

Investigation Into Machinability Improvements For FC-0208

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ABSTRACT

Iron-copper-carbon alloys are the most utilized alloys in ferrous PM steels. Machining of these pearlitic steels can be challenging and several additives have been introduced to improve machining performance. MnS is widely used as it improves machinability in many different operations, but lacks long term stability and contributes to surface rusting. It tends to revert to an oxide, and as such, its machining enhancement degrades over time. It would therefore be desirable to develop a complimentary material that has enhanced stability. This paper describes the ongoing development activities toward an improved machinability system.

INTRODUCTION

The PM process produces net or near-net shape components, nevertheless, many parts are machined to deliver high precision features, cross holes, transverse grooves, etc. Machinability is an important cost consideration in the production of many ferrous PM components, with poorly machinable parts resulting in a negative cost implication due to extended machining times, tool failure and greater tooling consumption. It is known that the machinability of PM steels differs from that of wrought steel due to the presence of porosity and the often heterogeneous microstructure [1]. Additionally, PM alloys typically contain higher levels of carbon (>0.5%) to achieve similar strengths as 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. The most popular PM alloys combine these higher levels of carbon with nominally 2% copper. The copper forms a liquid during sintering and infiltrates into the fine pores, where it later diffusively solidifies, and thereby increases the volume of sintered necks in the compact. The copper also strengthens ferrite in steels, and the combination of larger and stronger sintered necks is responsible for the improved mechanical properties of the Fe-Cu-C system. This higher strength, however, reduces machinability.

One of the advantages of PM is that a machinability enhancer can be incorporated into the powder prior to compaction. Free-machining additives improve machinability by assisting in chip formation, lubrication of the tool face and reduction of both flank and crater wear [1]. In wrought steels, machining enhancers, such as MnS, oxides, lead and bismuth, form during the steel-making process and therefore must be

compatible with the liquid steel chemistry and technology. In PM, since the machining additive is added to the steel in the solid state, additives that can not be used in wrought steels are possible. Examples in the patent literature include talc, hBN, mica, and enstatite, to name a few. Just because the incorporation of a whole range of additives is possible, however, does not mean they will be successful. The additive must improve machinability while also not strongly affecting the properties of the steel in a negative way. The most common additive used is MnS. 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]. While manganese sulfide has many beneficial attributes, it has some limitations and potentially negative effects. High humidity environments can quickly oxidize the MnS and deteriorate the machinability enhancing properties [4-6]. In addition, MnS becomes less effective as alloy content increases [7,8].

An additive (designated MA) was introduced by Hoeganaes Corporation prior to 2006 to improve the machinability of PM steels. The additive is chemically inert and therefore reduces the tendency for rusting compared with MnS [8]. The additive was found to be particularly effective in sinter-hardened steels, especially when advanced tool materials, such as multi layered coated carbide and boron nitride, are used [8]. More recent data has shown that this additive can be effective in Fe-Cu-C alloys when certain cutting conditions are used [9,10], but cutting speed in particular needed to be optimized. Further enhancements to extend tool life over a wider range of cutting conditions are desirable, so an effort was undertaken to develop an improved machining system. In this study, the machining behavior of FC-0208 was investigated and the benefits of a developmental process to improve machining are discussed under several different processing conditions.

EXPERIMENTAL PROCEDURE

An FC-0208 premix (Ancorsteel® 1000B, 2% AcuPowder Cu, 0.85% Asbury graphite) was produced that contained the developmental machinability enhancer. A baseline premix with no additive and a premix with 0.35% MnS were also evaluated. Standard transverse rupture bars and machining rings measuring nominally 45 mm (1.75 inch) outer diameter, 25 mm (1 inch) inner diameter and 32 mm (1.25 inch) tall were compacted to 6.9 g/cm³ density and sintered in an Abbott belt furnace at 1120 °C (2050 °F) in 90% N₂ – 10% H₂ atmosphere. Time in the hot zone was 45 minutes. The sintered density of the compacts was nominally 6.8 g/cm³.

