MEANS TO IMPROVE MACHINABILITY OF SINTERED PM STEELS

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ABSTRACT

Powder metallurgy (PM) is a method known for producing components of great complexity i.e. to near net shape and to very close tolerances. Nevertheless, some components require at least some type of machining operation to fully obtain the definitive shape and geometry, e.g. holes perpendicular to powder pressing direction, bevels, slots and threads. Machining operations are also used to fulfil the demands of higher surface quality and to further improve tolerances.

Once the decision to carry out a machining operation of a PM steel component has been made the need to understand the characteristic of machinability will be inevitable. However, machinability of PM steel will not be influenced by the material properties alone but by all parameters concerning the machining operation, i.e. tool grade and geometry, cutting speed and machine stability.

This paper describes how machinability for some sintered PM steels can be improved by optimizing different parameters, e.g. tool material, additives and cutting fluid.

INTRODUCTION

PM is a well established method for producing large series of complex parts to very close tolerances. However, today many PM components require some type of machining operation to reach final shape, e.g. shapes impossible to create with the compaction exclusively or due to demands for even higher 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 if also necessary, additives, it is in many cases possible to reach a productivity level as high as for standard steels.

In this study a drilling operation was performed on four different types of PM materials, where two were as-sintered and two were sinter hardened and tempered. The influence of tool grades, additives and cutting conditions when machining these types of PM materials is presented.

EXPERIMENTAL

PM materials

Four base powders [Table 1] were used for the powder mixes [Table 2] in this study of how different microstructures affect machinability together with enhancers (so-called additives) and tool grades. In the tests two different additives were used; manganese sulphide (MnS-E) as reference and an alternative test additive (T1) with the intention to increase machinability.

Table 1. PM base powders

Base powder	Composition
AHC100.29	Water atomized plain iron powder
D.AE	Diffusion alloyed iron powder with 1.5%Cu, 4%Ni and 0.5%Mo
Astaloy® CrM	Water atomized iron powder pre alloyed with 3%Cr and 0.5%Mo
Astaloy® A	Water atomized iron powder pre alloyed with 1.9%Ni and 0.55%Mo

Table 2. PM materials mixes

MPIF Designation	Powder mix	Abbreviation
FC0208	AHC100.29 + 2%Cu + 0.8%Graphite + 0.6%Lube E	FC
----“----“----	AHC100.29 + 2%Cu + 0.8%Graphite + 0.6%Lube E + 0.3%MnS-E	FC+MnS
----“----“----	AHC100.29 + 2%Cu + 0.8%Graphite + 0.6%Lube E + 0.3%T1	FC+T1
FD0405	D.AE + 0.5%Graphite + 0.6%Lube E	FD
----“----“----	D.AE + 0.5%Graphite + 0.6%Lube E + 0.3%MnS-E	FD+MnS
----“----“----	D.AE + 0.5%Graphite + 0.6%Lube E + 0.3%T1	FD+T1
FL5305	Astaloy® CrM + 0.55%Graphite + 0.8%Lube E	FL
----“----“----	Astaloy® CrM + 0.55%Graphite + 0.8%Lube E + 0.3%MnS-E	FL+MnS
----“----“----	Astaloy® CrM + 0.55%Graphite + 0.8%Lube E + 0.3%T1	FL+T1
FLC4608	Astaloy® A + 2%Cu + 0.8%Graphite + 0.8%Lube E	FLC
----“----“----	Astaloy® A + 2%Cu + 0.8%Graphite + 0.8%Lube E + 0.3%MnS-E	FLC+MnS
----“----“----	Astaloy® A + 2%Cu + 0.8%Graphite + 0.8%Lube E + 0.3%T1	FLC+T1

Powder mixes were compacted into drilling test specimens with geometry Ø80 x 12 mm, and tensile test bars to evaluate mechanical properties. Specimens made of powder mixes with AHC100.29 or D.AE were compacted to a green density of 7.1 g/cm³ while specimens of Astaloy® CrM or Astaloy® A were compacted to 7.0 g/cm³.

