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Production Case Studies on the Machinability of Powder Metal (PM) Steels

Roland T Warzel III[1*], Bo Hu [1]
[1]North American Höganäs, Hollsopple, PA, 15658, USA
*Corresponding author: roland.warzel@nah.com

***Abstract*—Machining of powder metal (PM) steels is often completed in order to meet final dimensions, provide a desired surface finish or impart features not possible during compaction. Understanding machinability is of increasing importance as more PM components are machined. Additionally, understanding the roles of machinability enhancing additives and their interaction with different material systems is critical in order to select the best additives for a given material system and machining conditions. This paper will detail the microstructure effects on machining and the effectiveness of machining additives. Production case studies will be presented for different material systems and operations. It will be shown that not all additives are effective in every material system and that pairing the microstructure to the machining additive and machining operation is key to maximizing the machinability.**

Keywords - machinability; machining additives; microstructure;

I. Introduction

While powder metallurgy (PM) is a proven net shape manufacturing technology, a majority of PM components undergo some machining operations. The machining operations are utilized to impart features not capable in compaction, achieve final dimensions or provide a required surface finish [1]. Understanding and maximizing the machinability of the workpiece is therefore critical to ensuring the competitiveness of PM against other manufacturing technique.

Machining is a very complex topic due to the large number of variables which can influence the process. Variables such as the alloying method, processing conditions, machining operations, tooling, and machining parameters can all have a significant effect on the overall machinability [2]. Optimization of the machining parameters, tooling, etc. requires finding the optimum machining conditions for a given material and processing conditions. Part of this optimization process often involves the addition of a machinability enhancing additive.

One of the main advantages of the PM process is the ability to mix in special additives to impart a particular performance response. Improving the machinability is often achieved by mixing machining enhancing additives into the material system. This practice has long been employed as an effective means to achieve higher productivity and improved machining performance from PM steels [3].

The most common additive which has been utilized in PM has been manganese sulfide (MnS). MnS acts as a solid lubricant while also providing chip breaking and tool protection functions [3]. MnS has long been used as a general additive which improves machinability. However, due to increased concern with the negative effect MnS has on corrosion resistance, research efforts have resulted in a number of additives which aim to provide superior machining performance without the negative aspects associated with MnS. [3-7].

II. Experimental

Three production examples will be detailed in this study. The material systems which were used to manufacture the components were different providing an opportunity to evaluate different microstructures and machining enhancing additives. The three material systems which will be discussed are iron-phosphorus, iron-copper-carbon and iron-molybdenum-nickel-carbon.

As each of the production case studies were completed by different customers, the details on the components, materials, processing and machining operations will be detailed in each section. The evaluation of machinability performance was determined in accordance with the standard quality procedures for each case. In some cases, information deemed proprietary will be omitted or generalized in order to protect privacy.

III. PRODUCTION CASE STUDIES

A. Iron-Phosphorus

The iron-phosphorus material system is commonly used in soft magnetic applications. The material system utilizes a high purity iron powder to which the ferroalloy Fe_3P is admixed to achieve a phosphorus content between 0.4 – 0.8%. During standard sintering temperatures, the admixed Fe_3P melts and liquid phase sintering occurs resulting in a ferritic structure with rounded porosity. The phosphorus segregates into low phosphorus and high phosphorus areas.

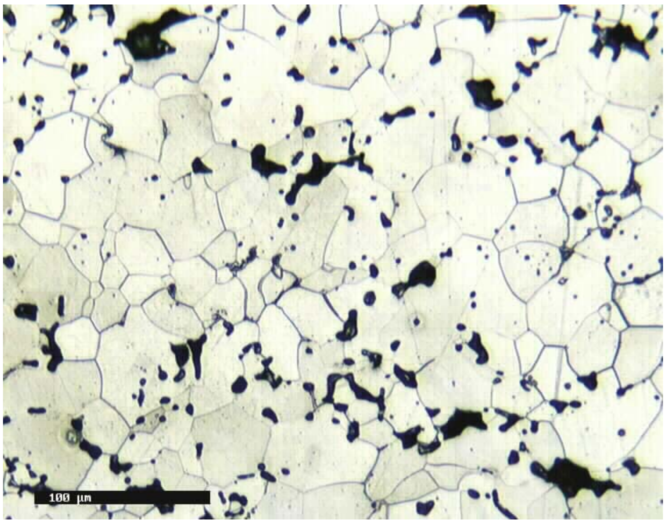

Fig. 1. Microstructure of Fe-0.45P showing a ferritic structure with rounder porosity

While the microstructure is ferritic, the addition of the phosphorus provides an increase in hardness compared to a plain iron material. This hardness level, though, is much less than a traditional PM steel material. The soft structure results in a material which can be difficult to machine due to lack of hardness. During machining, this structure can become gummy and issues with material buildup on the tooling are common.