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: 152 smpm (500 sfm), 229 smpm (750 sfm), 308 smpm (1000 sfm) and 381 smpm (1250 sfm). 25 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. The turning tests were run using a Haas ST-10 CNC lathe with no coolant. Machinability was measured in several ways. Flank wear on the tool was measured and documented at select intervals. Additionally, the diameter of the machined ring was measured after the first and last pass using an automated 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. Finally, the temperature of the machined ring was measured using a contact thermocouple after every 25 cuts to assess if worn tools result in more frictional / adiabatic heating. The tool used in this experiment was an alumina-TiCN coated carbide insert (Kennametal KCP25) with an insert geometry of CNMG 432 FN. The new system is compared with a baseline FC-0208 premix that was reported previously [9]. The wear scar of the tool upon the completion of the test was also examined in the SEM.

RESULTS AND DISCUSSION

Mechanical Properties and Microstructure

A small reduction in strength often accompanies the incorporation of machining enhancers, and it has been shown previously that a reduction of 5% or less relative to no additive is often found with the addition of MnS or MA. In comparing the standard baseline premix and the developmental material, little difference in sintered properties was found. The hardness, rupture strength and dimensional change are quite similar, as shown in Table I. The transverse rupture strength is slightly reduced but within the typical 5% reduction found with additives. The 0.35% MnS premix shown has a similar decrease in TRS. Green springback was slightly higher with the developmental material, leading to the lower green density. It is important that the developmental material not have a negative effect on properties relative to currently established machining additives.

Table I. Sintered properties

Mix	Green Density, g/cm ³	Sinter Density, g/cm ³	Dimensional Change, %	TRS, MPa (psi x 10 ³)	Hardness, HRA
Std Premix	6.92	6.81	0.44	1050 (152)	50
0.35% MnS	6.91	6.81	0.42	1020 (148)	50
Developmental	6.88	6.79	0.44	1003 (146)	50

The sintered microstructure was not affected by this developmental system as seen in Figure 1. The nearly fully pearlitic microstructure is similar in the base line material and the new system. The distribution of Cu and C appear unaffected, as well as the pearlite spacing. The occasional free copper particle seen in Figure 1b is present in both samples.

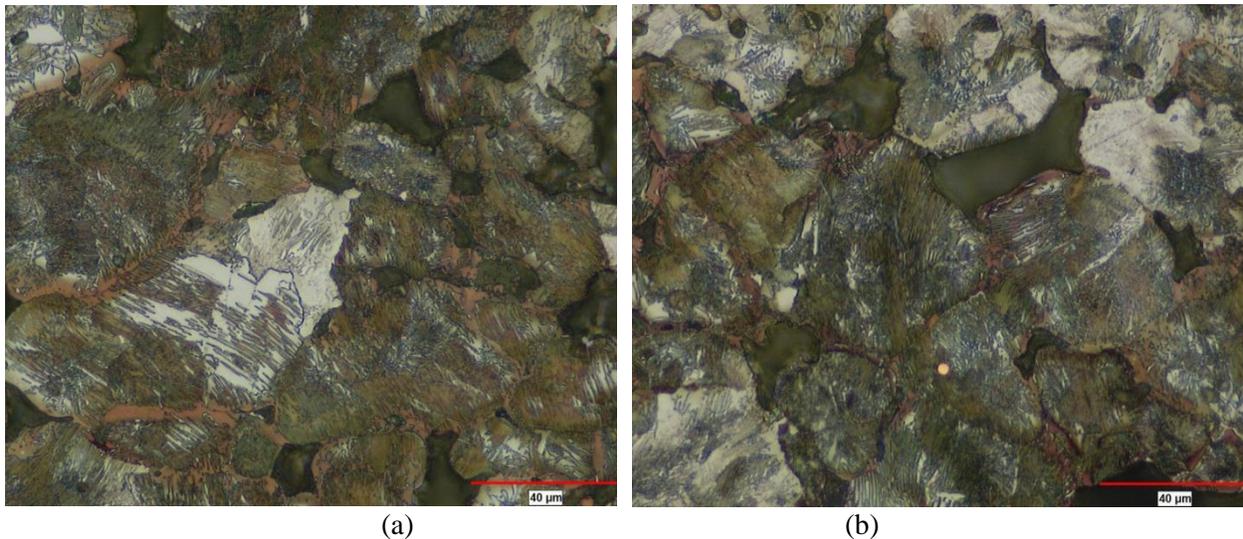


Figure 1. Microstructure of (a) the baseline FC-0208 and (b) FC-0208 with the machinability enhancer.

