CHARACTERIZATION OF THE PROPERTIES OF BONDED MIXES USED TO MANUFACTURE POWDER METAL (PM) COMPONENTS

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ABSTRACT

Resin bonding of powder metal (PM) mixes has been shown to improve the flowability and fillability of the mix by bonding the fine particles to the larger iron particles. The improvement in powder properties results in the ability to obtain more consistent components and tighter tolerances. A new bonded mix has been developed which provides improved lubricity while maintaining other powder properties. With many bonding options available it is important to understand the benefits and optimum working conditions of each Starmix® bonding system. In this study, the properties of the new bonded mix will be compared to a conventional Starmix® and Starmix® Boost. Properties such as apparent density, flow rate, green strength, ejection, and filling performance will be compared for each system.

INTRODUCTION

In a PM mix, lubricants are added to a material to reduce particle friction and to aid in the ejection of a part during the compaction process [1]. To improve the flowability and fillability of a material, as well as the ejection, resin bonding can be used. Instead of adding a lubricant to a mix, a binder/lubricant system can be applied to improve these qualities. The use of a binder/lubricant system helps the graphite and other fine particles bond or "glue" to the iron particles [2]. The added benefit to using a bonded mix is that the amount of segregation is reduced. In addition, the flowability and fillability of a part is improved because the graphite and fine particles are not free to move throughout the mix. The bonding helps the material fill the die cavity more uniformly which leads to improved dimensions of a part and improved consistency between the parts produced [2].

In the compaction process, several factors such as the ejection and the filling performance play a role in the molding of a part. During ejection, the stripping pressure and the sliding pressure work together to eject the part out of the die. The peak ejection force or the stripping pressure refers to the point in the ejection process where the part begins to eject out of the die. The sliding pressure refers to the pressure used to keep the part moving out of the die. The ejection curve diagram in Figure 1 shows where the stripping pressure and the sliding pressure occurs [3-4]. An increase in the level of the stripping and sliding pressure would indicate that more pressure is used to eject the part out of the die. To improve the movement of the part, the type and the amount of a lubricant can be adjusted or a binder/lubricant system can be used [2].

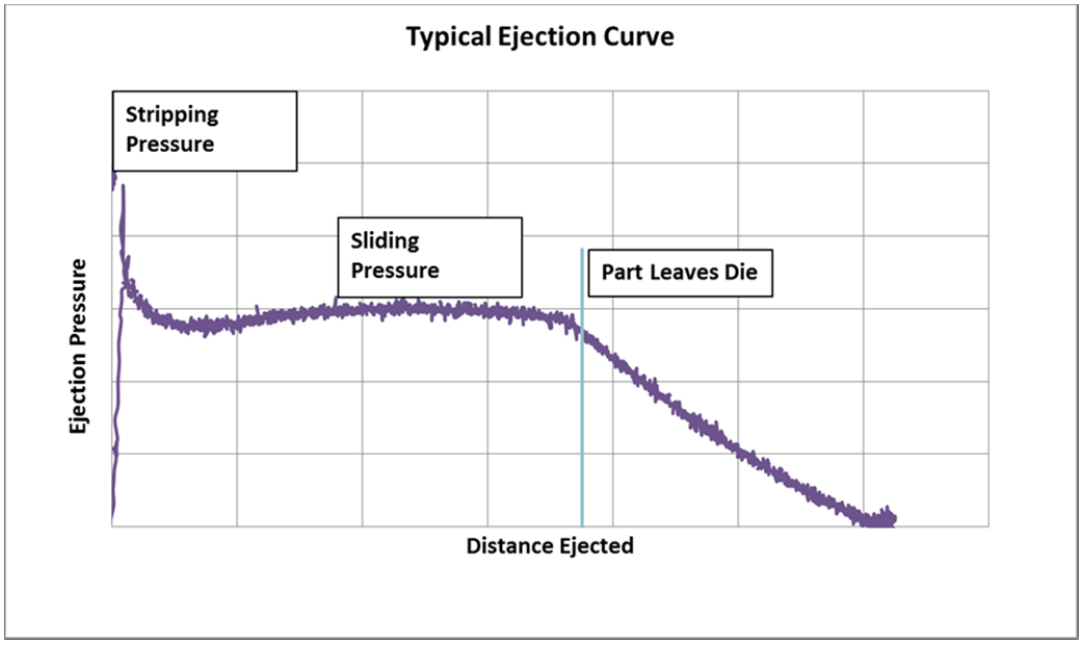


Figure 1: Ejection Curve Diagram [3-4]

A perfectly filled die is difficult to achieve in PM due to the particle shapes and sizes. A PM mix contains irregularly shaped particles with various sized distributions [4]. For thin die sections, filling powder completely can be challenging if the powder does not have good filling properties. Determining how powders fill the die cavity and how the dimensions are affected can lead to significant improvements in manufacturing near-net shaped components. A number of bonded/lubricant material systems have been developed to overcome these challenges [2].

