THE CAPABILITY OF A BONDED MIX TO IMPROVE THE PRECISION OF A POWDER METAL (PM) COMPONENT

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ABSTRACT

In order to meet the increasing precision requirements of new applications, bonded mixes are required. Previous studies have shown that by bonding the finer particles to the base iron increased flow rates and tighter tolerances can be achieved. With a number of bonded material solutions available, understanding the relative performance of each is required. In this paper, different bonding systems are compared to a conventional premix for powder properties and final component performance. The precision of the components over a production run will be compared for each bonding system.

INTRODUCTION

As powder metal (PM) faces competition from other manufacturing techniques, the efficiency of the PM process to achieve the final component shape will need to improve. While advances have been made with regards to machining of PM components[1], the simplest way to achieve the final shape is to arrive as close as possible out of the sintering furnace. Resin bonding technology has been utilized to improve the dimensional tolerances of PM components for almost 30 years.[2] Resin bonding involves adding a binder / lubricant system to the material system instead of just a plain lubricant. The binder is used to "glue" graphite and other fine particles to the base iron (Figure 1). By bonding the graphite and other fine particles to the base iron particle, improvements in flow rate and apparent density lead to a more uniform filling of the die cavity by promoting planar sliding of the particle surfaces.[2]

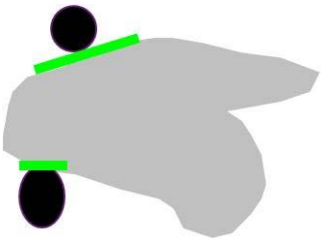


Figure 1. Schematic of resin bonding concept.

The dimensional tolerances can be further improved by utilizing a diffusion alloyed material in combination with a resin bonded system. Studies have shown this combination can improve the precision of a component.[3] This concept results in a homogenous distribution of the alloying elements in the individual component and throughout the production run.

A recent study documented the use of a new bonded material system in difficult applications to eliminate common production issues.[4] In this study, the bonded material system was compared to premixes of the same composition. By achieving better fill and apparent density compared to the premix, improved dimensions and part performance were achieved.

Little work has been done to show the differences between different bonded material systems. It is easy to understand how moving from a premix to a bonded mix can result in an improvement in the properties. However, it is not clear in most cases how different bonded material systems compare to one another. In this study, water pump pulleys were manufactured from a premix and three different bonded material systems. The study shows the different capabilities of the bonded mixes with regards to compaction and ejection performance, productivity improvement, and improvements in precision. The goal of the study is to aid component manufacturer in selecting the proper bonded material system for different components with different performance criteria.

EXPERIMENTAL PROCEDURE

Component

For this trial, a current production component (water pump pulley) was utilized to determine the effect of bonding system on the manufacturing performance. A picture of the water pump pulley and the dimensions are shown in Figure 2.

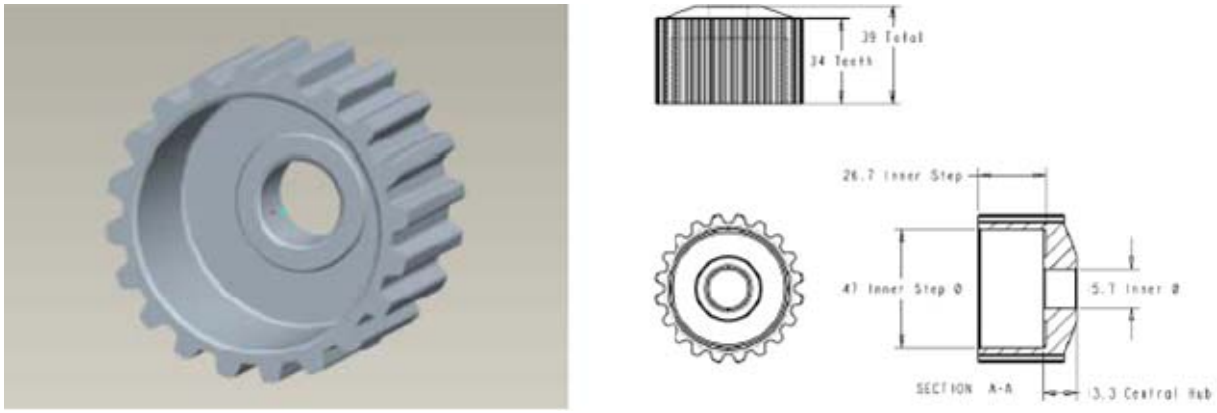


Figure 2. Picture and dimensions of water pump pulley.