Machining

The initial turning tests were run at a cutting speed of 229 surface meters per minute (750 sfm) and it was found that the material under development greatly improved machinability of FC-0208 relative to the baseline data. Figure 1 shows the change in part diameter with increasing number of cuts and the developmental material (in orange) exhibited significantly less change in part diameter. The tool only lasted 500 cuts for the baseline premix, whereas the tool for the developmental material lasted 1500 cuts and given the rate of part diameter change, the developmental material appears likely to last about an

order of magnitude more cuts than the baseline. The diameter change of the developmental material is comparable to the 0.35% MnS premix shown in blue. Similar performance is expected with these two machining enhancers.

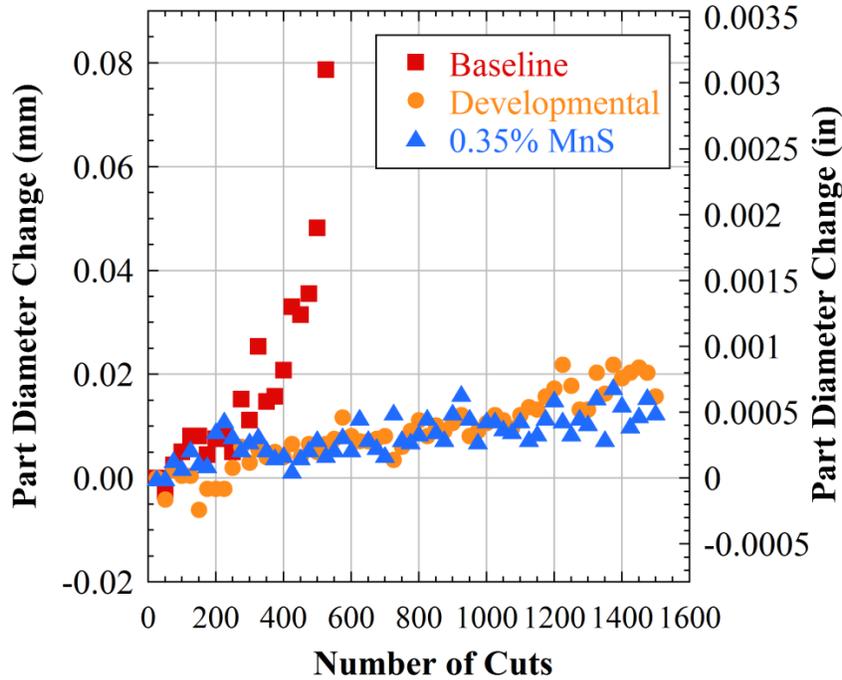


Figure 2. Change in part diameter at 229 smpm (750 sfm). Diameter measured every 25 cuts.

Effect of Cutting Speed

The influence of cutting speed was investigated with the material under development. Four speeds were investigated and it was observed that over this range, cutting speed had little effect on the change in part diameter (Figure 3). This is a desirable result, as this new 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. In the baseline material, rapid tool wear was observed at cutting speeds from 500 sfm to 1250 sfm and only at a speed of 250 sfm did the tool survive 1500 cuts.

The temperature of the parts after machining also showed little change with modification to cutting speed. A 5°C (9°F) difference in average part temperature was observed over the range of 500 to 1250 sfm. This difference is quite small and reinforces that the material has consistent behavior over a range of speeds. While this study is limited to cutting depths that simulate finishing passes, it is encouraging that the developmental system is robust with respect to cutting speed.

