# THE USE OF A NEW MACHINABILITY ENHANCER FOR IMPROVING THE MACHINABILITY OF PRE-ALLOYED POWDER METAL COMPONENTS

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## ABSTRACT

To achieve better machinability of powder metallurgy (PM) components, machinability enhancers are often added. Recently a newly developed machinability enhancer, SM3, was introduced. This enhancer was compared to the industry standard additive MnS and showed improved machinability and corrosion resistance in a conventionally cooled prealloyed material system. This paper continues the previous study by examining the heat treat response of the components with different machining additives. The machinability of prealloyed PM components sintered with an accelerated cooling rate is presented.

## INTRODUCTION

As the market required components with increased strength, the PM industry introduced advanced materials such as prealloyed powders. These alloys exhibit harder and multiple phase microstructures compared with iron based materials. As a result, machining of prealloyed materials is more challenging, resulting in lower productivity and/or shortened tool life. Typically, traditional machinability enhancers become less effective as alloying content increases.[1,2]

One of the widely used machinability enhancers is manganese sulfide (MnS). The improvement in machinability achieved with MnS makes it the main machinability enhancer for PM. However, MnS is hygroscopic in nature and cannot be recommended for many applications which may be sensitive to corrosion. Rust is generally a major concern for original equipment manufacturers.

Recently a new machinability enhancer, SM3, developed by North American Höganäs was introduced.[3] This additive has been developed with the objective of improving the machinability of PM materials at low addition levels. In previous studies, machinability evaluations on six different sinter hardened and heat treated prealloyed materials demonstrated that the SM3 can be used as an effective machinability additive enabling productive machining and/or extending tool life.[3] Another study of a conventionally cooled prealloyed material system compared SM3 to the industry standard additive MnS and showed good improvement in machinability without any effect on corrosion resistance.[4]

This paper is a continuation of the previous study where the heat treat response of the components with and without different machining additives is examined. Mechanical properties, components strength tests and the machinability of sinter hardened prealloyed PM components is examined. The influence of machining additives on corrosion resistance is also presented.

## EXPERIMENTAL PROCEDURE

### Materials

A common PM material system (MPIF FLN2-4405) based on Astaloy 85Mo (Fe-Mo pre-alloyed base iron) was chosen for this study. Three mixes were prepared using the Starmix® binder treating process with and without machinability enhancers. Table 1 shows the chemical composition of each bonded mix. Nickel (Type 123, Inco) and natural graphite (SW-1651, Asbury) were utilized in the production of the mixes.

**Table 1.** Chemical compositions of bonded mixes.

| Premix | ID | Base iron | Chemical Composition, %wt | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mo | Ni | Graphite | Lubricant | Additive |
| FLN2-4405 | N | Astaloy 85Mo | 0.85 | 2.0 | 0.7 | 0.75 | None |
| | M | Astaloy 85Mo | 0.85 | 2.0 | 0.7 | 0.75 | 0.25 %MnS |
| | S | Astaloy 85Mo | 0.85 | 2.0 | 0.7 | 0.75 | 0.15 %SM3 |

### Compaction

Crankshaft sprockets were compacted by Cloyes Gear and Products, Inc. to a green density of 6.7 g/cm$^3$ in the body area and 7.1 g/cm$^3$ in the teeth (Figure 1).



**Figure 1.** Crankshaft sprocket with inner keyway.

The crankshaft sprockets parameters are shown in Table 2.

**Table 2.** Crankshaft sprockets base parameters.

| Parameter | Sprockets spec. |
|---|---|
| Outer Diameter x Inner Diameter x High | Ø50 x Ø38 x 45 mm |
| Number of Teeth | 22 |
| Weight | ~330 g |

In addition to crankshaft sprockets, test specimens were prepared from each mix according to MPIF Standards: Standard 41 – Transverse Rupture Strength (TRS); Standard 10 – Tensile Strength (TS) and Standard 40 – Charpy Impact Energy (IE).[7-9] Conventional compaction was used in order to obtain a green density of 6.8 g/cm³ for all test specimens.