Materials
The water pump pulley is currently manufactured from a FC-0205 material system. In the manufacture of the FC-0205 a diffusion alloyed copper material is used for the copper addition. In addition to the reference mix, three different bonded materials were manufactured using the Starmix® resin bonding process. Two of the bonded mixes are commercially available and one is an experimental bonded material currently under development. The materials used for this trial are shown in Table 1.

Table 1. Mix compositions

Description	MIX ID	ASC100.29	D.ACu	Graphite	Lubricant / Binder System
Reference	Ref.	Balance	10%	0.4%	0.75% Amide Wax
Standard Starmix	S	Balance	10%	0.4%	0.75% SL Amide Wax
Starmix BOOST	B	Balance	10%	0.4%	0.75% SL Boost
X - Starmix	X	Balance	10%	0.4%	0.75% X SLube

The D.ACu base powder is alloyed with 10% copper. The 10% addition of this alloy to the mix results in a total copper value of 1.0%.

Compaction & Sampling
Compaction of the pulleys was conducted at Metalsinter (Italy) using a Dorst TPA 160/3 HT compaction press. This compaction press is a 160 ton hydraulic pressed with three lower punches and two upper punches. The press also had the ability to measure and record ejection forces. Water pump pulleys were manufactured according to standard procedures for this geometry to a green density of 6.70 g/cm^3. Pulleys were manufactured at a rate of 8.7 parts / minute. The die filling mode was gravity fill. Each test run included a continuous run of 250 parts. Groups of three parts were sampled after 22, 47, 72, 97 etc. parts had been compacted. This resulted in 30 parts being sampled for each material.

At the end of the compaction run, the press rate was increased until incomplete fill was observed. This criterion was used to determine the maximum press rate for each material system.

Sintering Conditions
The pulleys were sintered in a production mesh belt furnace. Sintering was conducted at 1120 °C for 20 minutes in an endogas atmosphere with a carbon potential of 0.6%.

Evaluation of Sampled Parts
The mixes were measured for flow rate and apparent density according to MPIF standards 03 and 04 respectively.

The pulleys were automatically measured for ejection force and weight. The ejection force recorded was the stripping force. The stripping force is defined as the force needed to initially move the compact during ejection. The temperature of each pulley after ejection was also recorded. The sintered parts were measured for height of the pulley teeth. The value reported was the average of four tooth measurements. Run out was measured by placing the parts on a lash – free axis, rotating them and registering the maximum difference in radius by an indicator. The run out measurement includes both roundness as well as the centering of the hole.

RESULTS

Powder Properties
The flow rate and apparent densities for the materials used in this trial are shown in Table 2.

Table 2. Flow rate and apparent density

Mix ID	Flow Rate (s/50g)	Apparent Density (g/cm^3)
R	31.3	2.90
S	25.0	3.09
B	24.4	3.24
X	28.8	2.95

All of the bonded mixes showed better flow and apparent density properties compared to the premix. The Starmix® BOOST had the fastest flow rate and the highest apparent density. The X – Starmix® flow rate was better than the premix but not as fast as the standard bonded mix.

Compaction Results

Weight scatter calculated as one standard deviation is presented in Figure 3.