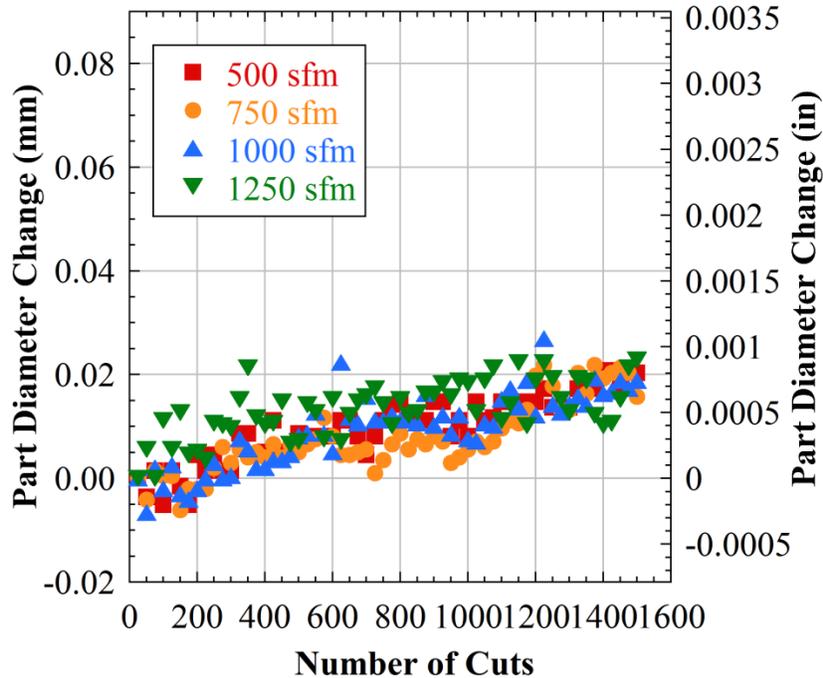
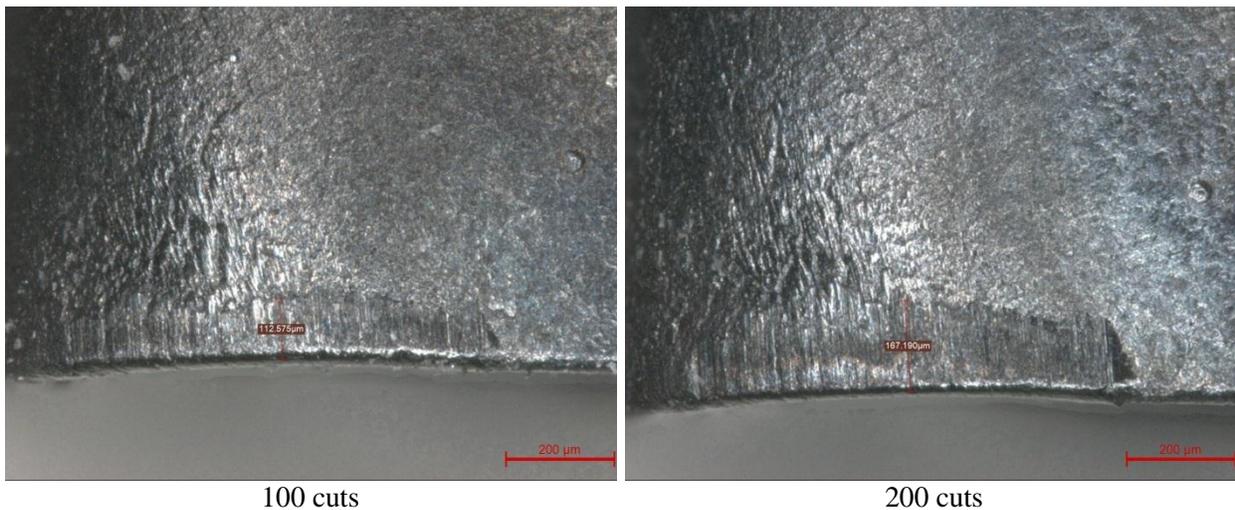


Figure 3. Tool wear at various cutting speeds after machining the enhanced FC-0208

Flank wear on the tool was observed and measured using a Leica stereoscope and Clemex imaging software at specified intervals. Figure 4 shows the wear scar progression for the baseline FC-0208 material. The wear scar becomes progressively larger with no machining enhancer until the cutting edge is lost after 500 cuts. Figure 5 shows an enlargement of the wear scar after 300 cuts and the different tool coating layers can be observed. The top most coating is alumina (Al_2O_3), with a under layer of gold-colored Ti(CN). The lighter gray color underneath the Ti(CN) is the base carbide, and more rapid wear would be expected once the protective coating is removed. This is evident by the complete loss of cutting edge at 500 cuts.



