Machinability response of PM steels with varying levels of alloy content

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ABSTRACT

Production of powder metallurgy (PM) components often includes post-sintering secondary operations. All of these operations add cost and as such the efficiency of these operations are important cost considerations. One of the most commonly employed secondary operations is machining; which is utilized to produce features unable to be pressed, and high tolerances on dimensions. To improve the machining response and lower overall costs, machining additives are often incorporated into the powder premix. The most successful and widely used additive, manganese sulfide (MnS), has greatly improved tool life in many applications. Another machining additive (AncorCut) has been recently introduced to compliment MnS in powder metallurgy PM steels. This new additive is also effective in reducing tool wear and has the added benefits of being chemically inert under production processing conditions, thereby not accelerating part rusting and increasing the stability of the machining response. In this paper, a variety of PM alloys was evaluated in turning and drilling, with both lab and industrial scale trials conducted. Tool wear measurements were made throughout the machining process, and the physical properties were tested for each machining additive condition.

INTRODUCTION

Metal machining is performed by the removal of a thin layer utilizing a wedge-shaped tool, as is found in drilling, milling and turning, all resulting in the formation of chips. Repeated passes (or rotations in drilling) are often used to obtain the final dimensions while avoiding damage to the final component. Interaction of the Method (process design), Machine (cutting conditions) and the Material (alloy, microstructure, porosity, and machining additive) dictate the machining performance. Different cutting conditions are present in drilling, turning, reaming, grooving, etc. and all resulting in potentially different machinability responses. Therefore multiple machining operations should be tested to evaluate machinability of alloys, additives or microstructure as these changes may alter the machinability rankings.

A wide variety of alloys and properties are also possible with ferrous powder metallurgy. Components are produced daily that range from ferritic microstructures in FY-4500 to martensitic microstructures in FLC-4808. Understanding of microstructure effect on machining is required to maximize part throughput and tool life. Porosity, high carbon content and heterogeneous microstructures are generally understood to have a negative impact on machinability. Increasing martensite content will also reduce tool life in PM steels, Figure 1 [1]. This can be offset to a certain degree by the incorporation of machining additives that assist in chip formation, lubrication of the tool face and reduction of both flank and crater wear [2]. For example, MnS deforms along the shear plane during the cutting process, reduces tool contact time, and forms a lubricating layer on the tool [3]. While manganese sulfide has many beneficial attributes, it has some limitations and potentially negative effects. Warm and humid environments can quickly oxidize the MnS and deteriorate the machinability enhancing properties [4-7]. Alternative additives have been introduced into the marketplace in an attempt to overcome these obstacles. One such additive designated AncorCut has been tested along with MnS and no additive in a variety of PM alloys to understand the effect of microstructure on machinability. Both drilling and turning were used in the evaluation.

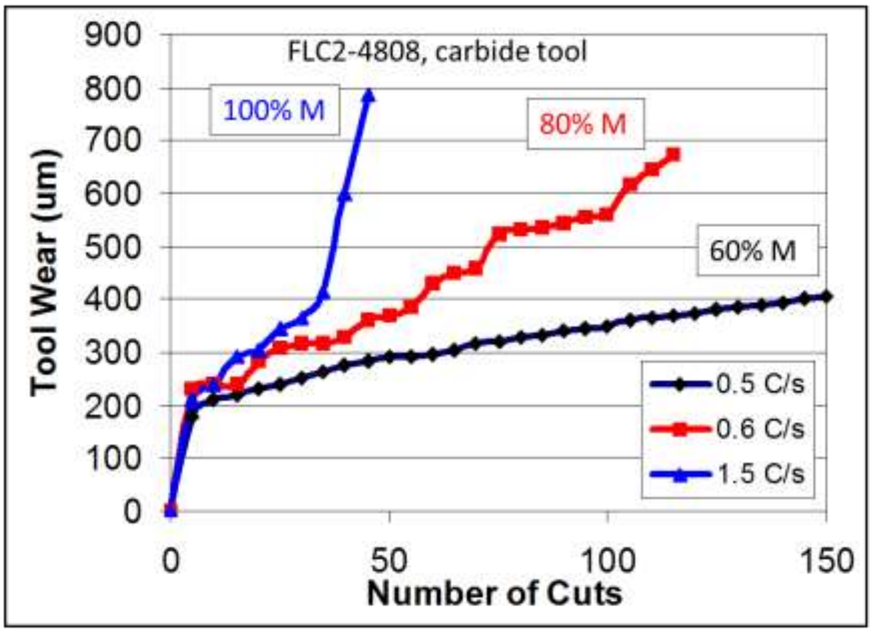


Figure 1. Effect of martensite content in FLC2-4808 on tool wear (replotted from [1])

