Improved Machinability by Selection of PM Materials, Additives and Tool Materials

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ABSTRACT

The strength of the PM manufacturing technology is the ability to manufacture net-shape or near net-shape components. Nevertheless there is a large share of PM components machined to improve tolerances or to make additional geometrical features which are not possible to press. The efficiency of the machining operations is of great importance to be cost competitive. A number of factors influence the efficiency of the machining operation. In this paper data for three alloying systems, Fe-Cu-C, Distaloy AE and Astaloy CrM are presented. The influence of machine enhancing additives and tool materials were investigated and based on the results guidelines for selection of additives and tool materials are outlined.

INTRODUCTION

The word “machinability” is generally expressed as the necessary effort to machine a material by a chip removing operation, e.g. turning, drilling or milling, to predefined goals in terms of quality, machining time and tool life within a settled manufacturing cost.
The machinability of PM is often considered to be hard and unsatisfactory. This consideration originates undoubtedly when high performance PM materials, e.g. sinter hardened or highly alloyed with heterogeneous structures, are subject to be machined. There are however several ways to improve machinability by careful selections of cutting parameters like tool grades, cutting speeds, feed rates and the use of cuttings fluids. A more elementary and fundamental parameter is the choice of PM material in terms of grade (alloy system) and condition (heat treatment). Two different PM grades with same material macro hardness do not necessarily mean same machinability, e.g. when a comparison between a homogenous and a heterogeneous microstructure is made.
A feature of PM materials is the freedom to add powder components and the amount of the addition. Besides powder components necessary for compaction and to establish desired mechanical properties of the sintered part it is also possible to make an addition of other powder components to improve machinability, so called machinability enhancers or merely machinability “additives”.

EXPERIMENTAL

PM materials

Three base powders, shown in Table 1, were used for the powder mixes, shown in Table 2, to determine how different microstructures affect drilling machinability together with enhancers, so-called additives. In the tests two different additives were used; manganese sulphide (MnS-E) and a new additive under development (T1). The performance of “T1” additive has reported in [1][2]. In the trials in these references a higher added amount of T1 was added. The particle size of the additive T1 used in this investigation has been optimized and differs from the previous trials.

Table 1: PM base powders

Base powder	Composition
AHC100.29	Water atomized pure iron powder
Distaloy AE	Iron powder, diffusion alloyed 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

Table 2: Mix compositions

Powder mix	Abbreviation
AHC100.29 + 2% Cu + 0.8% Graphite + 0.6% Lube E	AHC
AHC100.29 + 2% Cu + 0.8% Graphite + 0.6% Lube E + 0.3% MnS-E	AHC+MnS
AHC100.29 + 2% Cu + 0.8% Graphite + 0.6% Lube E + 0.15% T1	AHC+T1
Distaloy AE + 0.5% Graphite + 0.6% Lube E	DAE
Distaloy AE + 0.5% Graphite + 0.6% Lube E + 0.3% MnS-E	DAE+MnS
Distaloy AE + 0.5% Graphite + 0.6% Lube E + 0.15% T1	DAE+T1
Astaloy® CrM + 0.55% Graphite + 0.8% Lube E	CRM
Astaloy® CrM + 0.55% Graphite + 0.8% Lube E + 0.3% MnS-E	CRM+MnS
Astaloy® CrM + 0.55% Graphite + 0.8% Lube E + 0.15% T1	CRM+T1

Compaction of test specimens

Powder mixes were compacted into drilling test specimens Ø100/Ø42 x 28 mm, TS-bars (ISO 2740) to evaluate mechanical properties and IE-bars (ISO 5754) to evaluate impact energy. All specimens made were compacted to a green density of 7.0 g/cm³.