A production component manufactured using the Fe-0.45P material requires an inner diameter turning operation in order to provide a specified surface finish. The current material utilized MnS in order to provide improved machinability of the material. Issues with low productivity and corrosion resulted in a program to remove the MnS and replace it with a different machining solution.

Components were manufactured from the materials listed in Table 1.

Table 1. Materials evaluated

ID	Composition		
	Base Iron	***% P***	***% Additive***
M	ASC100.29	0.45	0.5 MnS
S	ASC100.29	0.45	0.3 SM3

Components from each mix were compacted to a green density of 7.1 g/cm^3 and sintered in a mesh belt furnace at 1120 °C in a dissociated ammonia atmosphere. After sintering, the components were machined in an automated machining line using a coated carbide insert and water based coolant. The surface finish requirement was the key quality feature of this operation. The number of components which were machined and met the surface finish requirement were tracked per insert used.

The results of the testing found an improvement in productivity by using the SM3 additive.

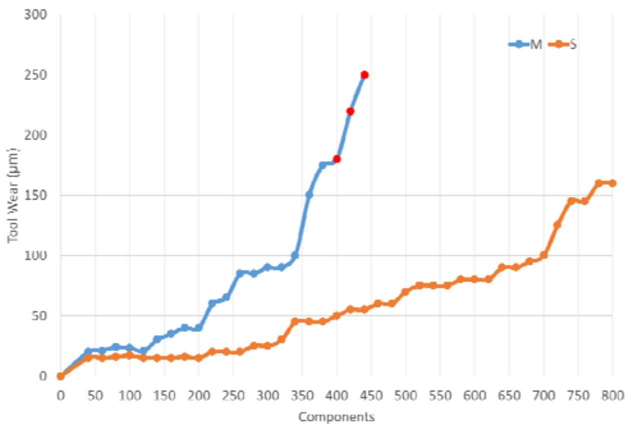

Fig. 2. Results of production machining on Fe-0.45P components showing a large improvement in productivity. Red markers indicated out of specification for surface finish

During the evaluation, it was determined that at approximately 200 μm of tool wear, the surface finished started to degrade and result in non-conforming components. By using the SM3 additive, a low amount of tool wear was achieved resulting in the ability to machine an increased number of components per insert. Significant differences in the inserts were observed for tool wear at the same amount of components machined. A large amount of abrasive wear was found on the flank for the components which utilized MnS compared to a low amount of wear for the SM3 components.

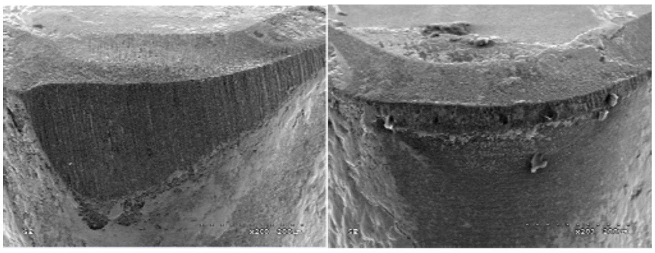

Fig. 3. Comparison of inserts used to machine Fe-0.45P material. The amount of components machined for each insert was 400

The study showed a 100% improvement in tool life under production conditions when using the SM3 additive to provide tool protection.

B. Iron-Copper-Carbon

C. Iron-Molybdenum-Nickel-Carbon

IV. Discussion

V. Conclusion

The selection of machining enhancing additive should take into account the material microstructure and machining operation(s) which are to be conducted. Production case studies indicate that large improvements in productivity can be achieved by using the advanced additions without degrading the corrosion resistance.

As the microstructures of PM steels can vary significantly, the additive and addition level may not be the same in all cases. Choosing the additive and level on a case by case basis taking into the above considerations will result in machining improvement over the standard 0.5% MnS addition which is commonly utilized in industry today.

Acknowledgment

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