EXPERIMENTAL PROCEDURE

Several alloy systems, shown below in Table I, were evaluated for machinability. Additionally, these premixes were prepared with no machining additive, with 0.35% MnS and 0.2% AncorCut additive. Standard transverse rupture bars, machining rings and cylinders measuring nominally 45 mm (1.75 inch) outer diameter, 25 mm (1 inch) inner diameter (rings only) and 32 mm (1.25 inch) tall were compacted to 6.9 g/cm^3 density and sintered in an Abbott belt furnace at 1120 °C (2050 °F) in 90% N_2 – 10% H_2 atmosphere. Time in the hot zone was 45 minutes. The sintered density of the compacts was nominally 6.8 g/cm^3. Multiple cooling rates were used to achieve targeted microstructures.

Table I. Alloys studied in the machinability study

Alloy	Mo	Ni	Mn	Cu	Gr
FC-0208	-	-	0.1	2.0	0.9
FD-0405	0.5	4.0	0.1	1.5	0.6
FLC-4208*	0.6	0.5	0.2	2.0	0.9
FLC-4905*	1.5	-	0.1	2.0	0.65
FLC2-4808	1.2	1.4	0.4	2.0	0.9

*Not an officially designated MPIF alloy

Turning studies were run using a 0.25 mm (0.01 inch) depth of cut and 0.25 mm (0.01 inch) feed at different cutting speeds: 150 smm (500 sfm) and 230 smm (750 sfm). Abbreviations smm and sfm are surface meters/min and surface feet/min, respectively. Twenty five cuts were made on each ring so that final diameter of a machined ring was nominally 32 mm (1.25 inch). The target number of rings per test was 60, for a total of 1500 cuts per test in most cases. The turning tests were run using a Haas ST-10 CNC lathe under dry cutting conditions. Tool wear was evaluated by the change in ring diameter over the 60 rings. The diameter of the machined ring was measured after the first and last pass using an automated measurement probe within the lathe. This data was then normalized to zero at the start of the test so that the change in part diameter could be observed. An increase in machined part diameter over several parts is an indicator of tool wear. The tools used in this experiment were:

1. Alumina-TiCN coated carbide insert (Kennametal KCP25) in a CNMG 432 FN geometry
2. Polycrystalline boron nitride (cBN) tipped inserts in a CNGA 432 geometry, with a light hone edge preparation, from Shape-Master Tool.

Drilling studies were run using a carbide drill with pvd diamond coating at 3500 rpm and 508 mm/min feed. Flood coolant (LUBRICUT 4265 diluted with water (5:100 ratio)) was used during the evaluation. The tests were carried out on a HAAS VF-1 vertical milling center at the Hoeganaes Innovation center. A 2 mm (0.078”) tungsten carbide ball stylus 50 mm (2”) long from Renishaw has been employed for measuring machined parts and hole diameter. The machining setup comprises of three samples (pucks) held by an aluminum soft jaws. 33 holes can be drilled per puck; a total of 99 holes drilled per cycle. Infinite life has been set at 990 holes (10 cycles / 30 pucks). Drill bit diameter was selected to be 4.76 mm (0.188”, 3/16’’) and depth of drilling about 25 mm (1”). Screw machine length drill bits have been used to increase the rigidity within the testing process.

RESULTS AND DISCUSSION

The mechanical properties of the alloys studied can be found in Table II. Alloying method and amount drive up the apparent hardness, strength and % martensite in the samples. The alloys chosen represent a wide range of microstructures, from pearlitic (FC-0208) to heterogeneous microstructure containing ferrite, pearlite, bainite, martensite and Ni-rich austenite (FD-0405), to bainitic/martensitic (FLC-4208 and FLC-4905) to fully martensitic (FLC2-4808). This range in microstructure and properties was expected to produce different machining responses.