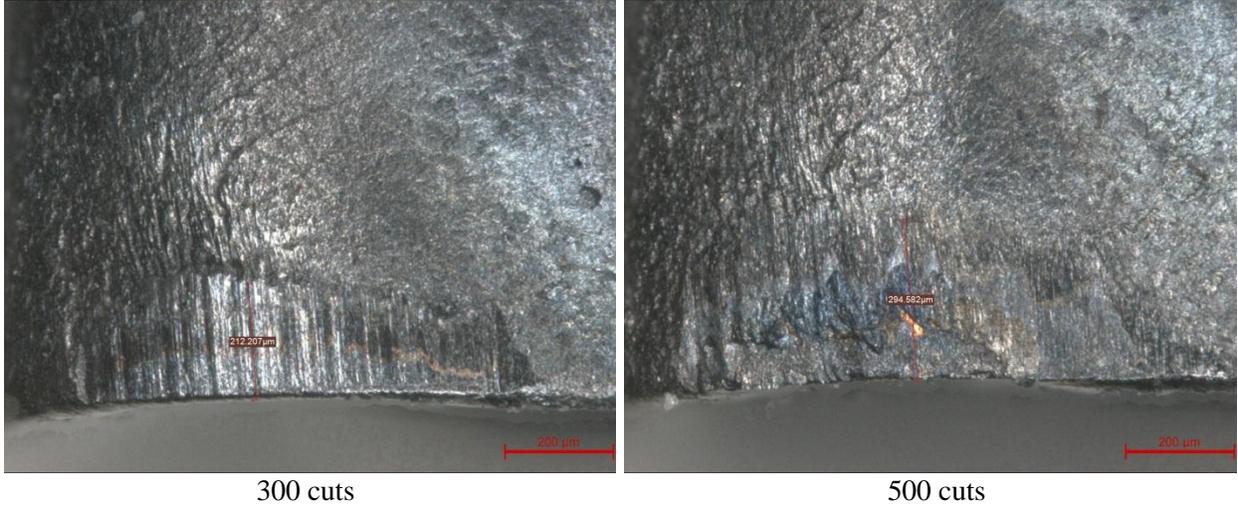


Figure 4. Flank wear on the cutting tool at 750 sfm with the baseline FC-0208 material.