Each binder/lubricant material system varies in properties. Bonded mixes are designed for a similar purpose but they all do not behave in the same manner. Progressing from a premix to a bonded mix significantly improves properties like ejection and the filling performance. Moving through the transition of choosing a proper bonded material for a specific application and determining how they differ from one another can be quite complicated [2]. The purpose of this paper is to compare and contrast different resin bonded material systems. The objective is to evaluate various properties of these material systems such as apparent density, flow rate, filling performance, green strength, dimensional change, apparent hardness and sintered carbon. A study was completed to compare three bonded mixes to a regular premix and to show how each bonding materials differ from one another.

EXPERIMENTAL PROCEDURE

Materials

A total of four mixes were evaluated in this study. Three resin bonded mixes utilizing different binder/lubricant systems were compared to a premix. Each mix was manufactured using ASC100.29, 1.8% Cu-165, 0.7% graphite, and a 0.75% lubricant/binder system. The material compositions that were used for the comparison are shown in Table 1.

Table 1: Mix Compositions

Description	ASC100.29	Cu-165	Graphite	Lubricant/Binder System
Premix	Balance	1.8%	0.7%	0.75% Amide Wax
Starmix® A	Balance	1.8%	0.7%	0.75% SL Amide Wax
Starmix® E	Balance	1.8%	0.7%	0.75% SL Lube-E
Starmix® B	Balance	1.8%	0.7%	0.75% SL Boost

Powder and Sintered Properties

Each mix that was manufactured in the North American Höganäs pilot mixing center in the quantity of 500 kg (1100 lbs.). Samples were pulled after the mixes were packaged. Sampling of materials was completed according to MPIF Standard Test Methods.[7]

The flow rate and apparent density was measured using a Hall flow apparatus. The filling performance was evaluated using a die fill simulator (Figure 2). The die fill simulator is designed to simulate the fill shoe movement and the filling of the die cavities on a press. The simulator used for the experiment contains eight die cavities of different sizes ranging from 1 mm (0.04 in) to 20 mm (0.79 in). The fill shoe travels from left to right and fills the die cavities as it moves over each one. The weight of the powder in the cavities is recorded. The density is calculated from the weight of the powder and the volume of the cavities. The filling index is calculated by using the fill density of the 13 mm (0.51 in) and 2 mm (0.08 in) die cavities (Equation 1). A lower filling index value represents a nice even fill. The filling index should be as close to zero as possible. A perfectly filled die would have a filling index of zero. The fill density of the 13 mm die cavity and the fill density of the 2 mm die cavity would be the same for the filling index to equal to zero [4].

$$\textbf{Experimental Filling Index (\%)} = \frac{FD13mm - FD2mm}{FD13mm} X100 \qquad \textbf{(Equation 1)}$$