Table II. Sintered properties

Alloy	Sinter Density, g/cm^3	0.2% YS, MPa (psi x 10^3)	UTS, MPa (psi x 10^3)	Total Elong. %	Hardness, HRA	Martensite Content %
FC-0208	6.79	396 (57)	520 (75)	1.2	47	0
FD-0405	6.88	375 (54)	622 (90)	2.0	55	39
FLC-4208	6.82	614 (89)	669 (97)	0.9	64	73
FLC-4905	6.78	590 (86)	670 (97)	0.8	65	65
FLC2-4808	6.83	625 (91)	827 (120)	1.3	69	100*

* some retained austenite present

The machinability of PM steels is often quite poor when no machining enhancers are used and from a cost / efficiency stand point, an unacceptable option. Figure 2 shows the part diameter change, or tool wear, as alloy content increases. With the carbide insert, rapid wear is observed once the alloy content increases beyond a simple Fe-Cu-C alloy. Both the diffusion alloy and the Ni-Mo prealloy resulted in poor life. cBN inserts are a bit more robust, and significant improvement was found for both the FC-0208 and the

FLC-4208 alloys. Inserts for both alloys survived the 1500 cuts. Sinter-hardening grades FLC-4905 and FLC2-4808, however, cause insert failure after a relatively low number of cuts. Part producer often struggle with machining these hardened steels. It is observed that the decrease in tool life generally follows the amount of martensite and alloy content in these steels.

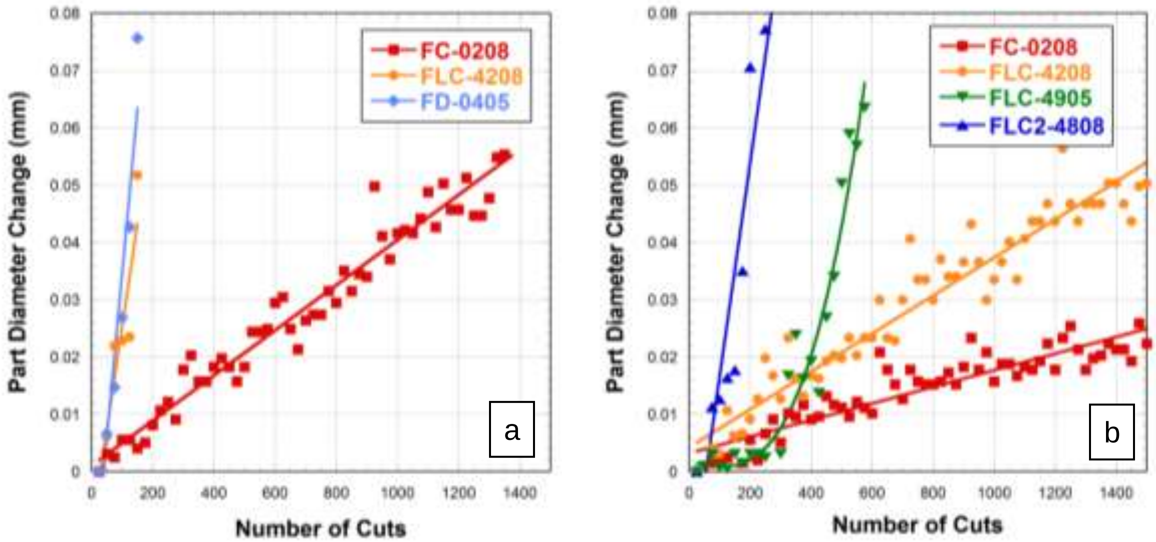


Figure 2. Machinability of different alloys containing no machining additive with (a) a coated carbide insert and (b) a cBN insert

A dramatic improvement in machining performance is found with the addition of machinability enhancers, Figure 3. With the coated carbide insert, the FC-0208 and FD-0405 alloys ran for the full 1500 cuts with both MnS and AncorCut additions. The partial sinter-hardening grade FLC-4208 did not make 1500 cuts, but tool life more than tripled with 0.2% AncorCut addition. The combination of the cBN insert and AncorCut was quite favorable for the sinter-hardening grades, as tool life was similar to the FC-0208 alloy at this condition. Little wear on the insert was found for these difficult to machine steels.