### Sintering and Sinter Hardening

Using each material, crankshaft sprockets and test specimens were sintered by Cloyes Gear and Products, Inc. in a production mesh belt furnace at 1121 °C (2050 °F) for 25 minutes at temperature in an atmosphere of 95 v/o nitrogen and 5 v/o hydrogen with a normal cooling rate of 0.8 °C/s.

An additional set of crankshaft sprockets and test specimens were sinter hardened by Cloyes Gear and Products, Inc. in a production mesh belt furnace at 1120 °C (2050 °F) with 5 v/o hydrogen, 95 v/o nitrogen, 5 IPM belt speed (25 minutes at temperature) and the Varicool set at 50Hz (3.0 °C/s).

**Heat treatment**

A set of sintered crankshaft sprockets were induction heat treated by Cloyes Gear and Products, Inc. After heat treatment the sprockets were tempered at 177 °C (350 °F) for one hour in air.

**Mechanical Properties Tests**

Tensile strength and charpy impact energy testing were performed according to ASTM E8 and ASTM E23 respectively.[10,11] The testing was completed by Westmoreland Mechanical Testing & Research (Youngstown, Pennsylvania) and Product Evaluation System (Latrobe, Pennsylvania). Apparent hardness of the crankshaft sprockets was tested at root areas as shown on Figure 2.



**Figure 2.** Apparent hardness test of crankshaft sprockets.

**Crankshaft Sprockets Tooth Strength Tests**

The crankshaft sprockets were subjected to two types of tooth strength tests: axial and radial. The testing was performed by Cloyes Gear and Products, Inc. (Figure 3).

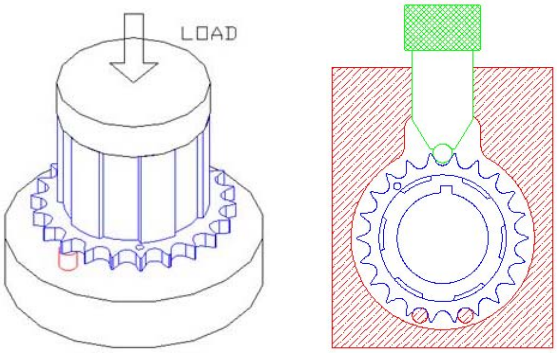



**Figure 3.** Axial and radial tooth strength tests.

**Metallography**

The microstructure of the different materials was examined using Leica optical microscope. The samples were etched with nital/picral.

**Machinability Tests**

After sinter hardening the machinability of all three materials was evaluated using dry machining without coolant. Machining was conducted by Cloyes Gear and Products Inc. in their current production machining line. A computer numerical controlled (CNC) lathe was used for internal turning in the ID of the sprocket. A cutting speed was 274 m/min (900 ft/min), the feed rate was 0.254 mm/rev (0.01 in/rev) and the cutting depth was 0.76 mm (0.03 inch). The keyway in the ID of the sprocket represented an interrupted cut once per revolution. Each sprocket was cut 6 times and each cut passed through a distance of 45 mm (1.75 inch). The cutting tools were TiCN coated carbide inserts (Sandvik).

Machinability was evaluated by measuring the insert wear after machining using a Hitachi S-2600N scanning electron microscope. Figure 4 shows SEM images of new and used inserts and the measurement technique. In this study 200 µm wear was used as criterion of failure. This criterion is typically accepted by industry.

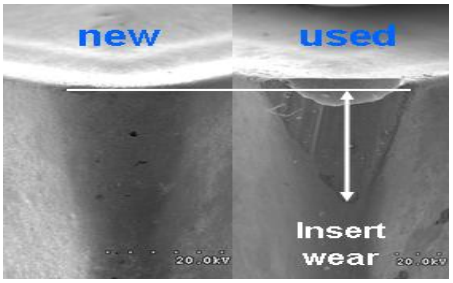



**Figure 4.** Measurement of tool wear.

**Corrosion Tests**

The influence of machinability enhancers on surface corrosion of sintered components was investigated by submitting TRS bars to an environment of 43 °C and 95% relative humidity using a humidity chamber. The amount of corrosion was examined visually and photographed every 24 hours for 24 days. In addition, the surface corrosion of sintered crankshaft sprockets was examined by holding in air at room temperature.