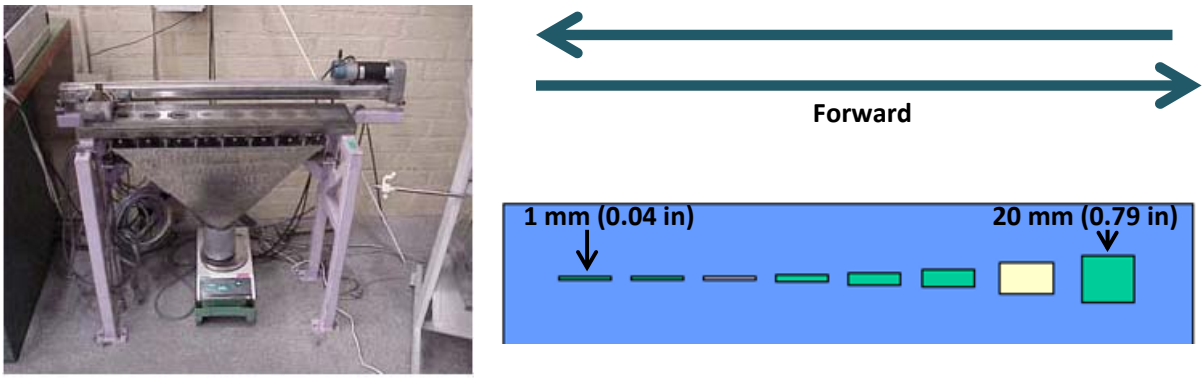
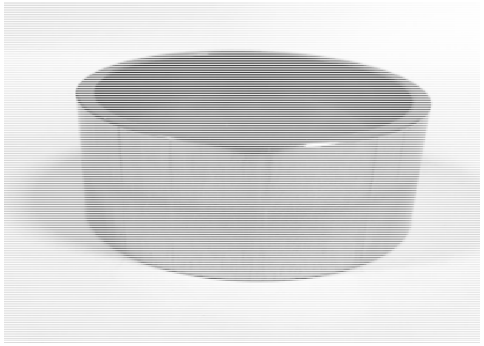


Figure 2: Die Fill Simulator [4-6]

The ejection characteristics for each mix were examined at 410-690 MPa (30-50 TSI). At each compaction pressure, a total of five transverse rupture strength (TRS) bars with a height of 13 mm (0.5 in) were compacted. To evaluate the green and sintered properties for each mix, a total of ten TRS bars were compacted to achieve a green density of 6.9 g/cm^3 with a thickness of 6.35mm (0.25in). Five of the TRS bars were used for the green strength and five were used to test sintered properties such as dimensional change, apparent hardness, and sintered carbon. The bars for the sintered properties were sintered in a laboratory mesh belt furnace at 1121 °C (2050 °F) for 20 minutes in a 90/10 N_2/H_2 atmosphere with a normal cooling rate of 0.5 ° C/s (1 ° F/s). All testing was completed according to MPIF Standard Test Methods.[7]

Production Trials

The premix, Starmix® A, and Starmix® E were sent to Symmco Inc. (Sykesville, PA) for production compaction trials. The objective was to compare the three material systems. Starmix® B was not used because the main focus was on comparing Starmix® A, Starmix® E to the premix to determine how each of the material systems compare and contrast from one another. Bearings were compacted for each mix on a 100 ton hydraulic press. The dimensions of the bearings are shown in Figure 4 below. The parts were compacted to achieve a green density of 6.5g/cm^3. The bearings were compacted at a rate of 7 parts per minute. For each material, a total of 500 parts were manufactured. Every tenth part was sampled to compare the weight scatter and out of round (OOR).



Inner Diameter: 57.2 mm (2.25 in)

Outer Diameter: 63.5 mm (2.50 in)

Height: 25.4 mm (1.0 in)

Wall Thickness: 6.35 mm (0.25in)

Figure 4: Bearing – Symmco Inc. Production Trials

RESULTS

Powder Properties

The flow rate and apparent density results for the mixes are presented in Table 2.

Table 2: Flow Rate and Apparent Density

Mix ID	Flow Rate (s/50g)	Apparent Density (g/cm^3)
Premix	**37.7**	**3.07**
Starmix® A	**26.8**	**3.07**
Starmix® E	**30.9**	**2.99**
Starmix® B	**26.7**	**3.35**

All the bonded mixes showed improved flow characteristics compared to the premix. Starmix A and Starmix® B had the fastest flow rates. Starmix® E was slightly higher than the Starmix® A and

Starmix® B. The premix and Starmix A had similar apparent densities. Starmix® B had the highest apparent density. Starmix® E had the lowest apparent density.

Green Strength

The green strength for each mix is shown in Figure 5.

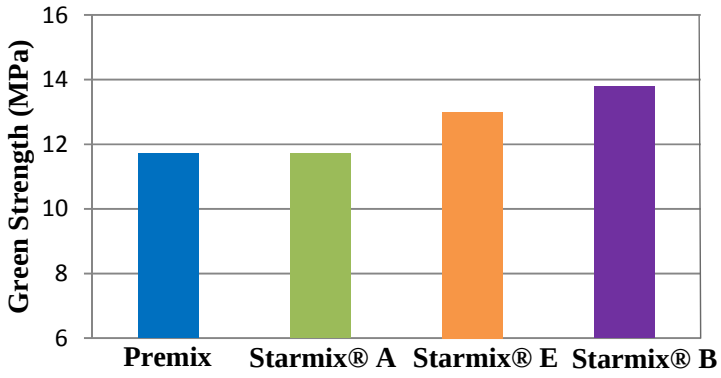


Figure 5: Green Strength

The green strength for the Starmix® E and Starmix® B was slightly higher compared to the premix. Starmix A had similar results to the premix.