Sintering and sinter hardening

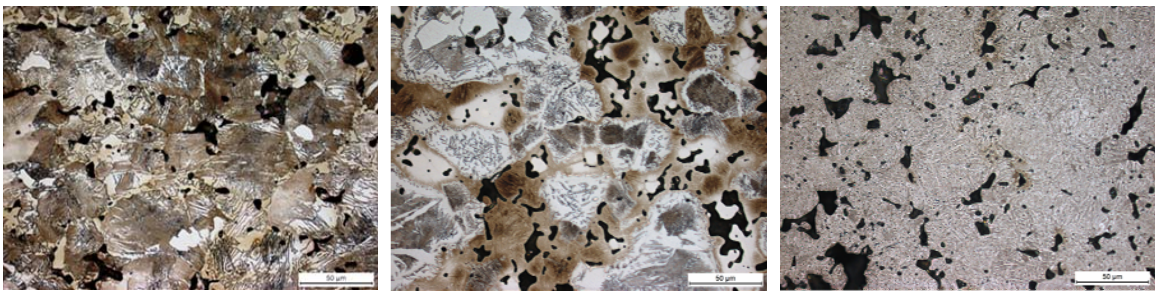
Sintering and sinter hardening, as shown in Table 3, were carried out in a conveyor belt sintering furnace, Cremer 25-115/E, at Höganäs AB. All green specimens based on AHC100.29 and Distaloy AE were sintered for 30 minutes at 1120ºC in 90/10 (N_2/H_2) atmosphere without hydrocarbon addition.
The Astaloy CrM specimens were sinter hardened for 30 minutes at 1120ºC in 90/10 (N_2/H_2) atmosphere without hydrocarbon addition. The cooling rate of sinter hardening was 1.5ºC/second. Directly after the sinter hardening all specimens were tempered at 200ºC in air for 60 minutes in air.

Table 3: Sintering or sinter hardening

Specimen	Type of sintering
All “AHC“ material	Sintering at 1120ºC for 30 minutes in atmosphere 90% N_2 and 10% H_2
All “DAE” material	Sintering at 1120ºC for 30 minutes in atmosphere 90% N_2 and 10% H_2
All “CRM” material	Sinter hardening at 1120ºC for 30 minutes in atmosphere 90% N_2 and 10% H_2

Microstructures

The micro structures of as-sintered and sinter hardened PM materials are shown in Figure 1. The sintered material “AHC” consists of an almost fully pearlitic micro structure. The sintered “DAE” consists of a heterogeneous micro structure with ferrite, pearlite, bainite, nickel rich austenite and martensite all represented. The sinter hardened “CRM” is fully martensitic.



AHC100.29 + 2%Cu + 0.8%C *Distaloy AE + 0.5%C* *Astaloy® CrM + 0.55%C*

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

Mechanical properties

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

Material	DC	HRB	HRC	TS	YS	A	IE
AHC	0.23	83	-	611	476	1.7	14.1
AHC+MnS	0.30	82	-	575	455	1.5	11.9
AHC+T1	0.32	82	-	579	451	1.8	13.0
DAE	-0.20	92	-	788	434	2.2	27.7
DAE+MnS	-0.17	91	-	756	428	2.2	24.8
DAE+T1	-0.14	92	-	729	417	2.2	25.6
CRM	-0.11	-	35	1076	994	0.3	16.9
CRM+MnS	-0.14	-	35	1005	945	0.3	16.4
CRM+T1	-0.12	-	34	933	894	0.3	12.3

DC: Dimensional change from as-green to as-sintered or sinter hardened & tempered [%]
HRB: Hardness according to Rockwell B
HRC: Hardness according to Rockwell C
TS: Tensile strength [MPa]
YS: Yield strength with 0.2% remaining deformation [MPa]
A: Elongation [%]
IE: Impact energy [J]

Drilling machinability test - method and setup

The drilling machinability tests were performed in a CNC lathe (Mazak Quick Turn Nexus 200II-MY) which was equipped with rotary tool holders for e.g. drills and mills. Depending on PM material hardness the drilling operation was carried out either with HSS ("High Speed Steel") or solid carbide drills, seen in Table 5.

Table 5: Type of drill

Drill	Used in PM material
Dormer A002 Ø3.5, PVD TiN HSS 	In as-sintered "AHC" and "DAE"
Dormer R002 Ø3.5, PVD TiN solid carbide 	In sinter hardened "CRM"

The drilling machinability criterion was to drill as many holes as possible before total drill failure. Total drill failure was to a complete breakage or to extreme heat release i.e. when drill started to glow. For each material and cutting speed eight drills were used to establish an average value. All drilling tests were carried out in dry condition, i.e. without cutting fluid. The cutting data used in all drilling tests are shown in Table 6.