## RESULTS

**Mechanical Properties**

The mechanical properties of Material N, Material M and Material S were tested after sintering and sinter hardening (Table 3).

**Table 3.** Mechanical properties.

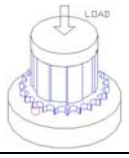
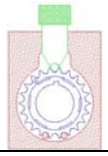
| Properties | Sintered | | | Sinter hardened | | |
|---|---|---|---|---|---|---|
| | **N** | **M** | **S** | **N** | **M** | **S** |
| Density, g/cm³ | 6.84 | 6.82 | 6.82 | 6.80 | 6.82 | 6.82 |
| Carbon, % | 0.60 | 0.59 | 0.60 | 0.60 | 0.59 | 0.59 |
| Apparent Hardness | 86 HRB | 86 HRB | 85 HRB | 21 HRC | 20 HRC | 23 HRC |
| UTS, MPa ($10^3$ psi) | 496 (72) | 496 (72) | 517 (75) | 634 (92) | 600 (87) | 614 (89) |
| Impact Energy, J (ft-lbs) | 12 (9) | 11 (8) | 12 (9) | 7 (5) | 8 (6) | 7 (5) |

The materials with additives have similar mechanical properties as the material without additive (either as sintered or sinter hardened).

**Crankshaft Sprockets Tooth Strength**

The induction heat treated crankshaft sprockets tooth strength tests results (axial and radial) are shown in Table 4.

**Table 4.** Teeth strength tests of crankshaft sprockets, kg (lb).

| **Axial** | | | **Radial** | | |
|---|---|---|---|---|---|
|  | | |  | | |
| **N** | **M** | **S** | **N** | **M** | **S** |
| 1441 (3176) | 1297 (2859) | 1437 (3169) | 1938 (4273) | 1818 (4008) | 2007 (4424) |

There is no significant difference in the induction hardened tooth strength between the materials.

**Microstructure**

Figure 5 shows sinter hardened microstructures for the materials. Sinter hardened microstructures of all specimens and sprockets contain martensite with upper and lower bainite, and Ni-rich phases (austenite). The amount of martensite is elevated compared to the sintered stage.[4]

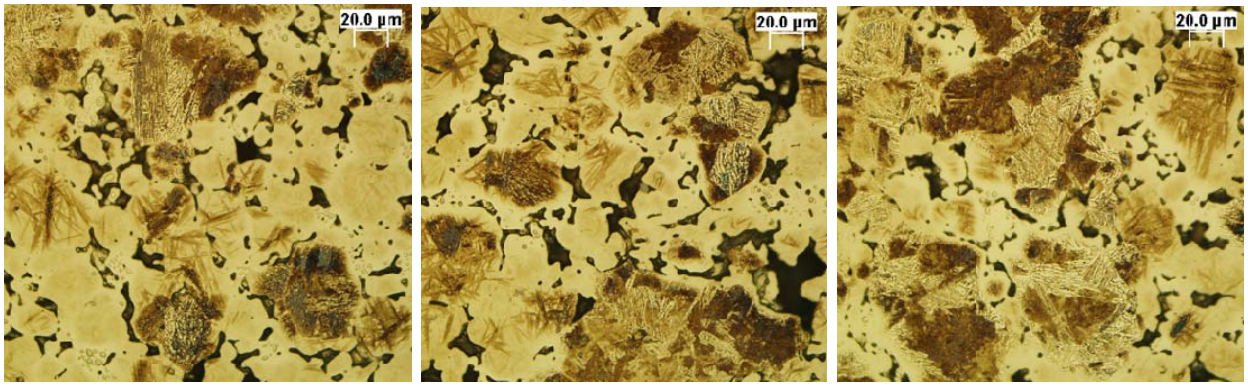



**Figure 5**. Sinter hardened microstructure: Material N (left), M (middle) and S (right).

Induction hardening of crankshaft sprockets changed the microstructure in teeth to martensitic with Ni-rich austenite areas. This microstructure continues through the root areas as a 0.5 mm case. The microindentation hardness varied depending on the distance from the surface and ranged from 673 to 782 $HV_{0.1}$. No difference in the induction hardened teeth was observed between the materials.

