# UTILIZING BONDED MIX TECHNOLOGY TO IMPROVE THE DIMENSIONAL CONSISTENCY OF COMPLEX, TIGHTLY TOLERANCED PM COMPONENTS

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## ABSTRACT

Improving the dimensional stability of PM components provides the opportunity to reduce overall cost by potentially eliminating secondary operation such as sizing. The ability to hold tight as-sintered tolerances becomes even more important when more difficult to size prealloyed materials are used. Dimensional stability is affected by many factors, including material handling and mix composition. This paper will investigate how STARMIX™ bonded mixes can improve dimensional stability by reducing the segregation of mix constituents. The investigations presented include conventional and bonded FC-0208 mixes in a simulated production environment.

## INTRODUCTION

The most common type of powder mix used in the PM industry is the conventional premix. The conventional premix combines iron powder and a variety of additives such as copper, graphite, nickel, and lubricants. These ingredients are dry mixed and packaged for use in manufacturing PM components. Conventional premixes provide advantages such as compositional flexibility and relative ease of manufacturing. However, premixes are susceptible to segregation during the handling process that may lead to inconsistency in properties and dimensions[1].

Two ways to reduce segregation and improve consistency are to improve the powder handling system or to bond the smaller, lighter particles to larger particles to prevent segregation[2]. The purpose of this paper will be to investigate the improvements achievable by bonded mixes using the STARMIX™ process combined with diffusion-alloyed copper.

## EXPERIMENTAL PROCEDURE

The performance benefits achievable using STARMIX™ bonded mixes were evaluated by comparing the powder characteristics of bonded and non-bonded mixes and by evaluating the dimensional stability of a gear. The powder characteristics evaluated included the degree to which the graphite was bonded and the flow characteristics of the mixes. The dimensional stability was evaluated by compacting and sintering 5,000 gears from different bonded and non-bonded mixes then evaluating the dimensional characteristics of the gears.

There are several different direct and indirect methods of evaluating the degree to which the graphite in a mix is bonded[2]. Each of these methods is similar in that each test mechanically separates the smaller and

lighter graphite particles from the larger and heavier iron particles. The differences in the tests are the method of separation and whether the results are quantitative or qualitative. Direct methods reviewed are elutriation and separation using standard sieving techniques. Indirect methods include dust monitoring and the paper test[2].

The degree of bonding is evaluated according to Formula 1[2]. The graphite content of the sample before separation is determined by removing the lubricant by Soxhlet extraction then evaluating the carbon content using combustion techniques. The graphite content of the sample after separation is then evaluated by the same technique. The ratio of graphite content after extraction and before extraction are converted to a percentage, or bonding degree[3].

$$\text{Bonding Degree (\%)} = \frac{\text{\% C* Before Separation}}{\text{\% C* After Separation}} \text{ X 100\%}$$

**Formula 1: Bonding Degree**

Elutriation is performed by passing a current of air through a powder sample contained in a tube (Figure 1). The powder is carried up the tube into a chamber, where the air velocity decreases. In the chamber, the air velocity is sufficiently reduced so that heavier particles fall back into the tube. Lighter particles, such as graphite are carried up through the chamber and removed. In order to improve the opportunity for separation, the sample is agitated by a bumper[3]. The degree of bonding is determined by evaluating the amount of graphite in the sample before and after the test according to Formula 1. The advantage of this test method is good separation of ingredients. The disadvantages of this test method are repeatability and length of testing time[2].

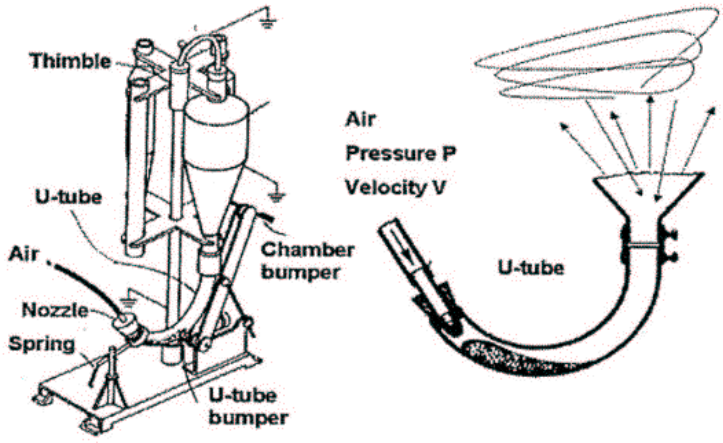



**Figure 1: Roller Air Analyzer**

The degree of graphite bonding may also be analyzed by using standard sieves and a Rotap, similar to MPIF Standard Test Method 05 (Figure 2). The Rotap is set up using a 150 µm and 75 µm screens and the pan. The powder sample is placed on the 150 µm screen and the Rotap operated for 5 minutes. The portion of the powder sample collected on the 75 µm screen is then evaluated for graphite content and compared to the graphite content of the original sample. The disadvantage of this test method is the fact

that in many cases, greater than 100% bonding is achieved. The advantages of this test method are relatively good repeatability and ease of use[2].



**Figure 2: Rotap**

Direct methods of determining bonding degree provide quantitative analysis of the degree of graphite bonding. There are also qualitative methods of determining the degree of graphite bonding. Two qualitative methods of evaluating degree of graphite bonding are dust monitoring and the paper test.