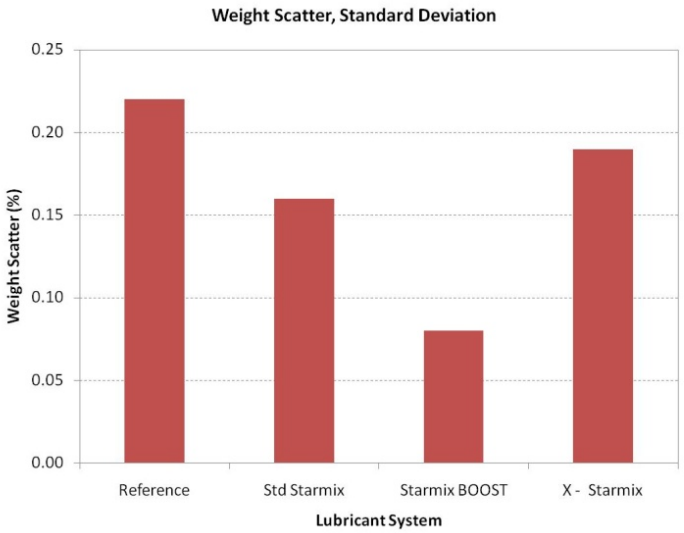


Figure 3. Weight scatter measured as one standard deviation for materials investigated.

The weight scatter was the highest for the premix followed by the X-Starmix®. The Starmix® BOOST had the smallest amount of weight scatter. The importance and relevance of weight scatter will be seen in the sintered component results. The trend for weight scatter correlates with the flow and apparent density measurements of the powder systems.

The maximum press rate achievable for each material is shown in Figure 4.

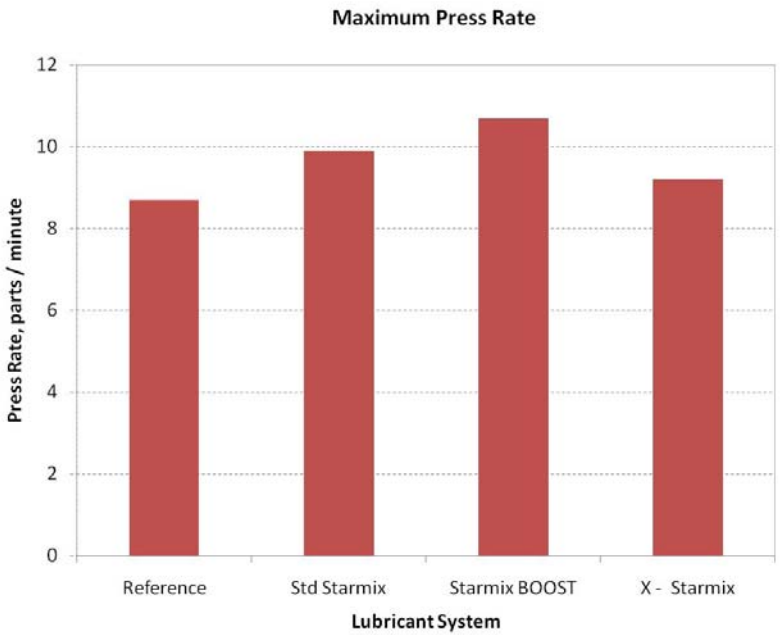


Figure 4. Maximum Press Rate.

The maximum press rate for each material was closely tied to the flow rate. The Starmix® BOOST had the fastest flow and the fastest press rate. The premix had the slowest flow and the slowest press rate. The ability to move powder into the die cavity is key to increasing the press rate.

The stripping force needed for each material system is shown in Figure 5.