**Machinability Evaluations**

The previous study examined the machinability of as sintered sprockets (Figure 6). By using the SM3 additive the amount of passes made before reaching the 200µm wear criteria was doubled compared to MnS.

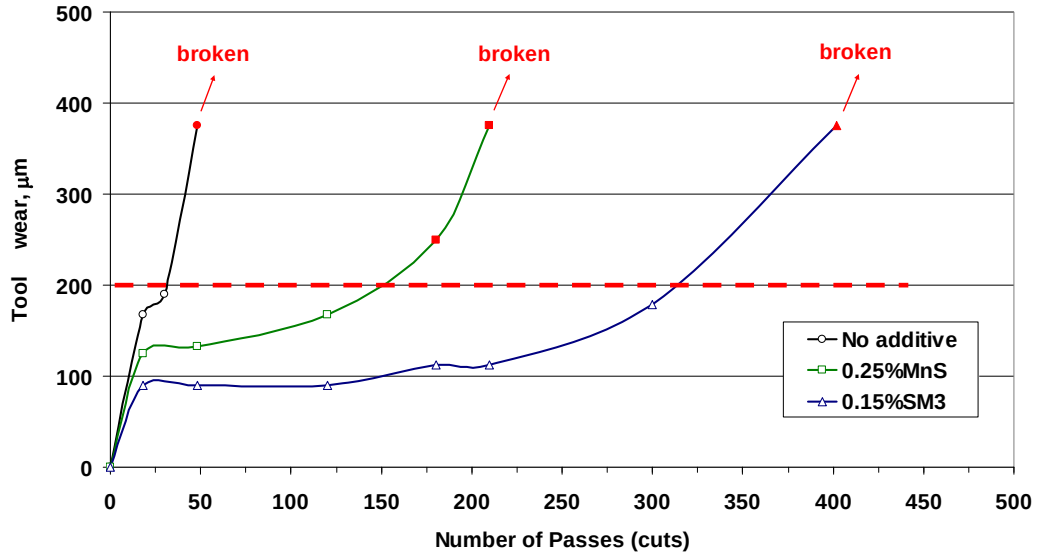



**Figure 6**. Tool wear after turning sintered sprockets.[4]

With the increased amount of martensite in the sinter hardened sprockets, the machining became decidedly more difficult. The tool performance for turning of sinter hardened crankshaft sprockets ID is presented in Figure 7.

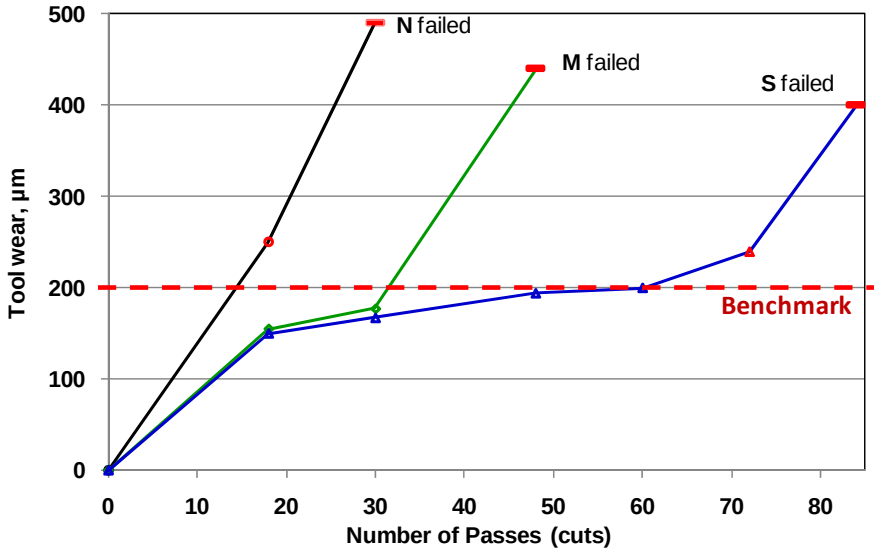



**Figure 7**. Machinability test by turning of sinter hardened crankshaft sprockets ID.

With no additive, the amount of cuts made before reaching 200µm of tool wear was less than 10. By adding MnS to the material, the amount of cuts was tripled. However, by adding SM3 to the material, the amount of cuts was over five times more than no additive and 60% more than MnS.

