Manuscript refereed by Dr Frank Baumgaertner (Schunk Sintermetalltechnik GmbH, Germany)

Characterization of a Novel Machining Additive in Diffusion-Alloyed Mixes: Sensitivity Analysis of Tool Life, Machining Quality and Wear Dynamics

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ABSTRACT

The ability to produce a component which is as dimensionally close to the finished product as possible can drastically reduce production costs and time, material waste, and possible post-processing errors. PM assures manufacturing near-net-shape parts, but despite this, the rising number of high precision applications supports ongoing research to improve machinability of PM products. Manganese sulfide (MnS), a common machining additive for PM, has the shortcoming of oxidizing when exposed to the environment, which is highly detrimental for tool life and accelerates rusting of parts. A novel machining additive has been designed and tested with the goal of replacing MnS both in turning and drilling applications. In the present work, extensive investigation of the machining behavior of diffusion alloyed premixes in drilling has been performed. Tool life and machining quality in the presence of no additive, MnS, and the novel machining additive have been quantified for several drill bit materials, coatings, coolant conditions, speeds and feeds. Surface roughness for different additives has also been measured. In addition, a wear model linking type of wear (abrasive or adhesive) to tool life, dimensional accuracy of machining process, drilling conditions and machining additive has been developed and implemented.

INTRODUCTION

40-50% of PM steels still require secondary machining, with the most common finishing operations being hard turning and drilling [1].The presence of porosity is the cause of reduced tool life in machining of PM components because of their heterogeneous nature (solid/pore) which creates an interrupted cut condition. Fatigue initiation cracks and chipped tool edges develop from such occurrence as well as from the presence of single hard particles. Oxides and carbides derived from sintering and heat treating can also contribute to be detrimental to tool life by increasing abrasion [2]. Nevertheless, the need for high machining throughputs, pivotal in industrial production, also accentuates the wear connected to the "intermittent-cut" condition. Manganese sulfide (MnS) added to premixes have been seen to improve machinability in a wide range of materials [3]. It is stable at sintering temperatures and does not interact with the alloy matrix. In addition to this, MnS does not affect the strength of components constituted of water atomized iron powder. MnS achieve machinability improvement by delivering lubrication between cutting tool and work piece, and thus minimizing wear at the cutting edge of the tool [4,5]. However, shortcomings related to the addition of MnS in PM components were found, the main one being enhanced oxidization in atmosphere and consequent augmented corrosion particularly when ad-mixed with Fe-Cu-C mixes. MnS carries other processing drawbacks limited not only to Cu containing materials, such as chemical reaction during storage and discharge of sulfur containing gas during sintering, which can results in detrimental deposits in the furnace. There is the compelling need for an effective machining compound that can be mass-produced and that is able to retain chemical stability along the production chain.

A new machining additive (AncorCut) has been conceived and extensively tested in Fe-Cu-C mixes for both turning and drilling operations [6-8]. Turning tests have also been performed [6,7] on diffusion-alloyed steel (FD-0405) and improvements in tool life have been noted.

Tool wear, measured by change in part diameter, is critically diminished with the addition of such machining additive. After 1500 cuts, AncorCut shows reduced tool wear of about 30% compared to MnS. The comparison has been made with fresh and unexposed MnS, therefore rusting did not affect the outcome of the tests in a manner that would favor AncorCut. Also, no harmful effects on the strength of the base alloy have been spotted [6,7]. Due to the promising turning results in FD-0405, AncorCut performance in drilling FD-0405 will be assessed. In this paper, machinability has been measured by number of holes drilled and hole diameter variation per test. In addition, the influence of machining additives and processing parameters (feed, drill bit materials and lubricant regime) will be investigated.