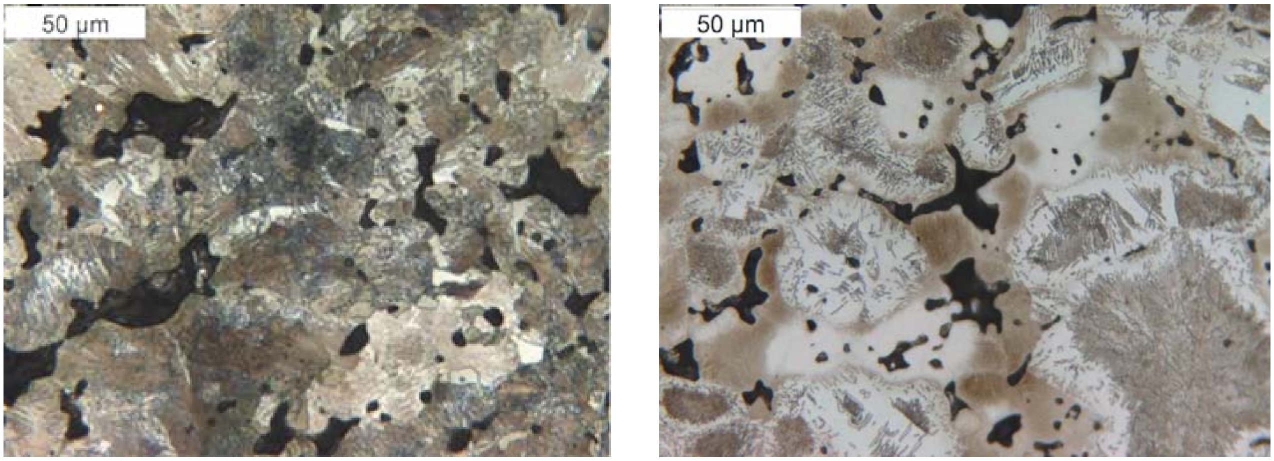
Sintering and sinter hardening, as shown in Table 3, were carried out in a conveyor belt sintering furnace, Cremer 25-115/E, at Höganäs AB.

Table 3. Sintering or sinter hardening

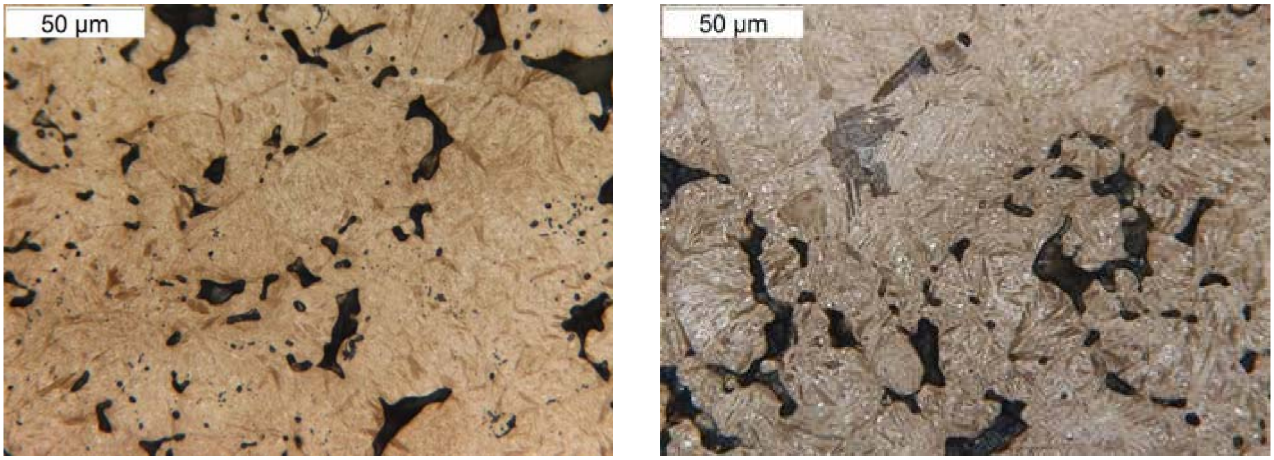
Specimen material	Type of sintering
All “FC“ material	Sintering at 1120ºC (2048ºF) for 30 minutes in atmosphere 90% N_2 and 10% H_2
All “FD” material	Sintering at 1120ºC (2048ºF) for 30 minutes in atmosphere 90% N_2 and 10% H_2
All “FL” material	Sinter hardening at 1120ºC (2048ºF) for 30 minutes in atmosphere 90% N_2 and 10% H_2
All “FLC” material	Sinter hardening at 1120ºC (2048ºF) for 30 minutes in atmosphere 90% N_2 and 10% H_2

