New Machinability System for PM Steels

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Abstract

PM steel machinability is an ongoing focus as part tolerances become tighter, geometries more complex, and machining throughput affecting the cost competitiveness of PM products. One advantage of PM is that machinability additives can be easily admixed into the powder and therefore into the final part. Manganese sulfide is a well-known additive for enhanced machinability, but lacks long term stability and contributes to both surface staining and rusting. A new machining system, designated AncorCut®, has been developed with improved stability and can therefore compliment MnS for use in PM steels. Turning tests were performed to evaluate the benefit of AncorCut on tool wear in different material systems. This paper describes the properties of this new machining system.

Introduction

Machinability of PM steels differs from that of wrought steel due to the presence of porosity and the often heterogeneous microstructure [1]. Reduced heat transfer, loss of coolant into porosity and micro-impacts at the tool-workpiece interface are some variables associated with porosity that make machining of PM steels more challenging. The variable microstructure in diffusion alloyed and hybrid alloyed steels make the selection of cutting tools difficult, as certain insert grades are often linked with a given hardness/microstructure. Additionally, PM alloys typically contain higher levels of carbon (>0.5%) to achieve similar strengths as fully dense wrought products. The resulting higher micro-indentation hardness in combination with the porosity is most responsible for the different machining response of PM compared with wrought steels.

An advantage of PM is that machinability enhancers can be incorporated into the powder compact. Manganese sulfide (MnS) is the most success enhancer and is admixed into the powder prior to compaction. During the cutting process, MnS deforms along the shear plane, reduces tool contact time, and forms a lubricating layer on the tool [2]. Many studies have shown the benefits of MnS additions to the machinability of PM steels [1,3-10]. MnS has been found to improve turning, milling, drilling and threading operations and is effective over a wide range of cutting conditions. While manganese sulfide has many beneficial attributes, it has some limitations and potentially negative effects. High humidity environments can quickly oxidize MnS and deteriorate the machinability enhancing properties [4-6, 10]. Both powder and component rusting is accelerated when MnS is present, especially in the Fe-Cu-C system. It has been proposed that sulfuric acid is evolved during the reaction of MnS and H_2O, and that the acid is responsible for the accelerated rusting. Staining due to lubricant burn out also worsens in the presence of MnS [8].

Chemically inert additives are therefore desirable. A program was undertaken to develop a better machining aid that moves beyond the oxidation and rusting issues of MnS while providing similar machining performance. In this study, the machining behavior of a new machining enhancer, designated AncorCut, was investigated in three different alloy systems and its advantages at various cutting conditions are discussed.

Experimental Procedure

The new machining system was evaluated with several alloy systems, shown below in Table I. Additionally, premixes with no machining additive and with 0.35% MnS were also investigated. Standard transverse rupture and dogbone tensile bars were compacted to 6.9 g/cm^3 for the FC-0208 and FD-0405 material and 7.0 g/cm^3 for the FY-4500 material. Machining rings measuring nominally 45 mm outer diameter, 25 mm inner diameter and 32 mm tall were compacted to the same density as the test bars. Sintering was conducted in an Abbott belt furnace at 1120 °C in 90% N2 – 10% H2 atmosphere. Time in the hot zone was 45 minutes. The sintered density of the compacts was nominally 6.8, 7.0 and 6.9 g/cm^3 for the three alloys, respectively.

Table I. Nominal composition of alloys used in this study

ID	Fe (wt%)	Cu (wt%)	Ni (wt%)	Mo (wt%)	P (wt%)	Gr (wt%)
FC-0208	Bal.	2.0	-	-	-	0.8
FY-4500	Bal.	-	-	-	0.45	-
FD-0405	Bal.	1.5	4.0	0.5	-	0.6

Turning studies were run using a 0.25 mm depth of cut and 0.25 mm feed at different cutting speeds: 150 surface meters per minute (smm), 230 smm, 310 smm and 380 smm. Twenty five cuts were made on each ring so that final diameter of a machined ring was nominally 32 mm. The target number of rings per test was 60, for a total of 1500 cuts per test. The turning tests were run using a Haas ST-10 CNC lathe with no coolant. Machinability was measured by change in part diameter. The diameter of the machined ring was measured after the first and last pass using an automated probe (1 μm accuracy) 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. TiCN coated cermet (Kennametal KT-315) in a CNMG 432 FN geometry
3. polycrystalline boron nitride (cBN) tipped insert (Shape-Master Tool) in a CNGA 432 geometry, with a light hone edge preparation.