Table 6: Cutting data

PM material	Drill	Vc	f	ap
"AHC"	Dormer A002	60 and 80	0.06	9.6
"DAE"	Dormer A002	40 and 60	0.06	9.6
"CRM"	Dormer R002	60	0.06	9.6

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

RESULTS

The drilling machinability of as-sintered AHC100.29 + 2% Cu + 0.8% C ("AHC") was strongly improved with 0.3% MnS ("AHC+MnS") and with 0.15% T1 ("AHC+T1"), see Figure 2. Increased cutting speed, i.e. from 60 to 80 m/min, decreased the tool life as expected.

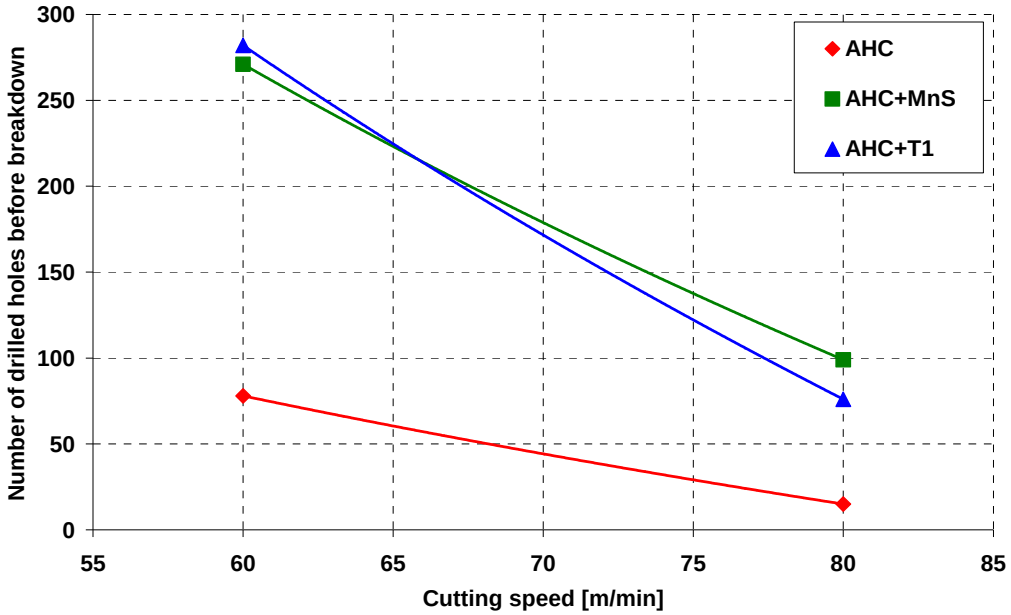


Figure 2: Drilling machinability of as-sintered AHC100.29 + 2%Cu + 0.8%C, with or without additive

The drilling machinability of as-sintered Distaloy AE + 0.5% C ("DAE") was not as good compared with AHC100.29 + 2% Cu + 0.8% C, yet strongly improved with 0.3% MnS ("DAE+MnS") and even more with 0.15%T1 ("DAE+T1"), see Figure 3. The performance of T1 was similar to MnS at the lower cutting speed but was superior at the higher cutting speed.