Directly after sinter hardening all specimens were tempered at 200ºC (392ºF) in air for 60 minutes.

The micro structures of as-sintered / sinter hardened PM materials are shown in Figure 1. The sintered material “FC” consists of an almost fully pearlitic micro structure. The sintered “FD” consists of a heterogenous micro structure with ferrite, pearlite, bainite, nickel rich austenite and martensite all represented. The sinter hardened “FL” is fully martensitic while the sinter hardened “FLC” is almost martensitic with a very small amount (<1%) of low temperature bainite.



FC: AHC100.29 + 2%Cu + 0.8%C *FD: D.AE + 0.5%C*



FL: Astaloy® CrM + 0.55%C *FLC: Astaloy® A + 2%Cu + 0.8%C*

Figure 1: Microstructures of as-sintered & sinter hardened PM steels

The influence of the additives on the mechanical properties is shown in Table 4.

Table 4: Mechanical properties of sintered or sinter hardened & tempered tensile test bars

PM material	DC	HV10	TS	YS	A
FC	0.09	198	639 (92680)	487 (70633)	1.8
FC+MnS	0.14	190	629 (91229)	488 (70778)	1.8
FC+T1	0.20	186	580 (84122)	453 (65702)	1.7
FD	-0.17	227	834 (120961)	461 (66862)	2.2
FD+MnS	-0.15	241	814 (118061)	458 (66427)	2.0
FD+T1	-0.14	237	781 (113274)	450 (65267)	2.2
FL	-0.12	391	901 (130680)	NA	0.12
FL+MnS	-0.09	405	893 (129520)	NA	0.11
FL+T1	-0.12	382	845 (122560)	NA	0.18
FLC	0.17	399	867 (125750)	802 (116320)	0.32
FLC+MnS	0.22	388	830 (120380)	815 (118210)	0.24
FLC+T1	0.32	379	812 (117770)	795 (115310)	0.27

DC: Dimensional change from as-green to as-sintered or sinter hardened & tempered [%]
HV10: Hardness
TS: Tensile strength [MPa (PSI)]
YS: Yield strength with 0.2% remaining deformation [MPa (PSI)]
A: Elongation [%]

Machinability test setup

A CNC lathe (Mazak Quick Turn Nexus 200-II MY) was used to carry out drilling tests. The lathe was equipped with a holder for rotary tools, e.g. drills and end mills. With the use of rotary tools the main spindle, i.e. chuck, acts as a circular indexing table holding the Ø80 mm specimen, seen in Figure 2.