Results & Discussion

Mechanical Properties and Microstructure
The mechanical properties of the various alloys and machining enhancers can be found in Table II. In general, a small reduction in strength can occur when enhancers are present, but the decrease was limited in this study.

Table II. Sintered properties

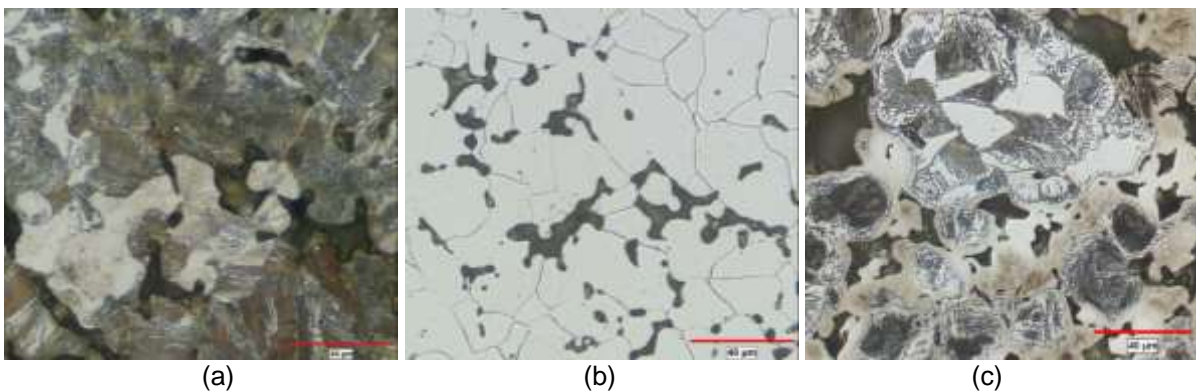| Alloy	Enhancer	Sinter Density (g/cm^3)	0.2% YS (MPa)	UTS (MPa)	Total Elong. (%)	Hardness (HRA)
FC-0208	No	6.79	396	520	1.2	47
	MnS	6.79	395	505	1.2	47
	AncorCut	6.78	397	476	1.3	48
FY-4500	MnS	7.06	240	282	3.2	37
	AncorCut	7.05	249	298	4.1	37
FD-0405	No	6.88	375	622	2.0	55
	MnS	6.87	376	629	2.1	56
	AncorCut	6.86	372	626	2.3	55

(a) (b) (c)
Figure 1. Microstructure of (a) FC-0208, (b) FY-4500 and (c) FD-0405

The sintered microstructure taken from the machining test ring mid-radius location for each alloy system can be seen in Figure 1. The alloys chosen represent a wide range of microstructures, from ferritic (FY-4500) to pearlitic (FC-0208) to a mixed microstructure containing ferrite, pearlite, bainite, martensite and Ni-rich austenite (FD-0405). The addition of machining enhancers should not affect the metallic portion of the microstructure, and this was confirmed to be the case throughout the study.