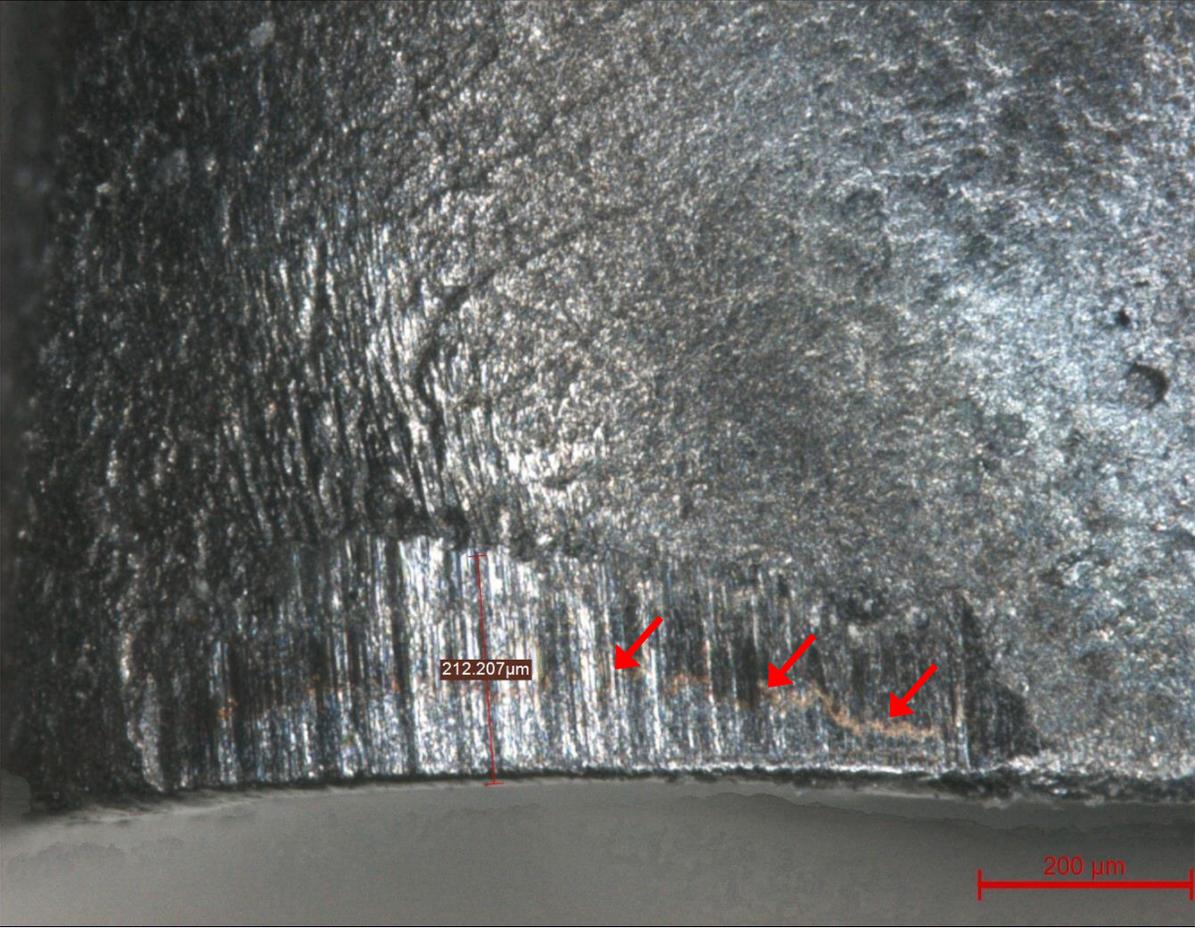


Figure 5. Flank wear on the cutting tool after 300 cuts at 750 sfm with the baseline material. The different coating layers are evident in the wear scar with the arrows marking the Ti(CN) layer.