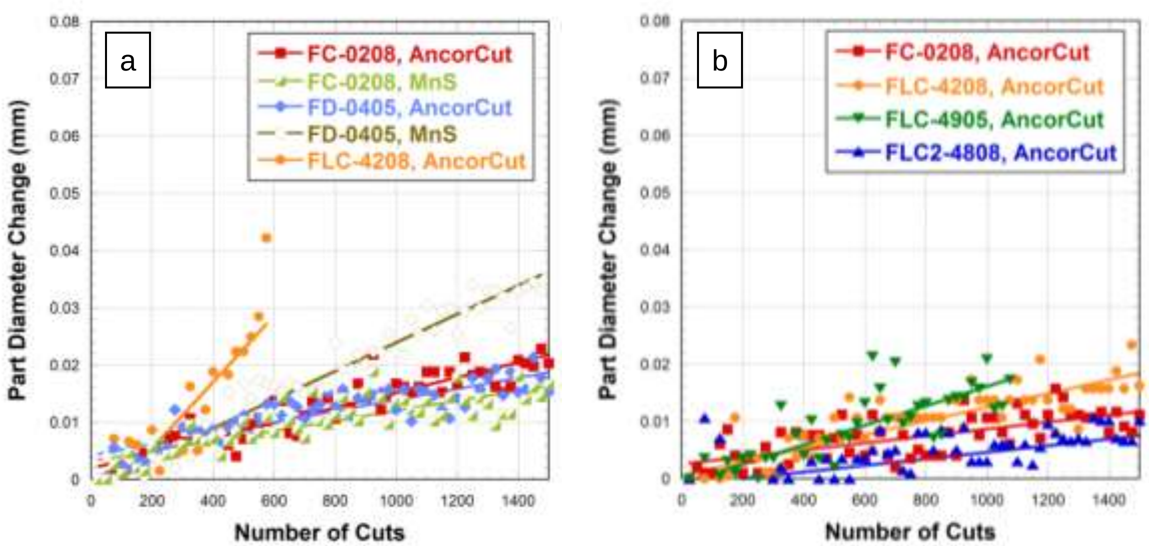
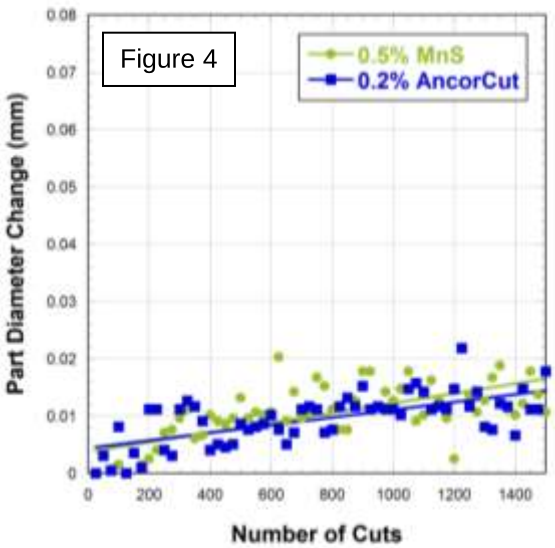


Figure 3. Machinability of different alloys containing machining additives MnS and AncorCut with (a) a coated carbide insert and (b) a cBN insert

An industrial trial was run with both FC-0208 and FLC-4905 in conjunction with Line Craft. The goal was to both improve machinability and to reduce the variable machinability often found with MnS additions. Tests were run at both the Hoeganaes R&D lab and at Line Craft. It was found that 0.5% MnS and 0.2% AncorCut produced virtually the same very low level of tool wear and can be seen in Figure 4. This finding was confirmed by Line Craft with 2000 cuts made with both additives and little tool wear observed. This result enabled either machining additive to be used in the final application. With the FLC-4905 application, no additive is currently used. The end user wanted to avoid any accelerated rusting often found with MnS. A dramatic improvement in tool life was found with the addition of AncorCut, Figure 5. The test with AncorCut was stopped after 1100 cuts due to a machine failure that damaged the cutting tool. Testing at Line Craft reported insert failure at 600 and 800 cuts with no additive, while the AncorCut sample had little noticeable wear after 2000 cuts. Figure 6 shows the physical wear scar on the inserts used at Line Craft.



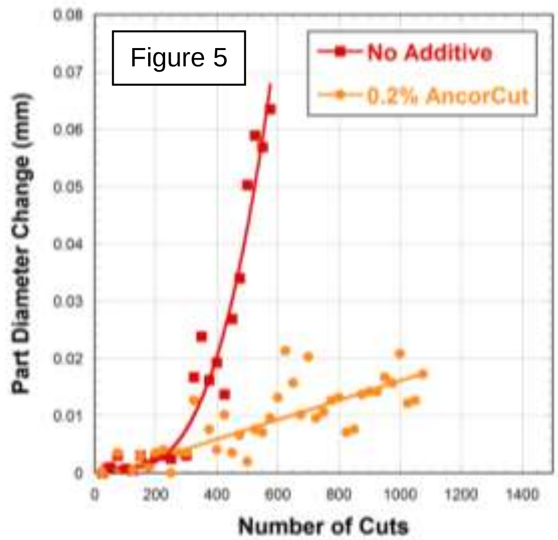


Figure 4. Direct comparison of 0.5% MnS and 0.2% AncorCut in FC-0208 with coated carbide.
Figure 5. Comparison of no additive and 0.2% AncorCut in FLC-4905 with cBN.