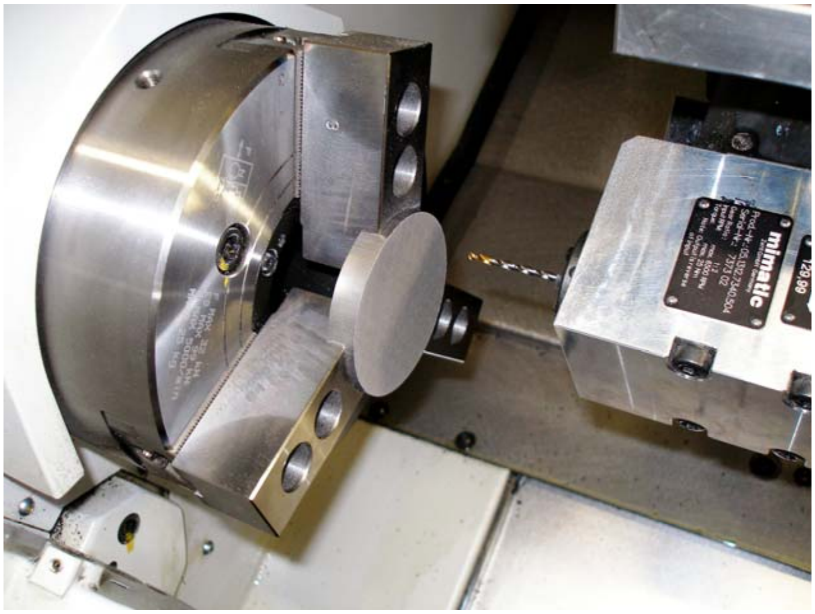


Fig. 2: Drilling operation in Mazak with Ø80 x 12 mm PM specimens

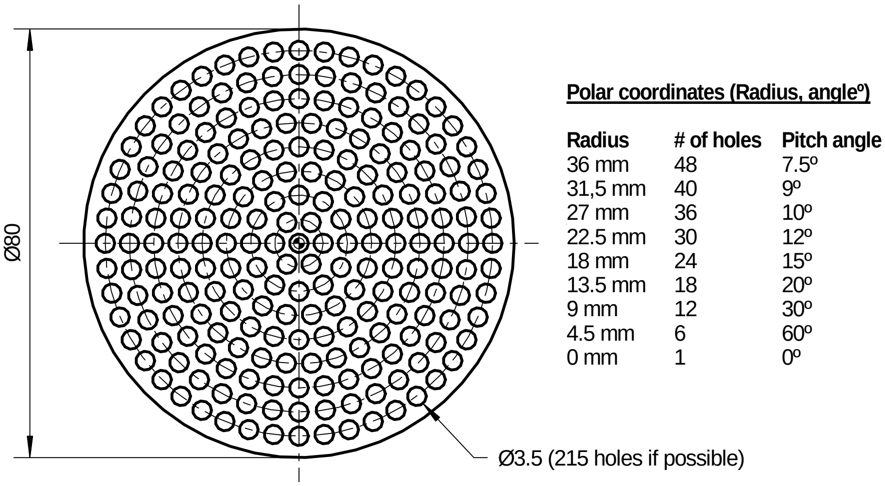
Three different types of drills, all from the same manufacturer, were chosen for the investigation and are seen in Figure 3.

Figure 3: Type of drills used in investigation

- Dormer A001 Ø3.5 jobber, high speed steel drill, un-coated but steam treated
- Dormer A002 Ø3.5 jobber, high speed steel drill, polished and partly PVD-coated with TiN
- Dormer R002 Ø3.5 jobber, solid carbide drill, partly PVD-coated with TiN

The Dormer drills A001 and A002 are made of the same high speed steel grade and manufactured with the same geometry. Drill A001 is however no longer available from Dormer Tools and has been replaced by drill A002. The solid carbide drill Dormer R002 has a different edge line geometry compared with A001 and A002, but all drills have a 118º point angle.

The drilling machinability criterion was to drill as many holes as possible before total drill failure. Total drill failure is to a complete breakage or to extreme heat release i.e. when drill starts to glow. With the test Ø80 specimen and CNC program it was possible to drill 215 holes with Ø3.5 drill. If no failure occurred the drilling program was restarted with a new Ø80 specimen. The design of drill pattern is shown in Figure 4.