EXPERIMENTAL PROCEDURE

Drilling tests were carried out on a HAAS VF-1 vertical milling center at the Hoeganaes Innovation center. The motor can deliver up to 22 kW and 8100 rpm, with resolution of 0.0025 mm. 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. Specimen features and processing details can be seen in Table 1. The chemistry for FD-0405 is also reported. The machining setup (Fig.1) comprises of three samples (pucks) held by an aluminum fixture (Fig.2). 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). Drill bit diameter was selected to be 4.763 mm (0.1875”) and depth of drilling about 25 mm (1”). Screw machine length drill bits have been used to reduce bending of the bit. Drilling response of FD-0405 containing no additive, MnS and AncorCut have been investigated (Table 2). Table 3 summarizes drill bit types, speeds, feeds, and coolant conditions. The coolant used is LUBRICUT 4265 diluted with water (5:100 ratio). The control sample of base material shows good degree of sintering, and microstructure containing ferrite, pearlite, bainite, martensite and Ni-rich austenite areas can be seen which agrees well with FD-0405 (Fig.3).

Table 1. Specimen Features for Machining Trials.

Geometry	Dimensions	Material	Density	Sintering Conditions	Hardness (HRA)
Puck	Diameter = 45 mm (1.75”) Height = 32 mm (1.25”)	FD-0405 (Cu=1.5%, Ni=3.9%, Mo=0.5%, C=0.6%, Wax=0.75%, Fe=rem.)	6.9 g/cm^3	T=1120 °C (2050 F) Atm:N_2/H_2 = 90/10	57

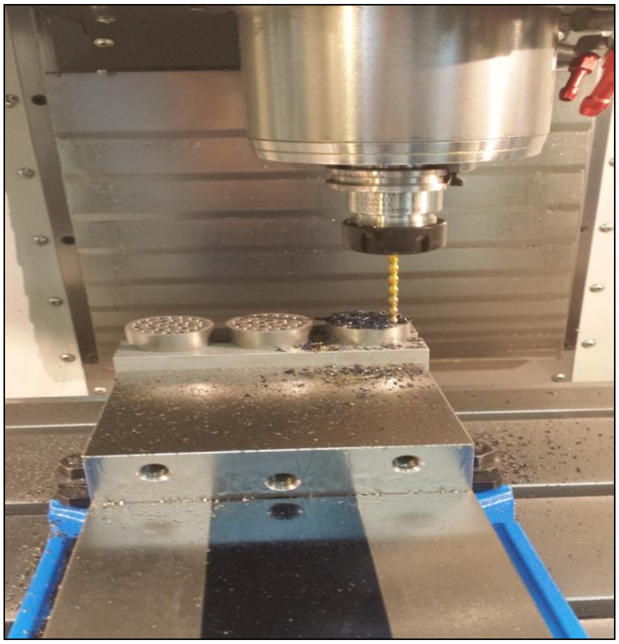

Figure 1. Drilling setup on HAAS VF-1.

