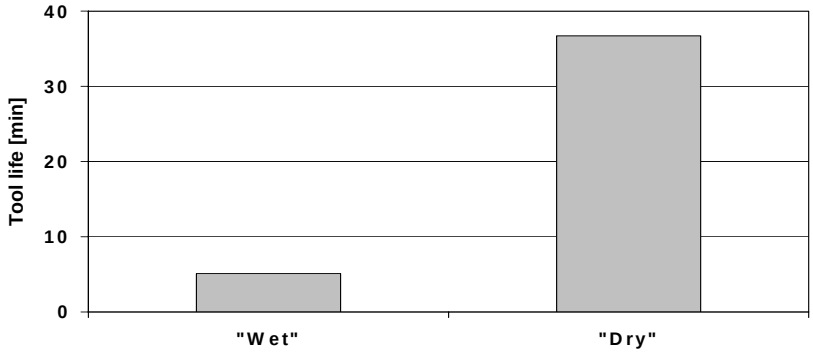


Figure 5: Tool life when turning with or without cutting fluid. CNGA120408, CB7050, Vc=150 m/min, f=0.20 mm/r, ap=0.15 mm, Crit. Vb=0.15 mm.

Machinability additives, MnS and MnX

As sintered, bainitic microstructure

The influence of additives in Astaloy CrM® was dramatically shown in the first test with tool insert CNMG120408-WF, Fig. 6. With the same type of tool insert and with the same cutting data that was used when Astaloy CrM® without additive was machined (Vc = 150 m/min, f = 0.1 mm/r, ap = 0.5 mm) the presence of BUE and smeared material on clearance flank was non-existent, even when the machining took place without cutting fluid, i.e. dry.

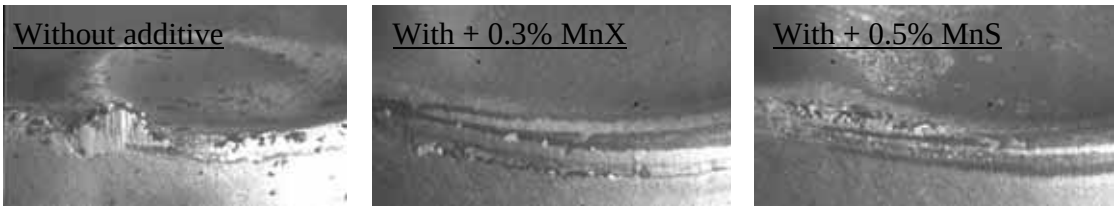


Figure 6: Edge integrity of CNMG120408-WF.

Gains by optimization of inserts and addition of MnX or MnS

A comparison of gains in tool life (number of passes) and productivity (feed rate) shows the influence of additive, figure 7. With addition of MnS the gain in tool life and productivity is remarkable, three times as high. Even the addition of MnX is beneficial with respect to productivity. Insert geometry and feed rate will by natural causes influence the surface roughness of the machined part. With the wiper geometry a lasting surface quality will be obtained on parts made of Astaloy CrM® + 0.5% MnS, even with feed 0.3 mm/r, Fig. 8.

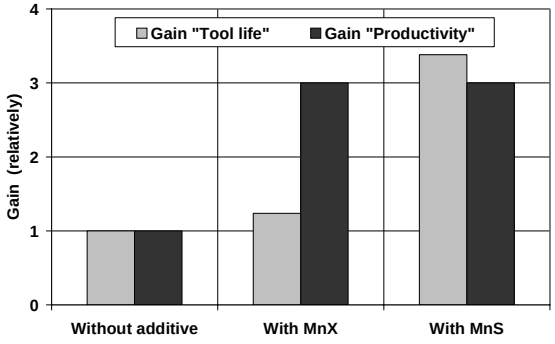


Figure 7: Comparison of tool life and productivity. Vc = 250 m/min, ap = 0.5 mm, with cutting fluid.

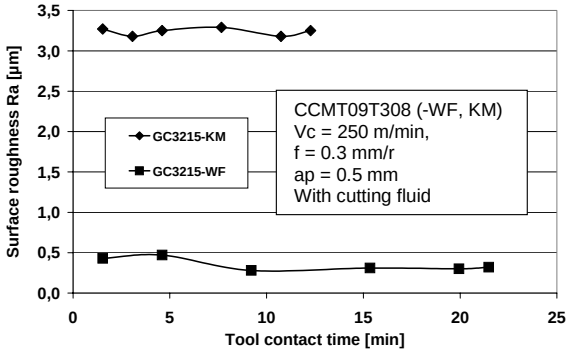


Figure 8: Surface roughness vs. cutting time. Astaloy™ CrM + 0.5% MnS

Sinterhardened, martensitic microsture

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 9. 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.

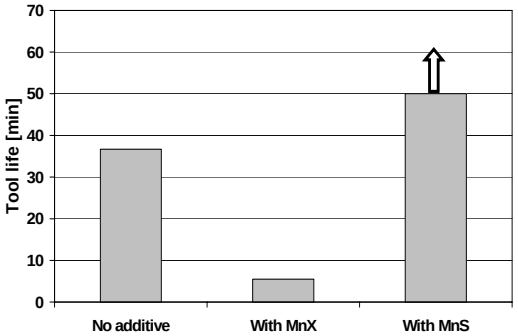


Figure 9: Tool life when turning Astaloy® CrM CNGA120408, CB7050, Vc=150 m/min, f=0.20 mm/r, ap=0.15 mm, dry condition, Crit. Vb=0.15 mm.

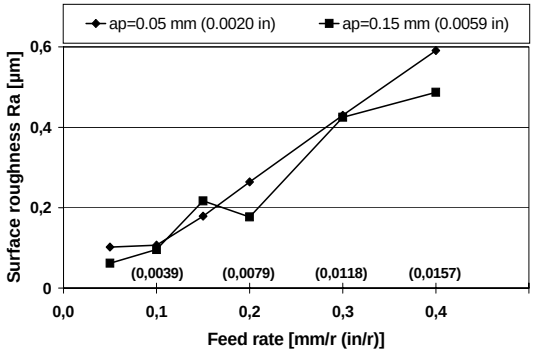


Figure 10: Surface roughness at different cutting depths vs. feed rate. CNGA120408 T01020 AWG,CB7050, Vc=150 m/min, dry condition.

Turning tests – Surface roughness
By using a cBN insert with Wiper technology, the CB7050 with geometry 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, shown in Figure 10.

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

CONCLUSION

As sintered - Bainitic microstructure

- The dominating wear mechanism without additives is adhesion in terms of BUE and pressure-welded material on clearance flank.
- The adhesion wear is reduced by using as sharp cutting edges as possible, increasing the cutting speed and the use of cutting fluid.
- Best machining performance is achieved by using cermet grade CT5015.
- It is not possible to use high feed rates and productive wiper inserts. A higher load will increase the adhesion wear.
- The machining exhibits a completely different behaviour compared to the non additive variant. BUE and smearing tendencies are in principle eliminated.
- Best machining performance is achieved with hard metal grade GC3215.
- Three times higher productivity and tool life is achieved by MnS compared with variant without additive.

Sinterhardened – Martensitic microstructure

- The dominating wear mechanism is flank wear.
- Though cubic nitride insert is to be selected
- Turning is to be done under dry condition
- MnS addition increases the tool life remarkably.
- CBN isert Wiper technology shows how a high surface quality can be obtained independent from cutting depths up to 0.15 mm, i.e. a higher productivity is possible without loss of quality.

References:

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