Polar coordinates (Radius, angleº)

Radius	# of holes	Pitch angle
36 mm	48	7.5º
31,5 mm	40	9º
27 mm	36	10º
22.5 mm	30	12º
18 mm	24	15º
13.5 mm	18	20º
9 mm	12	30º
4.5 mm	6	60º
0 mm	1	0º

Figure. 4: Drilling pattern with theoretical 215 drilled holes

All drilling tests were carried out in dry condition. Some PM specimens from the group without additive, i.e. FC1, D1, C1 and A1 were oil impregnated before the drilling tests. The specimens were placed in a container and covered by oil, with designation X-426 from company Q8. The container was then placed in a vacuum chamber made of glass. After sealing, the air was evacuated leaving an absolute pressure of 200 mbar in the chamber and air bubbles were starting to appear on the surface of the specimens. When air bubbles were no longer generated a valve was opened to the vacuum chamber to balance the pressure.

The cutting data used in all drilling tests are shown in Table 5.

Table 5. Cutting data

PM material	Drill	Vc	f	ap
FC0208	A001 and A002	40 (130)	0.06 (0.0024)	9.6 (0.378)
FD0405	A001 and A002	30 (98)	0.06 (0.0024)	9.6 (0.378)
FL5305	R002	40 (130)	0.06 (0.0024)	9.6 (0.378)
FLC4608	R002	40 (130)	0.06 (0.0024)	9.6 (0.378)

Vc: Cutting speed [m/min (feet/min)]
f: Feed rate [mm/rev (in/rev)]
ap: Cutting depth [mm (in)] of blind holes

RESULTS

Drilling machinability of FC0208 (AHC100.29 + 2%Cu + 0.8%C) was influenced by type of drill, oil impregnation and by additives, shown in Figure 5.
The Dormer drill A002 (HSS and PVD coated with TiN) improved drilling machinability more than seven times compared with drill A001 in test with FC0208 ("FC"). With oil impregnation and the use of drill A001 the improvement was also seven times. The most exceptional improvement was found with FC0208+0.3%MnS ("FC+MnS") and drill A001. With this combination the improvement was 40 times compared with FC0208 ("FC"). The drilling machinability was however much lower with drill A002 compared with drill A001 in the same material, i.e. "FC+MnS".

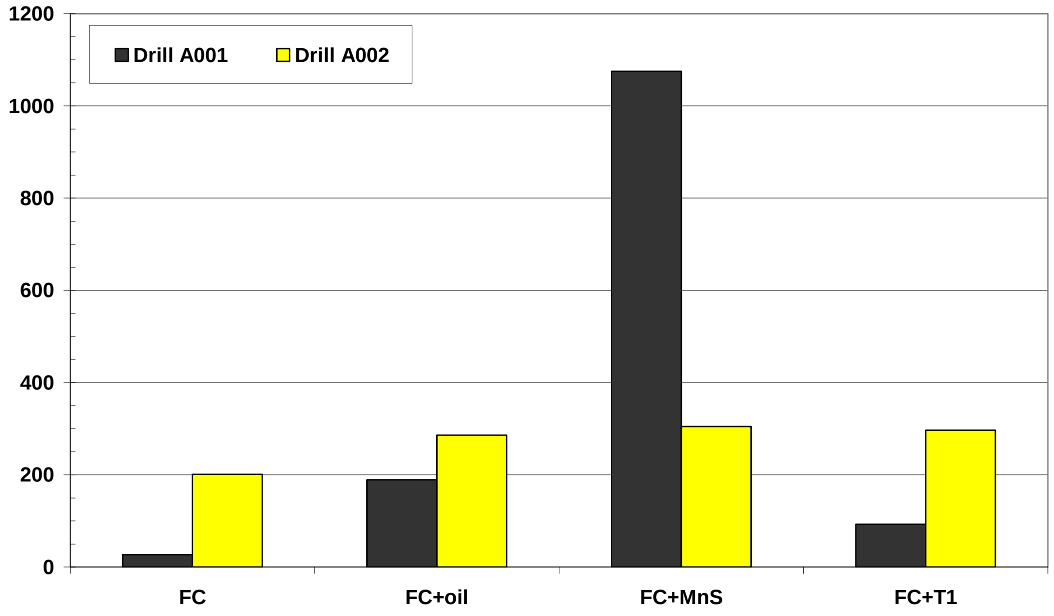


Figure. 5: Drilling machinability of FC0208 (AHC100.29 + 2%Cu + 0.8%C)