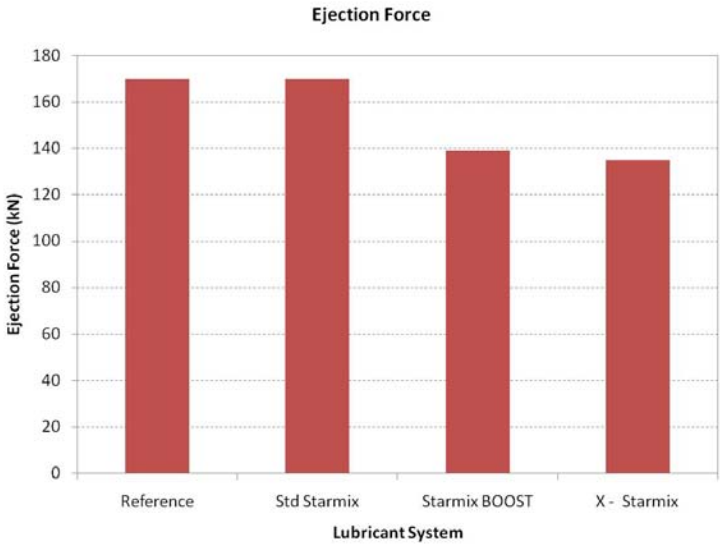


Figure 5. Ejection force experience for each material system.

The highest ejection force was observed using the premixed amide wax and the bonded version of the amide wax. Significant improvement in ejection was found for Starmix® BOOST and the X-Starmix®. A decrease in ejection force by over 20 kN was observed.

Part temperature measurement data is shown in Figure 6.

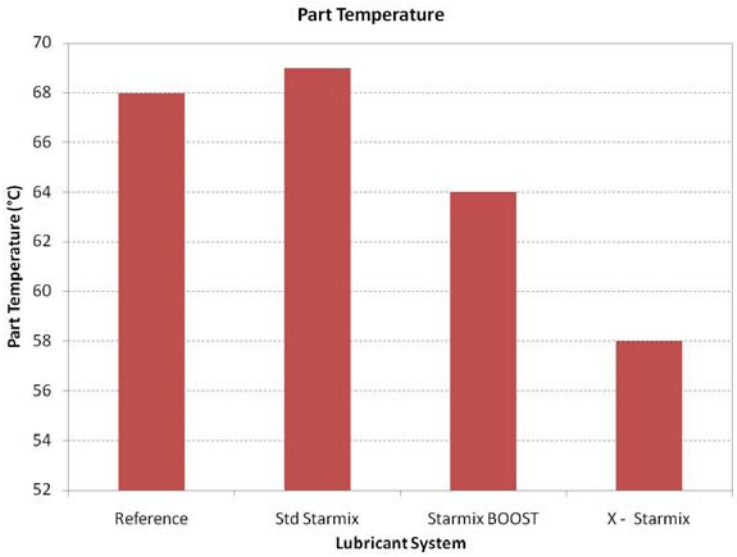


Figure 6. Average part temperature measurement after ejection.

The highest part temperatures were found with the amide wax based lubricant systems. This correlates to the high ejection forces recorded for these material systems. A significant decrease in part temperature was found with Starmix® BOOST and X-Starmix®. The X-Starmix® was measured to be on average 10 °C cooler than the amide based mixes.

Sintered Pulley Results

The scatter in the average tooth height is shown in Figure 7.