SEM images in Figure 8 show the status of tool wear after various cuts of Material N, Material M and Material S.

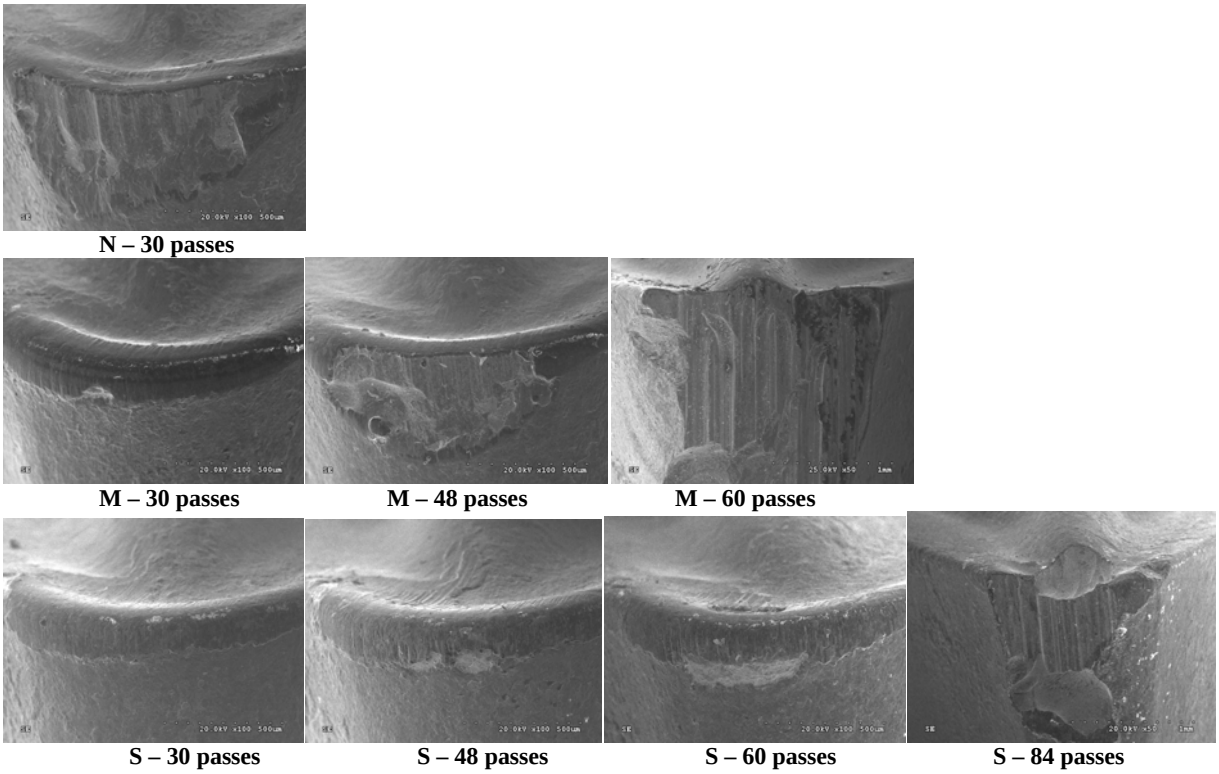



**Figure 8**. Tools wear after cutting different number of sprockets.

**Corrosion Resistance Evaluations**

The influence of machinability enhancers on surface corrosion of sintered specimens was investigated using a humidity chamber. Figure 9 shows the surface of TRS bars after holding in humid environment. Corrosion occurred over the entire surface of TRS bars made from Material M.