Drilling machinability of FD0405 (D.AE + 0.5%C) was influenced by type of drill, oil impregnation and by additives, as shown in Figure 6.
Dormer drill A002 strongly improved drilling machinability in all tests compared with drill A001. FD0405 without additive or oil impregnation, FD in Figure 6, was improved more than six times when drill A002 was used. Best machinability improvements were found with test additive T1 ("FD+T1") together with drill A002, almost five times compared with FD.

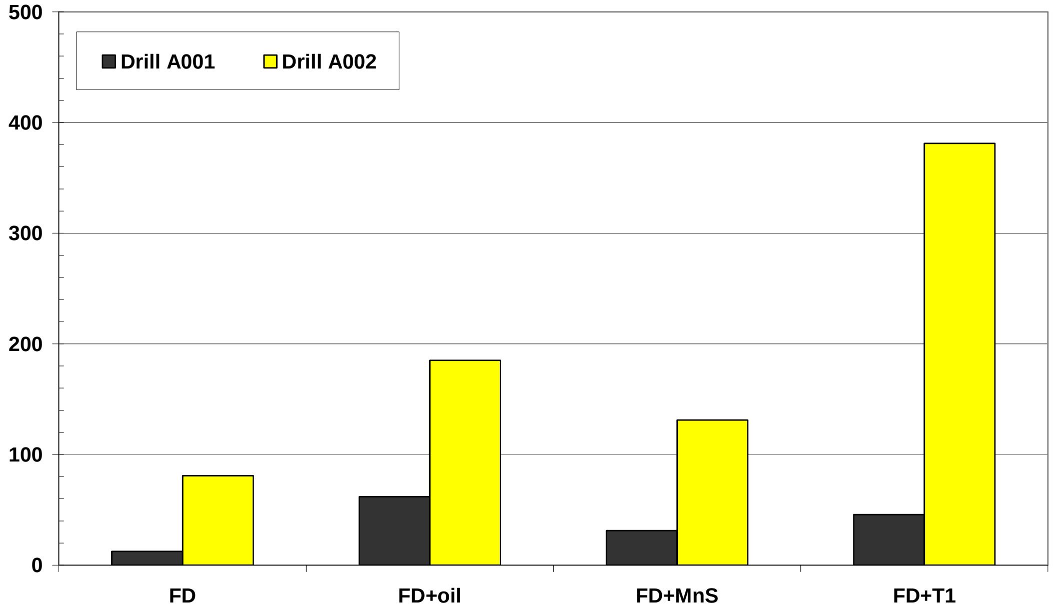


Figure. 6: Drilling machinability of FD0405 (D.AE + 0.5%C)

Drilling machinability of sinter hardened FL5305 (Astaloy® CrM + 0.55%C) and FLC4608 (Astaloy® A + 2%Cu + 0.8%C) was influenced by oil impregnation and by additives, as shown in Figure 7. Drilling machinability of FL5305 was especially improved by test additive T1, more than 12 times gain, but also significantly improved by MnS or oil impregnation. The additive influence on FLC4608 was not as strong compared with FL5305. Oil impregnation improved machinability significantly for both sinter hardened PM steels.