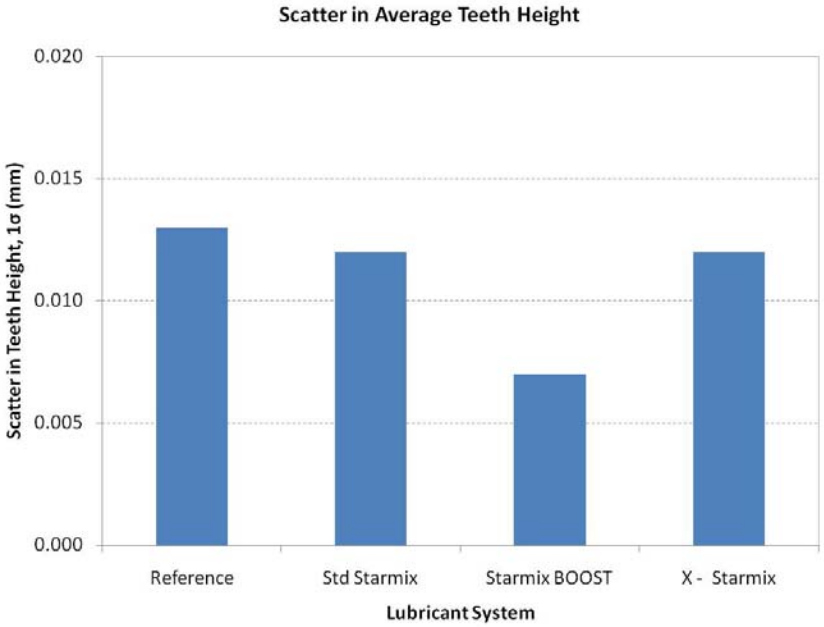


Figure 7. Scatter in average tooth height measured as one standard deviation.

The premix was measured to have the most scatter with regards to tooth height. By moving to a standard bonded mix, the scatter was slightly decreased. Significantly lower scatter was observed with Starmix® BOOST. The X-Starmix® showed similar performance to the standard Starmix®.

The run out for each material system is shown in Figure 8.

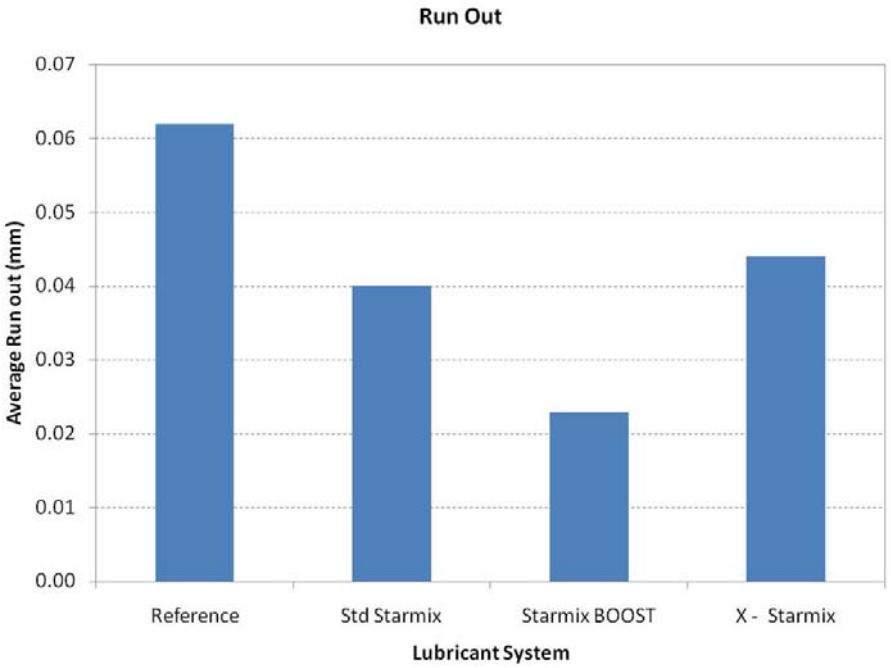


Figure 8. Average run out measurement for material systems investigated.

The highest run out was observed for the premixed material. The bonded mixes significantly reduced the average run-out of the pulley. The lowest run-out was observed with Starmix® BOOST. The X-Starmix® was slightly higher than the standard Starmix®, but still much improved over the premix material.

DISCUSSSION

Bonding of materials has been shown by numerous studies to improve the dimensional tolerances of a component compared to a traditional premix. By bonding the graphite to the base iron particle and eliminating the opportunity for the graphite to segregate, the overall consistency of the component is improved. This improved consistency in chemical composition leads to improved component precision.

In this study, the current manufacturing method already included using a diffusion alloyed copper material as the copper addition. Diffusion alloying the copper to the iron particle eliminates the opportunity for copper segregation and improves the chemical consistency of the component. This leads to improved consistency and precision of the final sintered component.