Compressibility

The compressibility for each mix was evaluated and shown in Figure 6. The compressibility was examined at 410-690 MPa (30-50 TSI).

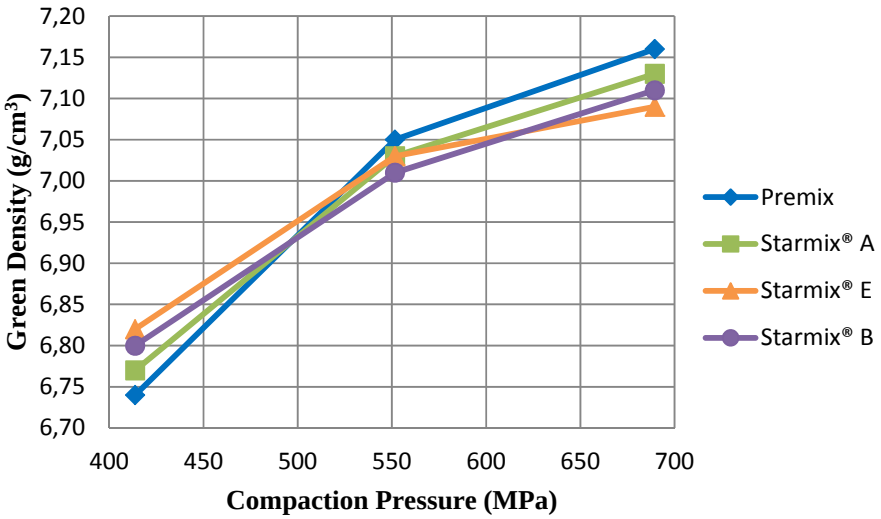


Figure 6: Compressibility Curve

At 400 MPa, the compressibility was slightly higher for each Starmix® compared to the premix. The density for each Starmix® was close to 6.80 g/cm^3. The density for the premix was around 6.75 g/cm^3. At 550 and 700 MPa, each Starmix® had a lower compressibility compared to the premix.

Ejection

The stripping pressure and the sliding pressure was calculated for each mix. The results are shown in Figures 7-8.

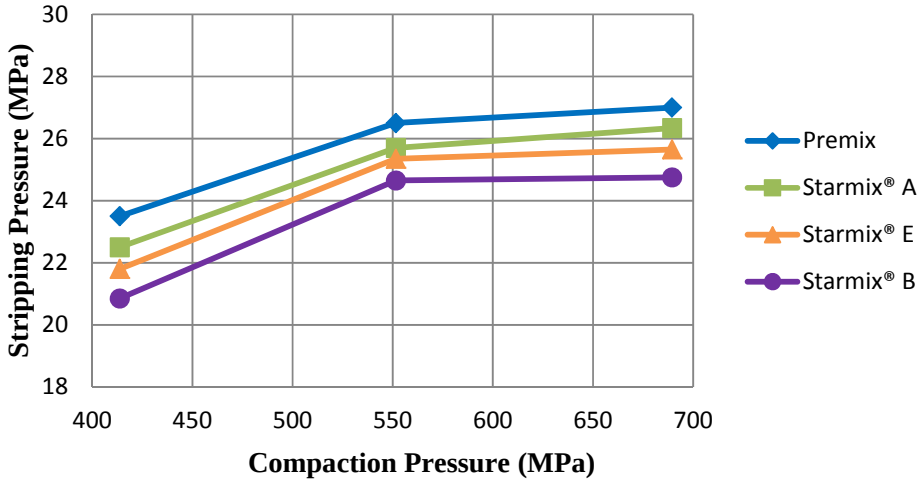


Figure 7: Stripping Pressure

The stripping pressure or the peak ejection force for Starmix® A, Starmix® E, and Starmix® B was lower compared to the premix.