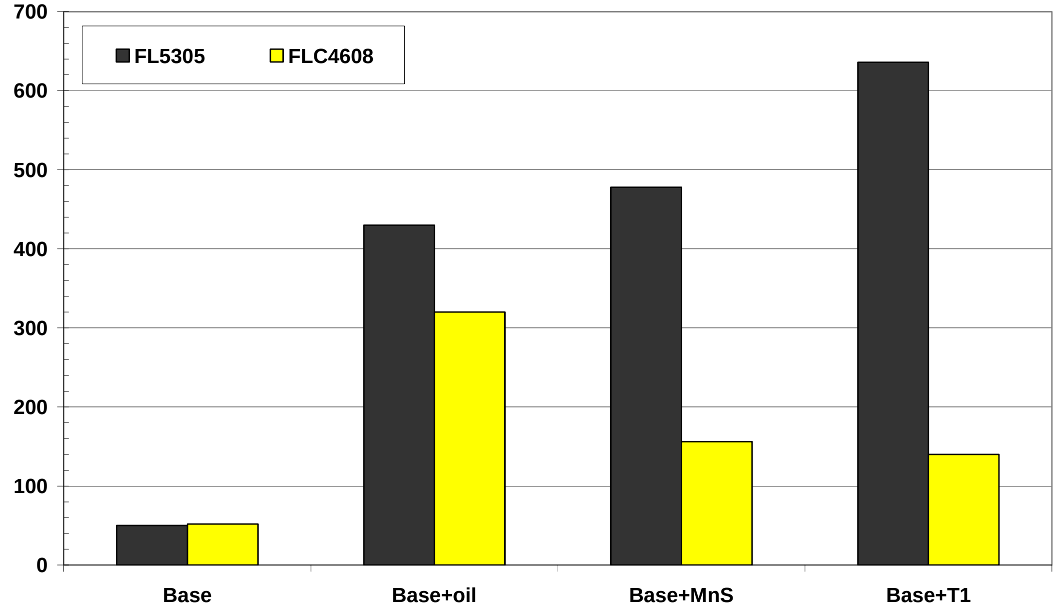


Figure. 7: Drilling machinability of sinter hardened PM material ("Base") with drill R002 FL5305 (Astaloy® CrM + 0.55%C) and FLC4608 (Astaloy® A + 2%Cu + 0.8%C)

CONCLUSIONS AND DISCUSSION

The drilling machinability of sintered PM steel FC0208 is in general terms improved by the PVD TiN coated drill A002 compared with the un-coated drill A001. The exception to this is when the un-coated drill A001 was used where an outstanding machinability was found with FC0208+0.3%MnS. This improvement with additive MnS and drill A001 has to be considered as an extraordinary interaction between tool and work piece materials.

The PVD TiN coated drill A002 improved in every test when FD0405 (D.AE + 0.5%C) was machined. Gains were found with oil impregnation and addition of MnS but the largest improvement was clearly found by the combination of drill A002 and the test additive T1. This improvement was primarily the result of a favourable interaction between tool and work piece materials.

Sinter hardened FL5305 (Astaloy® CrM + 0.55%C) was highly improved by oil impregnation and the additive MnS but especially with test additive T1. The drilling machinability of sinter hardened FLC4608 (Astaloy® A + 2%Cu + 0.8%C) was however not gained in the same way by additives or oil impregnation, maybe due to difference in microstructure compared with FL5305. The FLC4608 contained a small amount (less than 1%) of low temperature bainite and therefore not a fully 100% martensitic structure. Another reason why drilling machinability was different between FL5305 and FLC4608 could be the alloying element copper in FL4608 (2% added) which possibly had a negative effect on the solid carbide drill, i.e. a detrimental interaction

All tests were carried out dry, i.e. without any cutting fluid. A standard cutting fluid, e.g. emulsion with 95% water, would undoubtedly increase drilling machinability, both by improving the cutting mechanism and controlling cutting temperature. Especially drilling in sinter hardened PM material with solid carbide drills, e.g. like the Dormer R002, would extend the tool life by keeping the drill and work piece at low temperature. The oil impregnated specimens in this study improved the machinability in a similar way but not to the same extent.