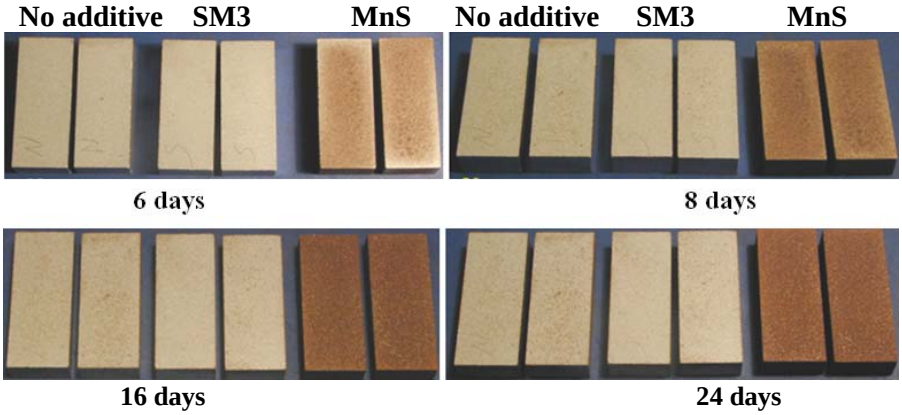



**Figure 9**. Surfaces of sinter hardened TRS bars after humidity chamber exposure at 43 °C & 95% RH.

Figure 10 shows the surface of the crankshaft sprockets after holding in air at room temperature for a week after sintering. Corrosion occurred on the surface of sprockets made from Material M. No corrosion observed on Material N and Material S.

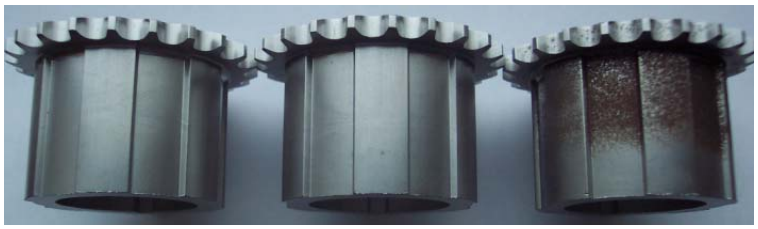


**Figure 10.** Crankshaft sprockets specimens, a week after sintering: Material N (left, no additive), S (middle, SM3) and M (right, MnS).

These results indicate SM3 has no detrimental effect on the corrosion of prealloyed PM materials.

## DISCUSSION

Machining of prealloyed materials can be difficult due to the multiple phase microstructure generated during the sintering process. Different amounts of phases result in the insert having to cut through a variety of hardness levels leading to poor machinability. This poor machinability is often acceptable due to the improvement in mechanical properties.

The machinability of sinter hardened materials can be improved by adding machining additives. MnS was demonstrated to provide triple the tool life when compared to no additive. This large gain in machinability leads to improvement in productivity and more pieces being machined per hour. This increase in productivity comes at a price. The corrosion resistance of the material with the MnS addition is compromised and the material becomes prone to corrosion. As corrosion is recognized as a defect, additional measures are sometimes implemented to reduce the corrosion limiting the total gain in the process.

The new machining additive, SM3, was shown to provide five times the tool life compared to no additive and 60% more than MnS. This machinability improvement was done without compromising the corrosion resistance. With the new additive a larger improvement machinability without the corrosion maximizes the potential improvement in the manufacturing process of this sprocket. As competition from other technologies becomes greater, maximizing the productivity of the PM process becomes more critical.

## CONCLUSION

The results of this study indicated the following:

1. Significant improvements in machinability can be attained using the newly developed machinability additive (SM3). A five-fold increase in tool life was achieved using SM3 over no additive. (MnS, by contrast, only provides a three-fold increase in machinability over no additive.).
2. Compared to the industry standard additive, MnS, the new additive improved the machinability by 60%.
3. No effect on the mechanical performance or microstructure was observed when using the new additive.
4. Unlike MnS, the new additive has no effect on corrosion resistance. In an accelerated testing environment, the new additive performed the same as the material with no additive. The material with MnS was completely covered in corrosion.

## ACKNOWLEDGEMENTS

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