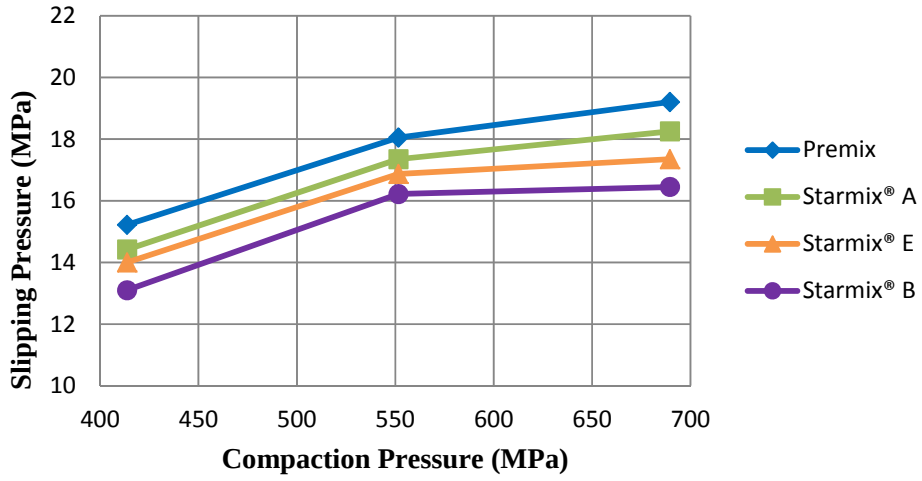


Figure 8: Sliding Pressure

The sliding pressure for Starmix® A, Starmix® E, Starmix® B was lower compared to the premix. Each Starmix showed better ejection compared to the premix.

Examining the stripping pressure and sliding pressure of the ejection process showed that less pressure is used to eject the part out of a die when a bonded mix is used.

Filling performance

The filling performance of each mix is shown in Figure 9.

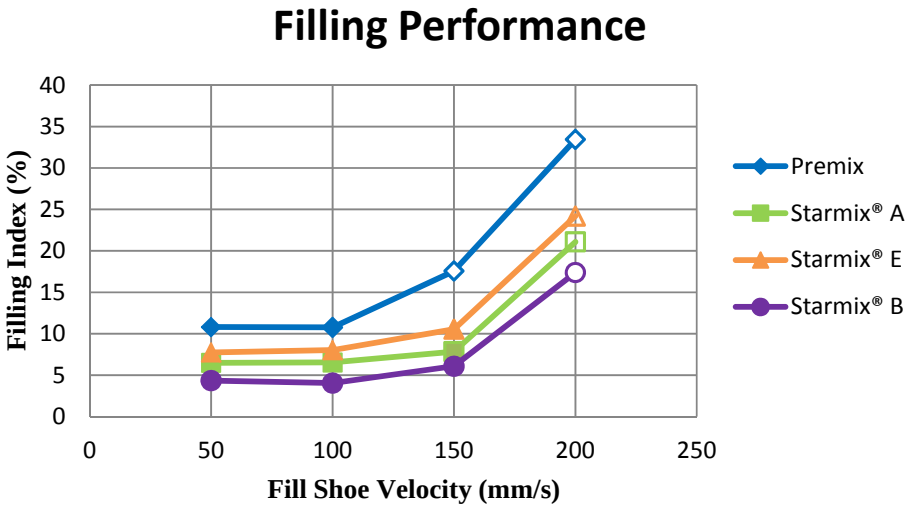


Figure 9: Filling Performance (Filled symbol: complete fill, Open symbol: incomplete fill)

Starmix® A, Starmix® E, and Starmix® B showed an improvement in filling performance compared to the premix. Starmix® A fell in between the Starmix® E and Starmix® B. A filled symbol represents trial runs where all the die cavities were completely filled. An open symbol represents an incomplete fill of the die cavities. At 50 mm/s all the die cavities for each mix was completely filled. At 100 mm/s, Starmix® A, Starmix® E, and Starmix® B had a complete fill but the premix had an incomplete fill. As the speed was increased, an incomplete fill occurred for all the mixes. At slower speeds, the materials had time to completely fill each die cavity.

Sintered Properties

The sintered properties for each material are presented in Table 3.