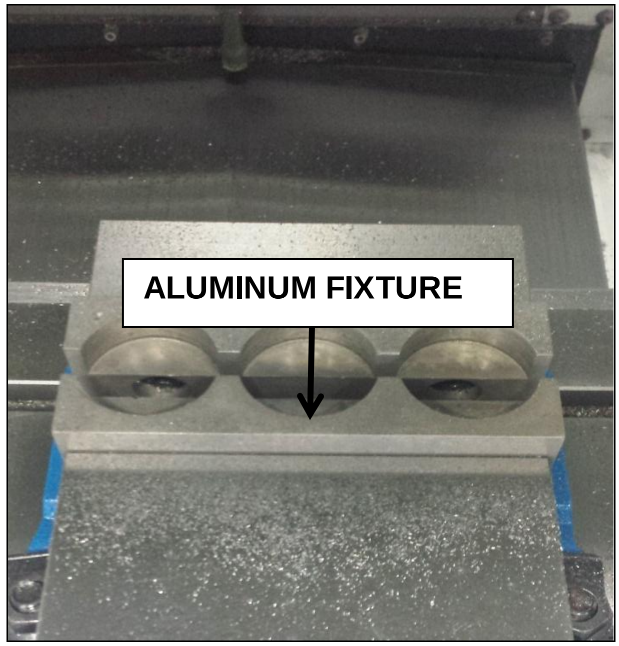

Figure 2. Aluminum fixture

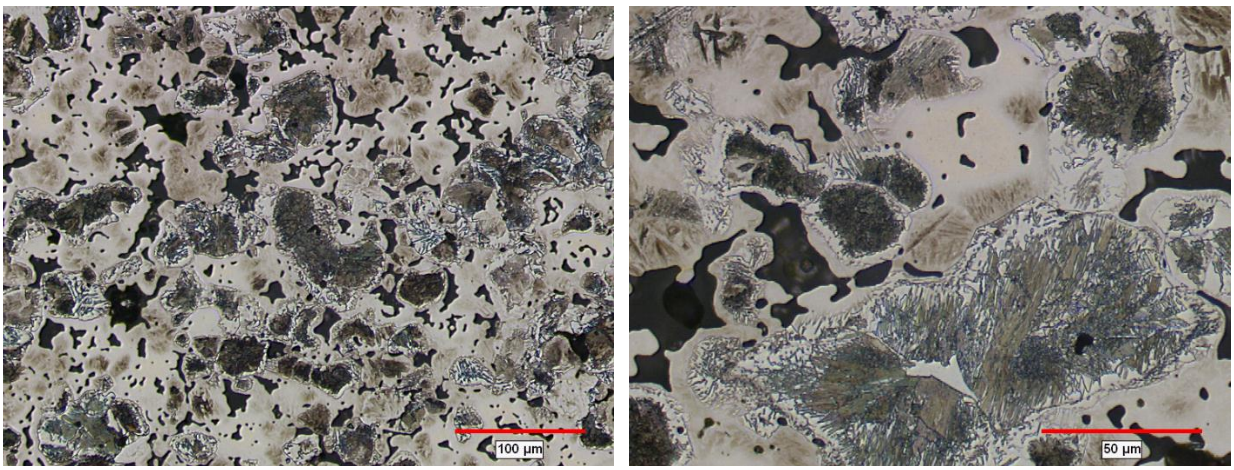

Figure 3. Microstructure of FD-0405. Etched 2% Nital / 4% Picral. Left) 200X. Right) 500X

Table 2. Materials Tested.

Materials Tested	Base Material	Machining Additive
1	FD-0405	None
2	FD-0405	+0.35% MnS
3	FD-0405	+0.2% AncorCut

Table 3. Matrix of Experiments.

Test Code	Drill Bit Material	Coating	Tip Angle	Manufacturer	Speed (rpm)	Feed	Coolant
HSS	HSS, Screw Machine Length	None	135	Chicago-Latrobe	2000	159 mm/min (6.25 ipm)	YES/NO
CD	Carbide, Short Length Jobber	PVD polycrystalline diamond	118, split point	Ultra-Tool International	3500	508 mm/min (20 ipm)	YES

RESULTS AND DISCUSSIONS

Two pivotal factors should be used to evaluate machinability in drilling operations:

- *Number of holes drilled:* this quantifies tool life. Long tool life is correlated to cost savings in production. Drill bits were run to tool failure (breakage) or infinite life.

- *Dimensional tolerances:* prints indicate dimensional tolerances that the machining operation is required to uphold. If this does not occur, components can be scrapped during quality inspection. Change in drill diameter corresponds to change in hole diameter

This paragraph will address both these elements per each process condition.

Number of holes

Table 5 summarizes tool life for each test condition and additive used. Trials were repeated in cases of unexpected or unusual data.