Machining of FC-0208

The initial turning tests with FC-0208 were run at a cutting speed of 230 smm. Three different inserts were used to evaluate the effect of machining additives with insert composition. The results in Figure 2 show the change in part diameter with increasing number of cuts; two effects are readily apparent. First, insert wear differs considerably between the three insert compositions. Rapid tool wear was found with the KT315 insert, whereas the cBN insert exhibited the least wear. Second, the improvement in tool life with AncorCut (Figure 2b) versus no additive is evident for all tool inserts. The KT315 and KCP25 inserts did not last the full 1500 cuts without the addition of machining additive. A less dramatic but no less significant reduction was also found with the cBN insert. Given the higher cost of cBN, the improved tool life has a significant financial implication.
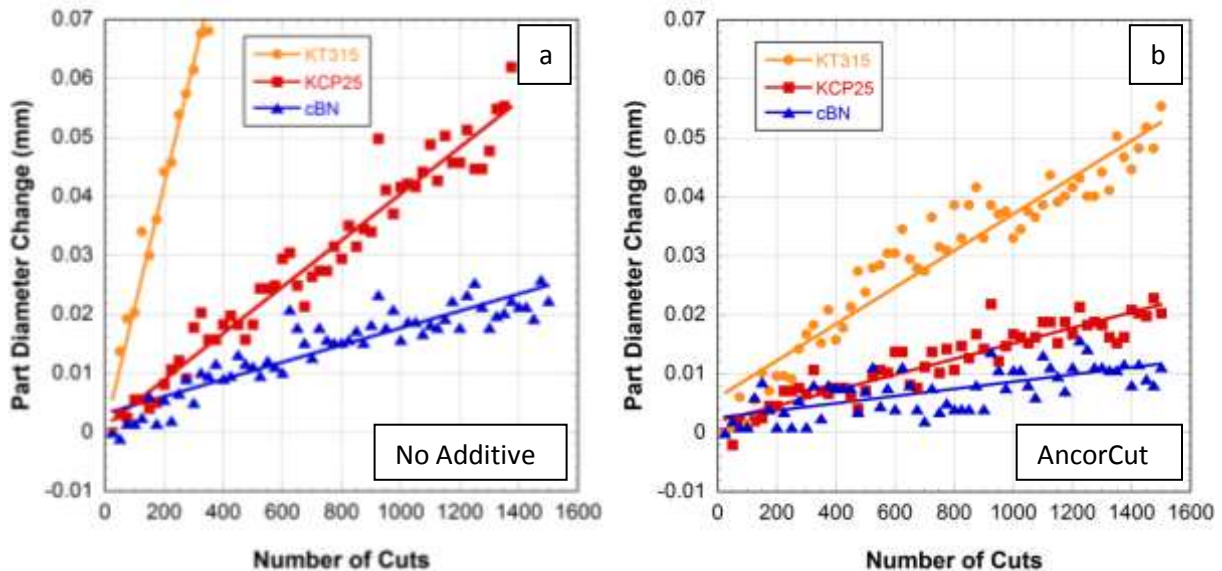

Figure 2. Change in part diameter with different insert compositions at 229 surface meters/min (750 sfm) for (a) the no additive and (b) AncorCut condition. Diameter measured every 25 cuts.
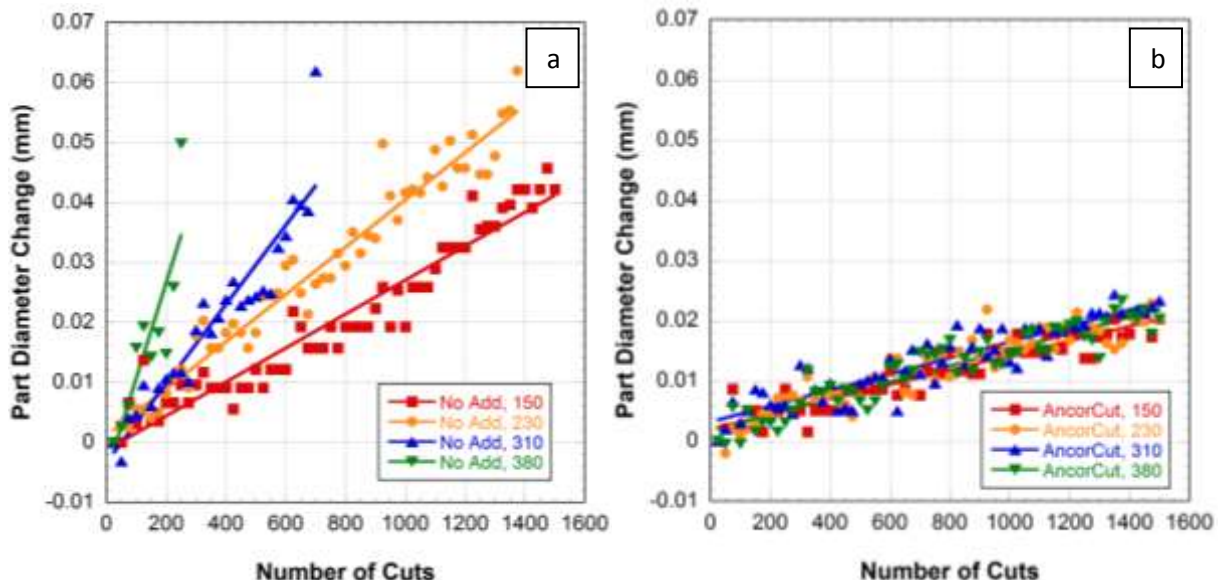