Table 3: Sintered Properties for the Mixes

Mix ID	DC (%)	HRB	TRS (MPa)	Sintered C (%)
Premix	**0.28**	**75**	**1020**	**0.61**
Starmix® A	**0.36**	**74**	**965**	**0.60**
Starmix® E	**0.27**	**76**	**1013**	**0.62**
Starmix® B	**0.35**	**75**	**992**	**0.62**

For all the mixes, the apparent hardness, transverse rupture strength and the sintered carbon were similar. The only difference between the mixes was the dimensional change. Starmix® E was similar to the premix. Starmix® A and Starmix® B showed a very slight increase in dimensions compared to the premix.

Production Trial Results – Bearings Compacted at Symmco Inc.
Starmix® A and Starmix® E were compared against the Premix for the production trials. Weight scatter and the out of round (OOR) were examined. The weight scatter for the bearings for each material is shown in Figures 10-12. Starmix® E showed the most improvemet. Starmix® A still showed less weight scatter compared to the Premix. The weight scatter is a representation of the flow and apparent density of each material. For each Starmix®, the amount of weight scatter was reduced during the compaction process due to the use of resin bonded materials.

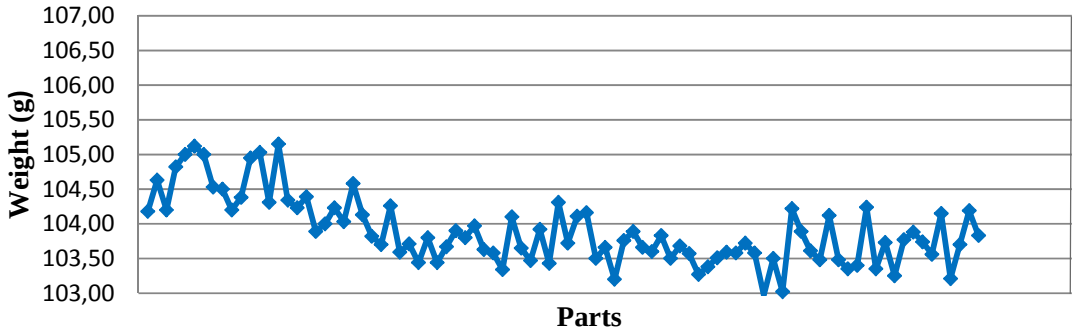


Figure 10: Weight Scatter for the Premix

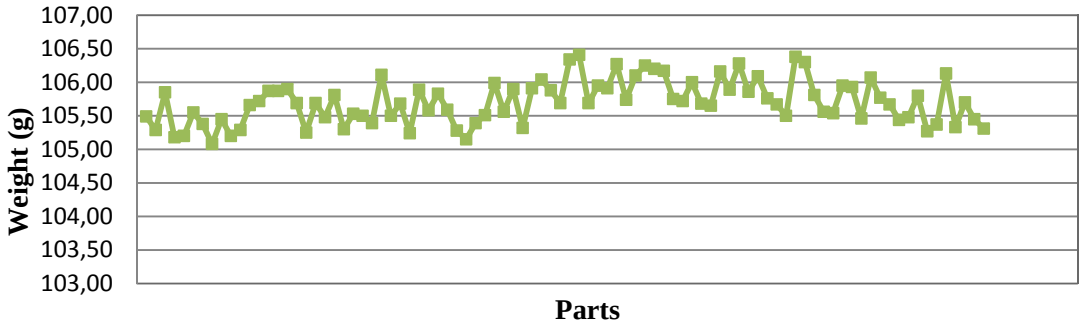


Figure 11: Weight Scatter for Starmix® A

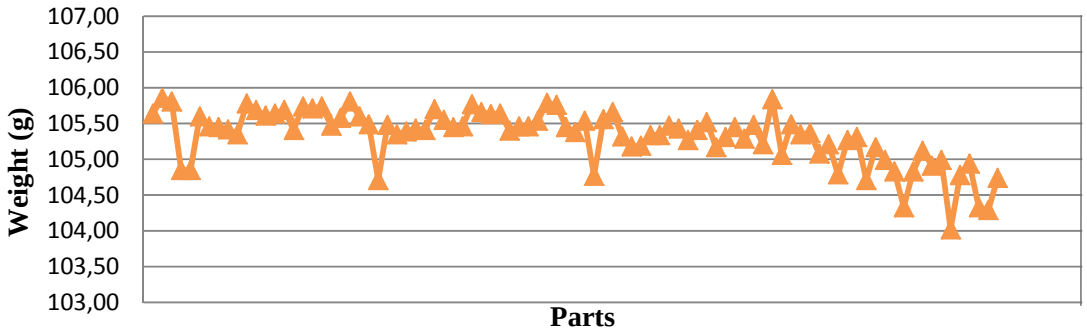


Figure 12: Weight Scatter for Starmix® E

Starmix® A does not show as much scatter as the premix. Starmix® E showed less scatter compared to the premix.