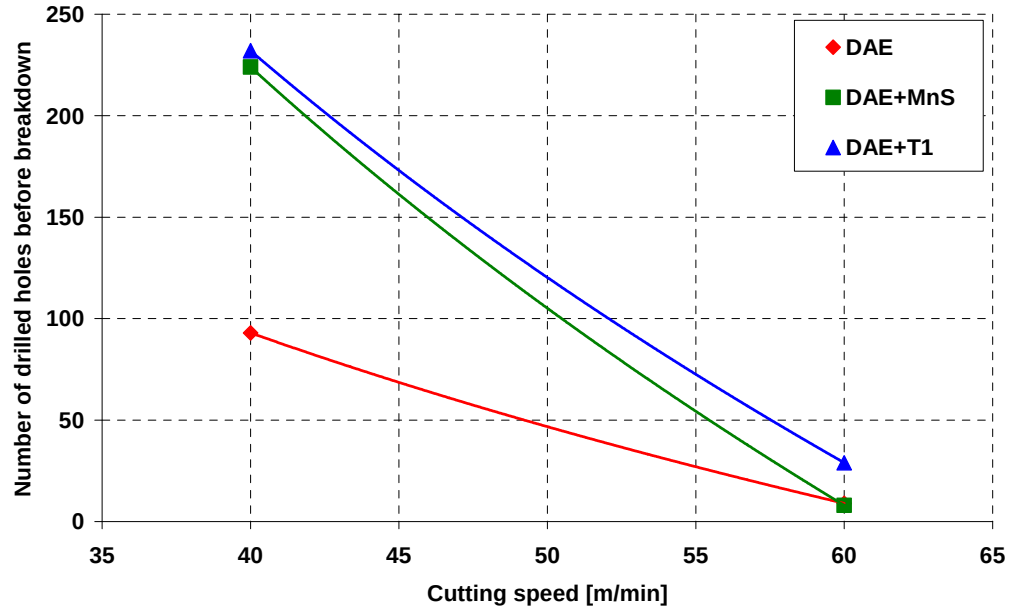


Figure 3: Drilling machinability of as-sintered Distaloy AE + 0.5%C, with or without additive

The sinter hardened Astaloy® CrM + 0.55%C ("CRM") was, due to very high hardness, impossible to drill with high speed steel drill (e.g. the Dormer A002) and solid carbide drills were instead used. With the chosen solid carbide drill the drilling machinability was improved with MnS ("CRM+MnS") but also with T1 ("CRM+T1"), shown in Figure 4.

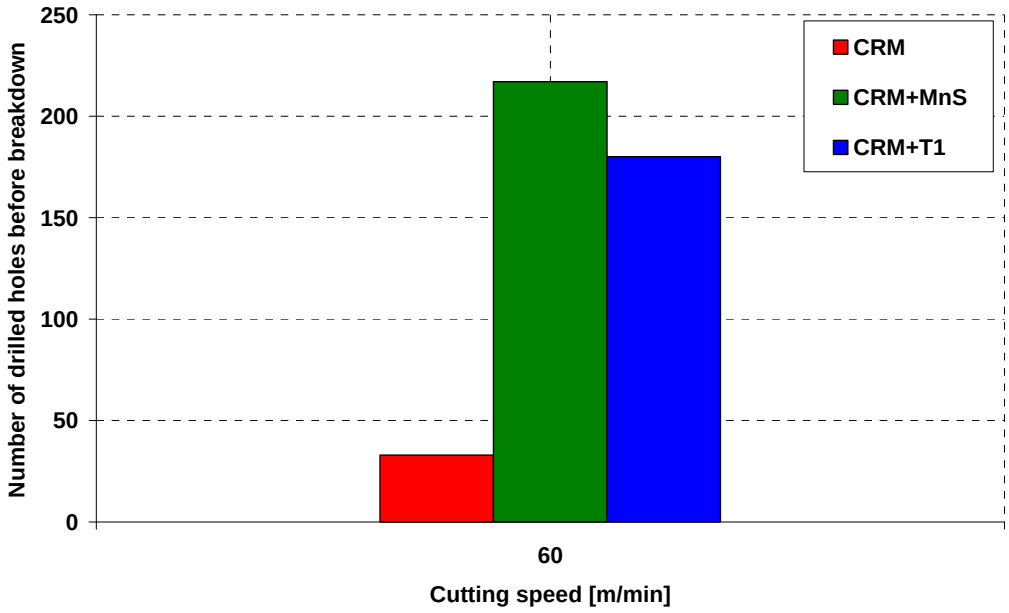


Figure 4: Drilling machinability of sinter hardened Astaloy® CrM, with or without additive

DISCUSSION AND CONCLUSIONS

MnS is an additive established since many years but it is still a very versatile machinability enhancer and it improves drilling machinability for an extensive field of PM materials, e.g. together with sintered PM steels with low hardness structures to extremely difficult sinter hardened ones. New and very efficient additives have been developed, where the addition can be reduced compared with the traditional amount of MnS (normally 0.3 – 0.5 wt%) without loosing the machinability improving effects. Since particle size distribution for MnS and the test additive T1 is comparable but the specific weight of T1 is only 50 - 60% of MnS, it is possible to obtain the same amount of machinability improving particles with less mass of T1.

In as-sintered PM materials (AHC100.29+2% Cu+0.8% C and Distaloy AE+0.5% C) and in sinter hardened PM material (Astaloy® CrM+0.55% C) an addition of 0.15wt% of the T1 additive is comparable with an addition of 0.3wt% of MnS in order to improve drilling machinability.

REFERENCES

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2. O. Andersson and M. Larsson. *Means to Improve Machinability of Sintered Steels*. Conference Paper, Euro PM2009 Congress, Copenhagen, Denmark, 12 – 14 October 2009