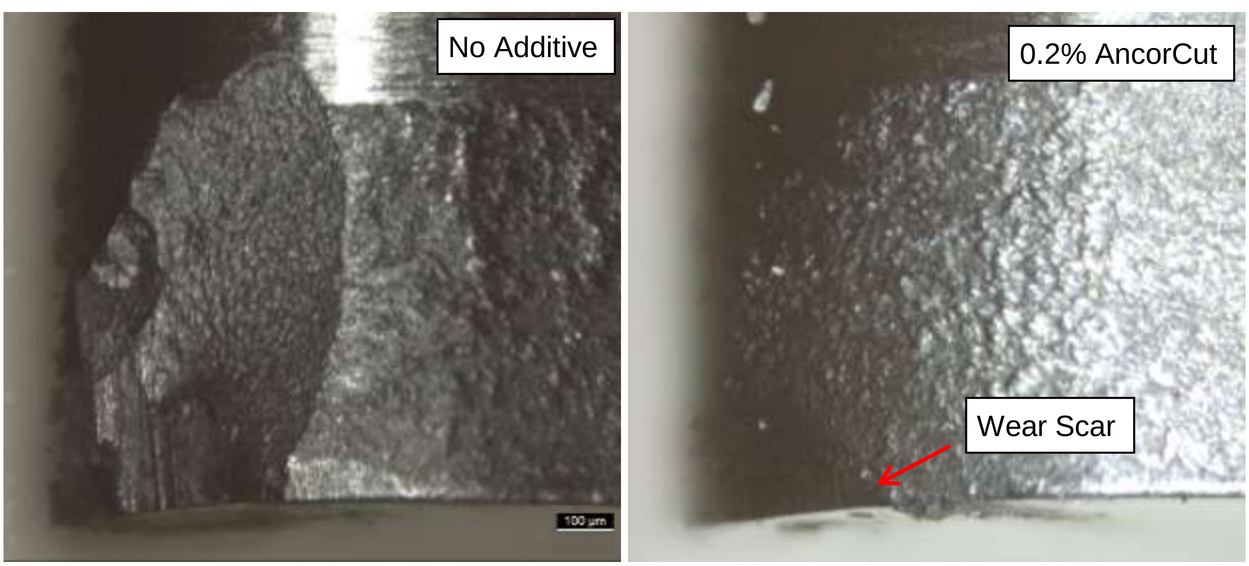


Figure 6. Wear scar on the cBN inserts used to machine FLC-4905 at Line Craft. Tip fracture is evident in the no additive condition.

Samples were drilled with carbide inserts and coolant as earlier results have found rapid failure with various steel bits and sinter-hardened steels. The relatively straightforward correlation with alloy / martensite content that drives machinability in turning was not evident in drilling. Table III shows the number of holes drilled for different alloys and additives. FC-0208, which contains no martensite, had drillability similar to FD-0405 for the no add and the MnS conditions. The number of holes in FD-0405 with AncorCut was surprisingly better than the FC-0208 with AncorCut. FLC-4905 machinability was perhaps slightly better in the no additive condition compared with FC-0208 and FD-0405, although the FLC-4905 with additives was clearly inferior to the other alloys containing machining additives. The 100% martensite alloy FLC-4808 was not reported as immediate drill failure occurs under these conditions.

Table III. Drilling results (number of holes) with carbide bit at 3500 rpm and 20 IPM.

FC-0208			FD-0405			FLC-4905		
No add	MnS	AncorCut	No add	MnS	AncorCut	No add	MnS	AncorCut
103	425	348	56	496	933	140	191	252

CONCLUSIONS

PM alloys with different microstructures were evaluated in turning and drilling, with additional industrial scale trials conducted on select grades. Rapid tool wear was observed in turning when no machining additives were used, with increasing wear corresponding to increasing apparent hardness and amount martensite. This correlation was less apparent once machining additives were introduced. With the coated carbide insert, increased tool wear was still observed with the harder steels, whereas with the cBN insert, no significant difference was found between the range of alloys containing AncorCut. Alloys machined utilizing a carbide drill did not exhibit a trend with the microstructure, but like turning, machining additives were always found to produce some benefit.

ACKNOWLEDGMENTS

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