Table 4: Standard Deviation

Mix ID	Standard Deviation (%)
Premix	**0.47**
Starmix® A	**0.40**
Starmix® E	**0.43**

The standard deviation for each material is shown in Table 4. The standard deviation for Starmix® A was lower than the premix. The standard deviation for Starmix® E fell in between the premix and Starmix® A.

Run Out

The run out is shown in Figure 13.

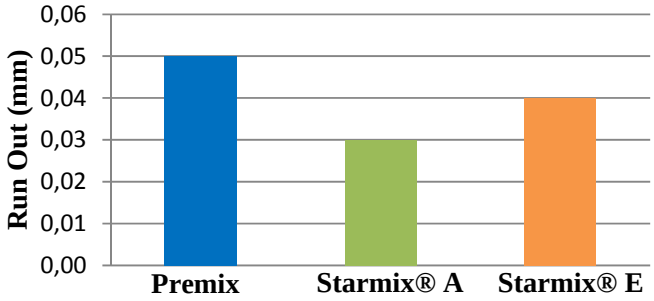


Figure 13: Run Out

The amount of run out for the Starmix® A and Starmix® E was reduced compared to the premix. When the fill in the die cavity is evenly distributed the amount of run out is decreased.

DISCUSSION

When selecting a proper bonding system for a specific application, filling performance and ejection are two properties that are taken into consideration. Mix properties such as the fillability and flowability are improved when a binder/lubricant system is used. Faster flow rates were achieved for all of the bonded mixes compared to the premix. The flow of the material into the die cavity is improved because the graphite and other fine particles are bonded to the iron particles. The bonding of the particles provides a more even die fill which leads to uniformly compacted and consistent components. The study showed that Starmix® A, Starmix® E, and Starmix® B all had a better filling performance compared to the Premix. Each Starmix® had an improvement compared to the premix for ejection performance. The stripping pressure and the sliding pressure were lower for each Starmix® compared to the premix which was best for lubricity.

The filling performance for each Starmix® is improved compared to the premix but not all of the properties for each Starmix® follow this trend or behave the same way. The apparent density for the premix and Starmix® A were similar as both are based on amide wax as a lubricant. Starmix® B showed the highest apparent density. The green strength for the premix and Starmix® A were similar but Starmix® E and Starmix® B showed improvements in the green strength.

The powder properties can be improved when a bonded mix is used, but the sintered properties will remain fairly the same. Each mix might vary slightly. The apparent hardness and sintered carbon for each mix was similar. The dimensional change for each mix varied slightly. The dimensional change for the premix and Starmix E was lower compared to Starmix® A and Starmix® B. The variations in the dimensions were caused by the differences in the bonding methods used. In this case, selecting the proper binder/lubricant system for a specific application is key.

In the production trial, the amount of weight scatter was decreased for Starmix® A and Starmix® E compared to the premix. Bonding the graphite and other fine particles to the iron reduces the amount of scatter between the parts. The run out after sintering was also decreased for the Starmix® A and Starmix® E. The run out was reduced for each Starmix®, due to the material filling the die cavity more evenly and consistently. Differences were observed between each Starmix®. Starmix® A showed improvements in the amount of weight scatter compared to Starmix® E. Starmix® E performed better than the premix.

When the bearings were pressed for the premix, some of the parts had a lower weight compared to the others. A higher amount of weight scatter occurred because the graphite and fine particles are not bonded to the iron.

CONCLUSION

The following conclusions can be drawn from the completion of this study:

- The fillability, flowability, and ejection of a material can be improved by resin bonding. The flow and apparent density is affected because the graphite and other fine particles are not free to move throughout the mix.
- In production conditions bonding systems showed improvements in weight stability and part consistency.
- Depending on the application and desired properties, a bonding system can be selected to properly fit those needs. Understanding the differences in the apparent density, flow rate, and dimensional change is key in the selection process. High precision and improved consistency between the components can be achieved.

ACKNOWLEDGEMENTS

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