The results of the trial showed that bonding the graphite to the iron particle could further improve the precision of the pulley. Depending on the Starmix® version utilized the improvement differed. The precision capability is related to the fundamentals of die filling. In all cases, the bonded materials had faster powder flow rates and higher apparent densities compared to the premix. The ability to move powder into the die cavity with ease allows for a more uniform fill. It is reasonable to assume that the more uniform the powder is put into the die, the more uniform the compact will be after compaction. Past studies have illustrated this concept.[4] This study, however, shows there are different degrees fillability within a bonded mix family.

The Starmix® BOOST had the highest apparent density and fastest flow rate out of the materials evaluated. This translated into over a 200% improvement in weight scatter, a 100% improvement in scatter of tooth height and 200% improvement in average run out over the premix.

The standard Starmix® and the X-Starmix® performed similar to each other with regards to weight scatter and average tooth height. There was a difference found with regards to average run out between the two. If the filling is not even around the part, the core rod will be pushed to the side with less powder and thus increase run-out. The standard Starmix® flowed slightly faster which allowed for better filling of the teeth on the pulley compared to the X-Starmix® system. Both had similar apparent densities which is more likely to affect fill height of the component and weight scatter. This is an item which should be considered when choosing a bonded material system.

When evaluating the best manufacturing route for a new component, the surface area of the component and the resultant ejection force often dictate the selection of a lubricant system. As this study showed, the standard Starmix® achieved similar ejection performance as the premixed amide wax. The introduction of Starmix® BOOST allows for more demanding components from an ejection standpoint to utilize a bonded mix system. The X-Starmix® is showed similar ejection properties to the Starmix® BOOST. Another item to consider is the internal lubricity of the powder particles. Better overall lubrication starts with better lubrication on the particle level. Better particle to particle lubrication allows for the powder particles to arrange with greater ease resulting in a more consistent component.

The goal of this study was to provide a guide for selecting the correct bonded system depending on the limiting property. Based on the results, a quick reference guide was developed evaluating lubricant systems with regards to surface area and precision requirements

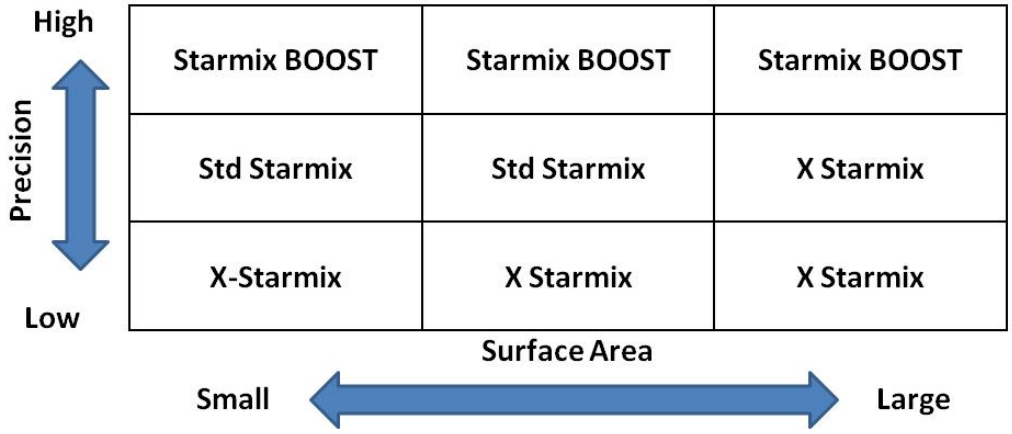


Figure 9. Selecting the correct lubricant system schematic.

CONCLUSION

The following conclusions can be drawn from this study:

- Bonding of graphite to the base iron particle results in improved precision capability.
- Bonding of graphite alone does not determine the precision capability of a material system. The flow rate and apparent density also play a role in determining precision.

- Depending on the dimension in question, different material systems performed slightly different. However, in all cases, the material with the fastest flow rate and highest apparent density resulted in the best precision.

- In order to achieve the final shape in the most efficient manner, the limiting criteria (whether dimensional or ejection performance in nature) should be understood and material selection made accordingly.

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