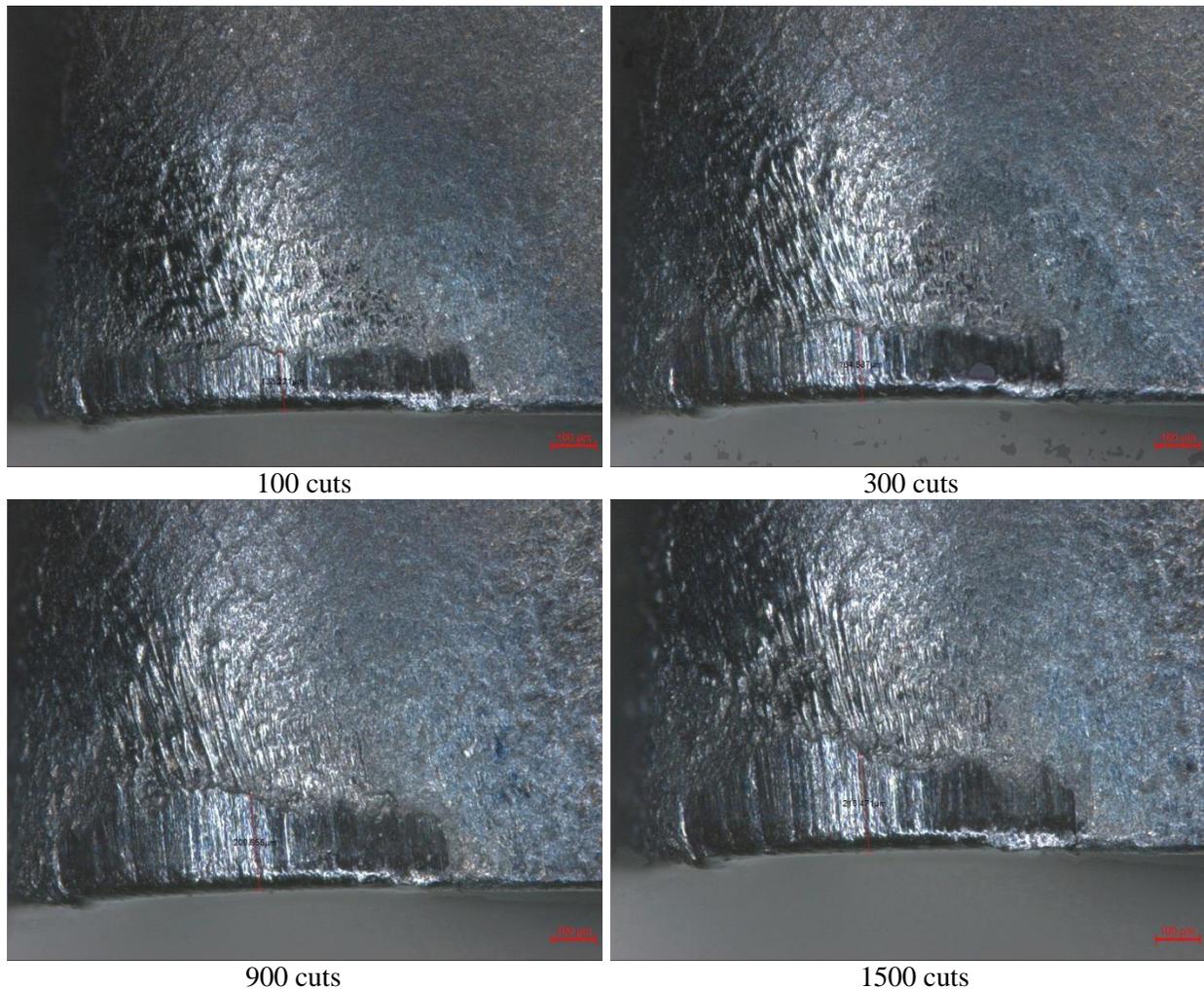


Figure 6. Flank wear on the cutting tool at 750 sfm with the developmental machining system.

A different behavior was found when the wear scar was observed on the tool used to machine the developmental material. Initially, the wear scar developed in a similar way compared with the baseline material, Figure 6, albeit at a much slower rate. The length of the wear scar is considerably shorter after 300 cuts, for example. In addition to the shorter length, there is no evidence that the Al₂O₃ coating has been removed or penetrated, as the gold colored Ti(CN) layer is not visible. Above the wear scar, the shiny region is a deposit on the tool. This deposit, which consists of iron and machining enhancer, acts to protect the tool from wear. A thinner deposit consisting of iron only was also seen with the baseline premix sample. There are competing processes of deposition and removal during the cutting process of this material, and it is thought that the greater deposition with the new system in combination with improved lubricity effectively reduced the wear rate. Measurement of the tool wear becomes more difficult due to this deposit as it can sometimes build up enough to cover portions of the wear scar. At times, the deposit is responsible for a smaller wear length to be recorded with an increasing number of cuts. An example of this reduced flank wear was observed at a speed of 1000 sfm from 900 cuts to 1200 cuts, Figure 7. The measured wear scar length decreased from nominally 200 to 155μm after an additional 300 cuts. The wear scar length was difficult to determine for the 900 cut sample, as the length varied considerably along the width. As the tool can not heal itself, a deposit onto the tool must be responsible for this change.

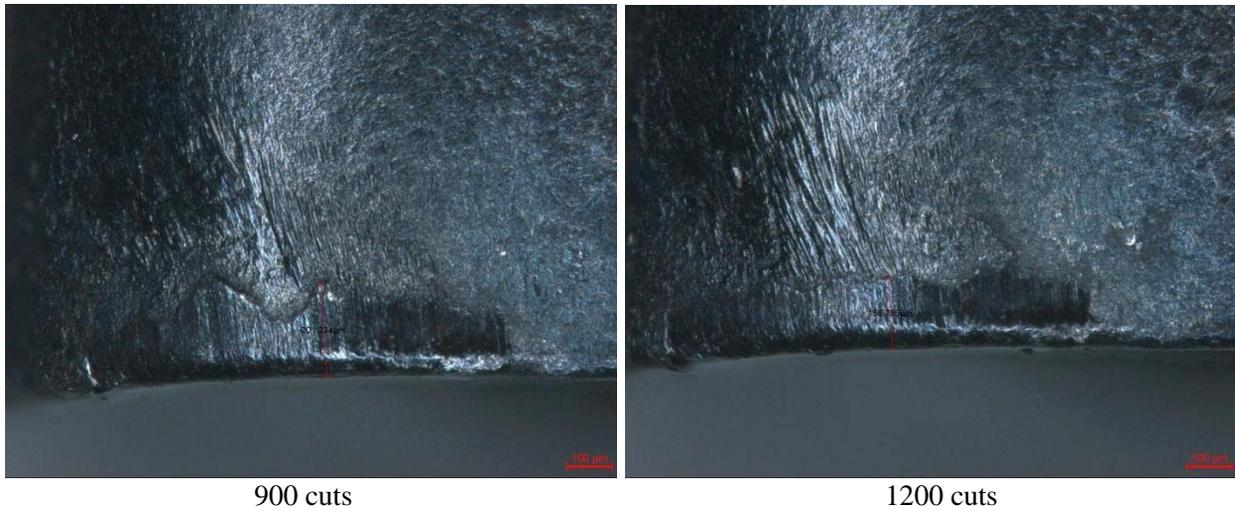


Figure 7. Tool wear at 900 and 1200 cuts for the developmental material machined at 1000 sfm.