Table 4. Number of Holes Drilled with Coolant

Test Code	Feed	Material		
		FD-0405	0.35%MnS	0.3%AncorCut
HSS	159 mm/min	499	138	310
CD	508 mm/min	56	496	933

Without the presence of coolant, no drill bit survived for more than ten holes. Therefore, such results have not been reported. With use of coolant, there was disparity in tool life between the additives. FD-0405 with no addition displayed the longest tool life with HSS bits, while the addition of AncorCut led to a dramatic enhancement in holes drilled for Carbide Coated drill bits. MnS tool life was only about 50% of AncorCut for Carbide Coated bits. The test with highest throughput (speed) and tool life is the combination of carbide drill bit with AncorCut.

Hole diameter vs. number of holes drilled

The variation in hole diameter (maximum diameter minus minimum diameter) has been measured for processing conditions HSS and CD. A wide variation simbolizes a change in machining quality and could translate into possible out of specification dimensional tolerances. Figure 4 clearly shows that for HSS drill bits, FD-0405 with no additive has the largest variation in diameter (three times compared to MnS and AncorCut), despite having drilled the highest number of holes. It is pivotal to notice that there is no direct correlation between tool life and machining quality, thus it is fundamental to analyze both. For Carbide bits, AncorCut showed the largest diameter variations: about 30% higher than MnS. Once again, the addition of AncorCut led to the longest tool life despite being characterized by dimensional tolerances higher than other materials.

Discrete Diameter Variation (DDV)

It is clear that machinability is influenced not only by machining additives but also from cutting conditions. In order to unify these two elements into one number and thus, compare different processing conditions and materials, the Discrete Diameter Variation (DDV) factor has been introduced. The main objective is to design an additive able to convey the overall best performance.

Table 5. Number of Holes and Diameter Variation. HSS and CD.

Test Code	Number of Holes	Diameter Variation
HSS	FD-0405	0.3%AncorCut
CD	0.3%AncorCut	FD-0405

The DDV measures how much the diameter varies per each hole drilled on average throughout the entire drilling process and can be expressed as:

$$\text{Discrete Diameter Variation (DDV)} = \frac{\text{Diameter Variation}}{\text{Number of Holes}}$$

Figure 5 illustrates that AncorCut is the optimal choice for both conditions for tool life and machining quality. It can be noted that MnS, currently the most utilized additive in the PM industry, has a DDV 50% higher than AncorCut for HSS bits and that FD-0405 has a DDV five times higher than AncorCut for Carbide bits. The same conclusion has been drawn in previous works for FC-0208 [8] where AncorCut was associated to overall low DDVs, confirming its efficacy on enhancing machining of a wide range of base materials.