Figure 3. Tool wear at various cutting speeds [150 smm, 230 smm, 310 smm and 380 smm] after machining FC-0208 with (a) no additive and (b) with AncorCut.

The influence of cutting speed was investigated for both the no additive and AncorCut samples using the KCP25 insert. Four speeds were investigated and it was observed that over this range, cutting speed had a significant effect on tool life for the no additive condition, Figure 3a. Tool wear was extremely rapid at high speed and became less severe with decreasing speed. The target insert life of 1500 cuts was only reached when the speed was dropped to 150 smm. The AncorCut sample exhibited a completely different response, with little effect on the wear rate (change in part diameter with increasing cuts) as speed was changed (Figure 3b). This is a desirable result, as this new

machining enhancement system appears to have a wide processing window. Previous work [9] showed that the addition of MnS had a similar effect on tool life over a range of cutting speeds, whereas the baseline material was highly sensitive to cutting speed. Assuming these results are applicable to the production of PM components, this robust processing window implies that throughput can be increased significantly by increasing cutting speed, thereby reducing the machining cost per part. The slope changes for both additive conditions are listed in Table IV.

Table IV. Effect of cutting speed on tool wear slope (μm/cut).

Condition	150 smm	230 smm	310 smm	380 smm
No additive	0.028	0.039	0.067	0.159
AncorCut	0.012	0.013	0.013	0.014

Comparison of the new additive with MnS was made using the KCP25 insert at a speed of 230 smm (750 sfm). Figure 4 shows the results of the trial. The no additive (red) and AncorCut (blue) results had been shown previously and the orange curves representing 0.35%MnS material. Two behaviors were observed with the MnS. In run 1, no special consideration was made for the MnS, meaning that after sintering, the samples were stored dry in closed steel containers for nominally 1 to 3 weeks until use in the machining test. This storage was used for all other samples as well. The machining response was significantly worse than the new machining additive. Given that MnS is an effective machining additive for the industry, and that also MnS has a poor shelf life in sintered parts, another test was made where the MnS-containing samples were machined within one day of sintering. A large improvement in tool wear was observed with these samples, indicating that freshly sintered MnS-containing parts may machine slightly better than AncorCut-containing parts. A machining test conducted within 1 day of sintering of the AncorCut samples was not performed, but given the stable nature of the AncorCut, it is not anticipated that a change in machining performance would occur.