This deposition phenomenon makes it difficult to use flank wear as the primary machinability measurement. The plot of flank wear vs. number of cuts is shown in Figure 8. The change in flank wear for speeds 750, 1000 and 1250 sfm is well behaved through the first 900 cuts. Little difference was observed at different speeds. After 900 cuts however, a reduction in wear was measured at 1000 sfm and after 1200 cuts at 1250 sfm. At this point it is surmised that the tool wear follows the 750 sfm behavior and that flank wear length is constantly changing based on the deposition and removal of the deposit observed earlier. It should be noted that the flank wear is significantly shorter for the test run at 500 sfm. This is interesting as the part diameter change as seen in Figure 3 did not show a difference at 500 sfm relative to the other speeds. It is likely that less deposit is present upon the tool used at slower speed. Upon reflection, the length of the wear scar is not the critical parameter for tool wear, rather the depth of the wear scar is important. This is much more difficult to measure directly on the worn tool, and for that reason, the part diameter change is a better measurement of tool performance and machinability.

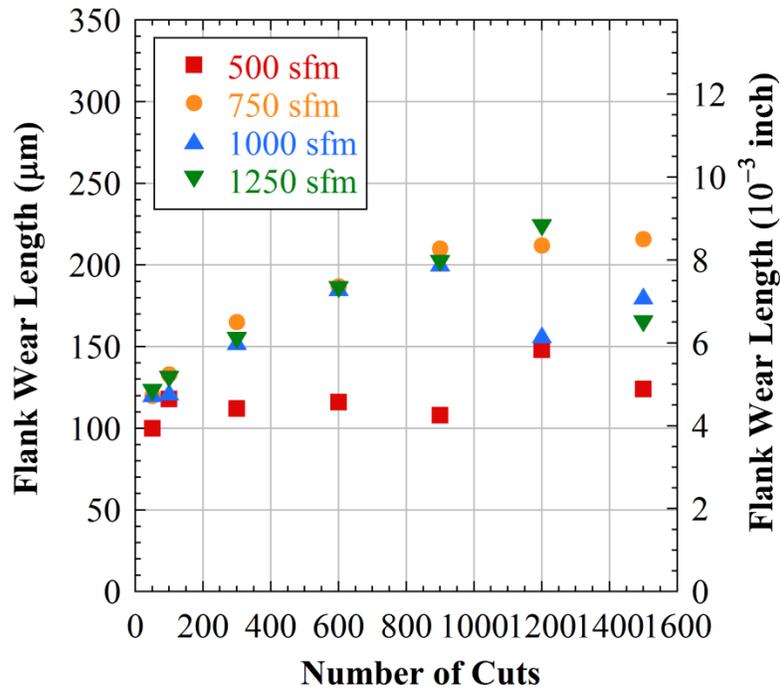


Figure 8. Length of flank wear at various cutting speeds after machining FC-0208 with the developmental system.

CONCLUSIONS

FC-0208 is a difficult alloy to machine due to its fully pearlitic microstructure and the copper strengthening of the ferrite phase. From the limited testing performed within the scope of this paper and from the greater PM literature, not using a machinability enhancer will lead to short tool lives and poor productivity. The developmental system used in this study greatly improved machinability compared with the baseline FC-0208 premix and had similar performance to 0.35% MnS. Tool life during finishing operations was greatly extended and it is estimated that tool life would be approximately one order of magnitude greater than the enhancer-free premix. Additionally, the developmental material results in consistent machining performance over a wide range of cutting speeds. Flank wear, which has been used in the past as the primary measure of tool life, was found to be less reliable than part diameter change for the machinability evaluation. This was due in part to deposition on the tool and the fact that depth of tool wear is more important than length of tool wear for coated tools.

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