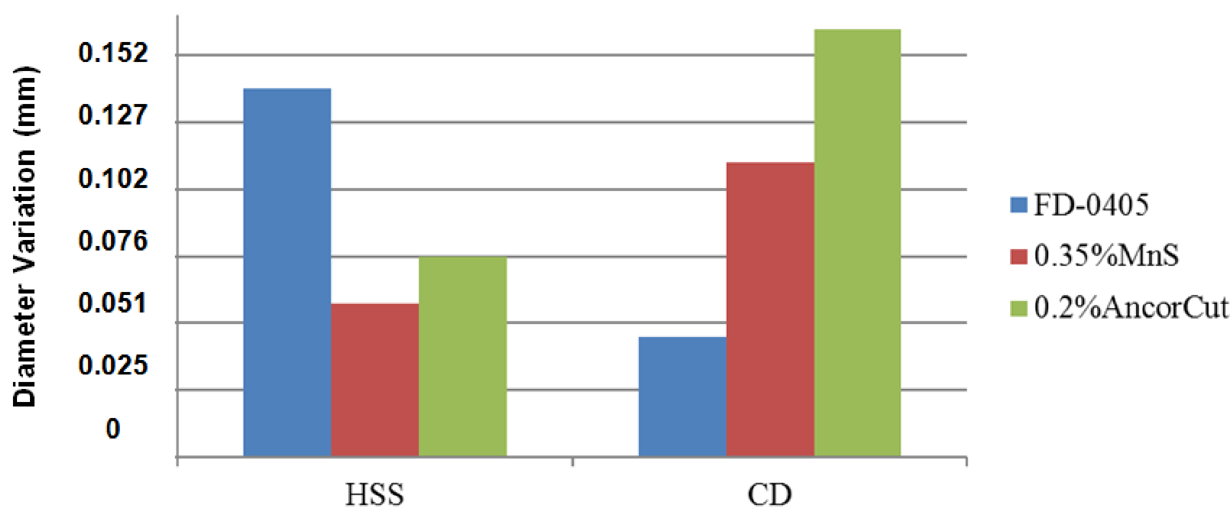

Figure 4. Diameter variation for HSS and CD.

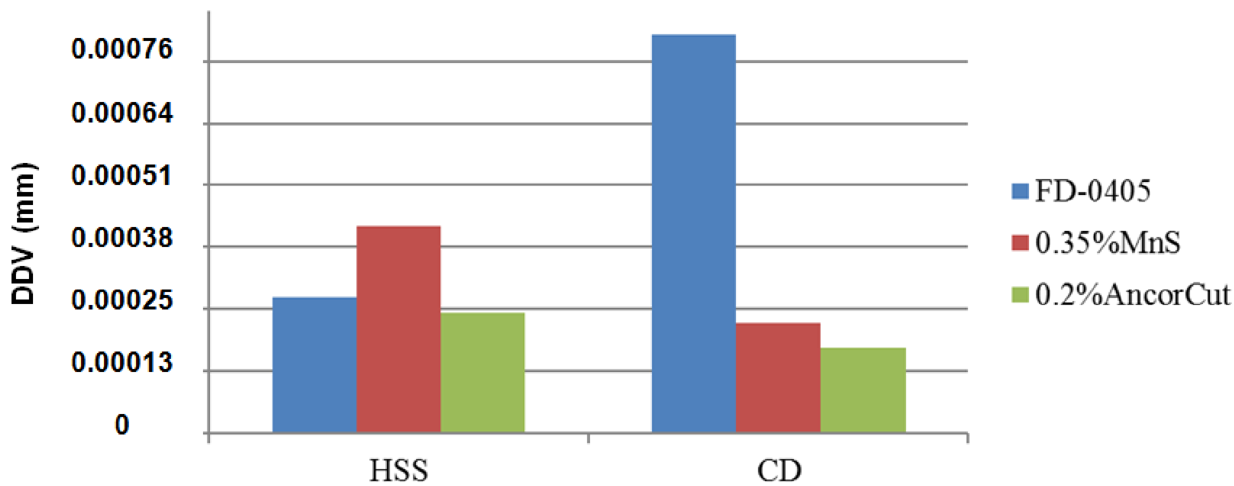

Figure 5. DDV (Discrete Diameter Variation) for HSS and CD.

CONCLUSIONS

The current investigation followed previous promising results from the addition of AncorCut to FC-0208 material [8]. Drilling tests have been continued and the effect of AncorCut on tool life and machining quality in diffusion-alloyed materials (FD-0405) has been analyzed. Results can be recapitulated as follows:

- Absence of coolant resulted in drill bit failure within the first ten holes. Machining with HSS and Carbide drill bits in the presence of coolant resulted in a significant increase in tool life.

- Tool life is highly dependent on test conditions, drill bit materials and machining additives. FD-0405 with no additive displayed long tool life for HSS drill bit, while AncorCut outperformed the other two materials for Carbide drill bits, approaching infinite life (990 holes). Variation of hole diameter was the lowest for MnS for HSS and for FD-0405 when Carbide (CD) bits are used.

- Discrete diameter variation (DDV), previously presented in [8], is a number that allows to benchmark different materials and test conditions, unifying tool life (number of holes drilled) and machining quality (variation of hole diameter). AncorCut exhibited the lowest DDV across both conditions, proving its overall efficacy as a machining additive.

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