The results highlight some of the challenges of machinability in PM parts, especially when MnS is used. MnS can be quite effective when parts are machined soon after sintering and rusting can either be controlled by a secondary process or is not a concern for the component. As will be demonstrated in a subsequent section, the new machining enhancer does not accelerate rusting of PM parts, provides stable machining response, and is significantly better than no additive.
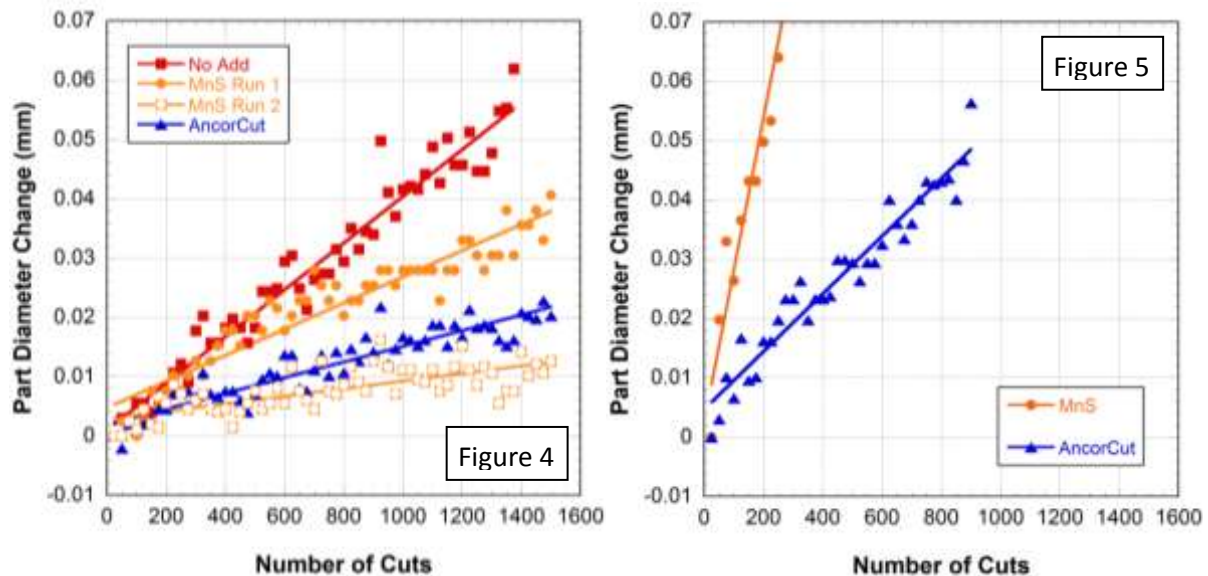

Figure 4. Comparison of AncorCut with MnS and no additive in FC-0208.
Figure 5. Part diameter change during machining of FY-4500 with MnS and AncorCut utilizing the KCP25 insert at 150 smm.

Machining of FY-4500

In addition to FC-0208, different alloy systems were tested to determine if the enhanced machining system worked with different microstructures. FY-4500 is completely ferritic and known to cause machining issues. This difficult to machine system was tested with both MnS and AncorCut and with the slower speed of 150 smm. The first observation from Figure 5 is that AncorCut greatly improved tool life compared with MnS. The number of cuts increased from 250 to 900 and the slope decreased

from 0.257 to 0.049 μm/cut. As discussed previously, the MnS samples were tested within one day of sintering to minimize any oxidation effects. The second observation is that FY-4500 has significantly worse machinability than FC-0208. When compared with the results in Figures 3 and 4, it can be seen that tool life is quite short with FY-4500.

Machining of FD-0405

The machinability of FD-0405 is also quite poor when no machining additive is used, Figure 6. Less than 200 cuts were made in the no additive condition, whereas the full 1500 cuts were achieved with both MnS and AncorCut. The tool wear was lowest with AncorCut, showing the potential of this new machining enhancer. The slope decreased from 0.570 to 0.025 to 0.010 μm/cut for the no additive, MnS and AncorCut conditions, respectively.
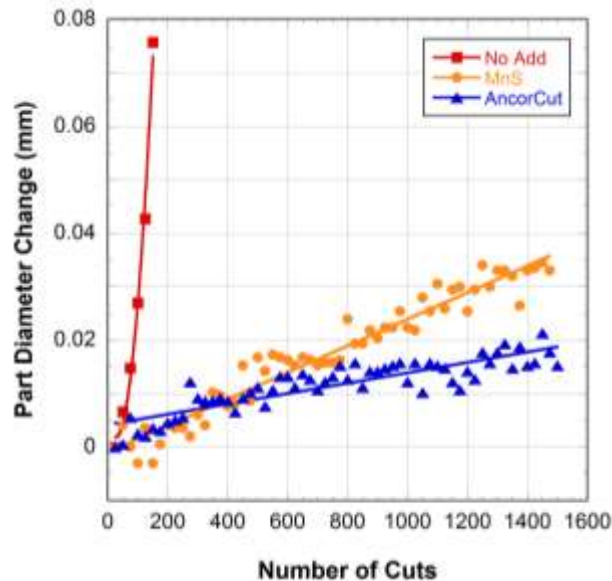

Figure 6. Part diameter change during machining of FD-0405 with no additive, MnS and AncorCut utilizing the KCP25 insert at 230 smm.

Rusting Tests

One of the primary benefits of MnS-alternative machining enhancers is the reduction in rusting and staining on the surface of PM components. MnS oxidizes to form manganese oxide or manganese sulfate type compounds and sulfuric acid may be evolved in the presence of water, thereby causing accelerated corrosion. Additionally, MnS can alter how lubricants are removed from PM parts during the delubrication process, leading to staining on the surface of parts. In many applications, MnS can not be used for these reasons. The new machining enhancer was evaluated in sintered compacts under humid environments to determine if any effect on rusting could be found. Figure 9 shows the results for the Fe-Cu-C system. The MnS samples exhibited the most rapid rusting, whereas the no additive and AncorCut samples had similar appearances. No accelerated rusting was observed in the other alloy systems tested.

Conclusion

A newly introduced machining enhancer, AncorCut, was found to improve machinability of a variety of alloy systems and microstructures. This benefit in machinability was also observed over a range of cutting inserts and cutting speeds. A key finding with the new enhancer is that it delivers consistent cutting performance over different cutting speeds in FC-0208, thereby allowing a user to run at faster speeds and better equipment throughput. The new enhancer shows benefits similar to MnS in machining while avoiding the accelerated corrosion (rusting) found in sintered PM parts containing MnS, thus providing parts producers another tool to improve the manufacturing and cost competitiveness of PM components.
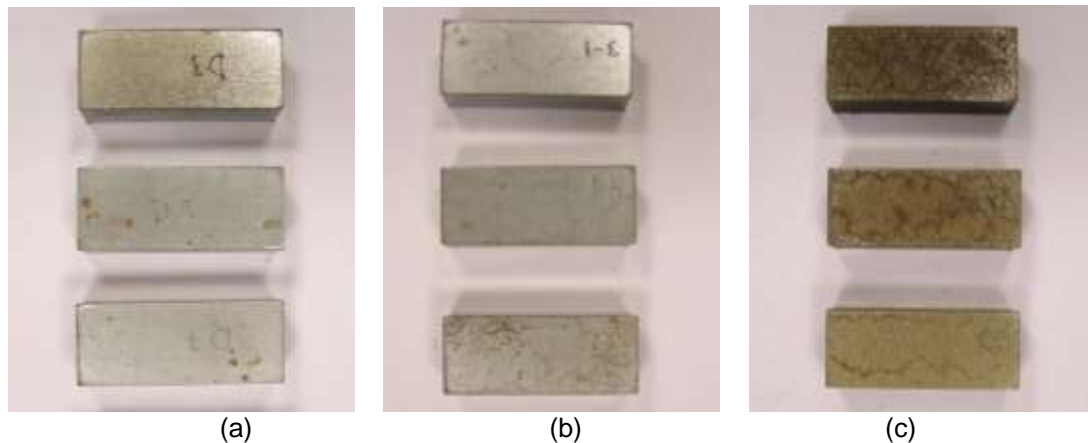
Figure 7. Surface rusting of FC-0205 test bars with (a) no additive, (b) AncorCut and (c) MnS exposed for 10 days at nominally 80% humidity.

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