Monitoring of the dust produced by a mix can be done either visually or by using an air sampling technique to measure the amount of fine particles in the air as the mix free falls in a controlled environment. A technique for measuring the dust by air sampling is described here and in Figure 3. In this method of dust monitoring, a Hall Flow Funnel is placed on top of a flask. A powder sample is poured through the funnel into the flask. The quantity of dust particles in the air is then evaluated over time. The lower the degree of bonding, the higher the amount of particles in the air for a longer period of time. The advantage of this test method is a qualitative comparison of different mixes. The disadvantages are the repeatability of the test method and the investment in the monitoring equipment[2].

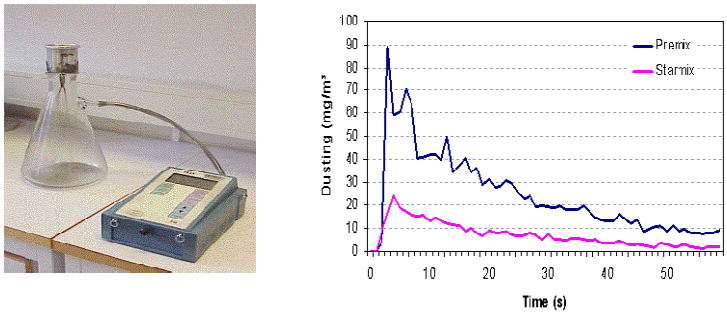



**Figure 3: Dust Monitor**

Another qualitative method of evaluating the degree of graphite bonding is using a sheet of plain white paper. In this technique, approximately 500 g of the powder sample are placed on the sheet of paper. The sample is then shifted around on the paper by lifting up alternating sides or corners of the paper. The sample is then poured off the paper and the residue left behind is then evaluated. The higher the degree of bonding, the lighter the mark left behind on the paper (Figure 4). The disadvantages of this method are lack of quantifiable results leading to differences in operator interpretation. The advantages of the paper test are low cost and ease of use[2].

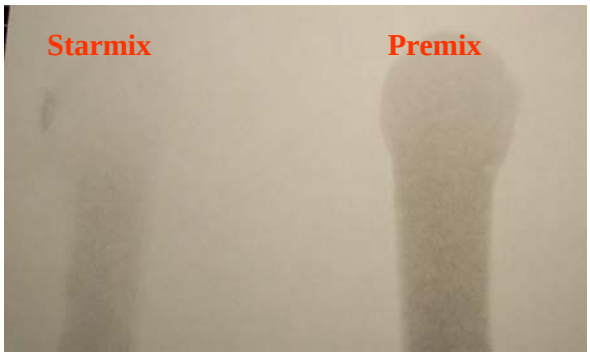



**Figure 4: Paper Test**

The improvement in flow for bonded mixes was also evaluated. Two methods of evaluating flow were conducted. The first was using the Hall Flow Test, according to MPIF Standard 04. The second was to use the Fillability Tester, developed by Höganäs AB in Sweden (Figure 5). The Fillability Tester has eight die cavities. The cavities are 30 mm long and 30 mm deep. The cavities begin with a width of 20 mm and decrease incrementally to 1 mm. A simulated fill shoe is passed over the row of cavities with variable speed. The apparent density of the powder in each cavity is then measured[3].

A theoretically perfect flowing material would fill each cavity, regardless of width or fill shoe speed, to the same apparent density. In reality, narrower cavities are more difficult to fill. The reduction in apparent density in each narrower cavities is also increased by less freely flowing powders and increased fill shoe velocity[3].

In order to more easily quantify the difference in flow between materials, a Fill Index was created (Formula 2). With the Fill Index, the difference in apparent density between the 13 mm wide cavity and the 2 mm wide cavity is dived by the apparent density of the 13 mm wide cavity and converted to a percentage. A theoretically perfect flowing material would have a Fill Index of 100%. Using this fill index, the performance of different powders at different fill shoe speeds can be compared[3].

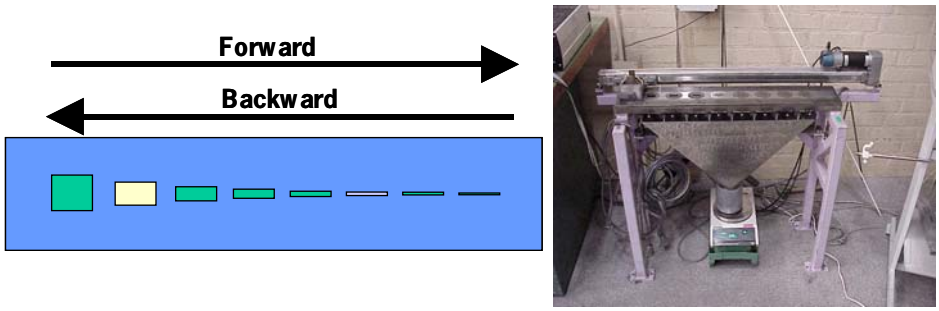



**Figure 5: Fill Tester**

**Formula 2: Filling Index**

The improvements in dimensional stability were evaluated by manufacturing gears from different types of mixes in simulated production. Gears were manufactured using three different types of FC-0205 mixes based on the atomized iron grade ASC100.29 and Asbury 1651 graphite (Table I). Mix 1 was a standard premix using ACuPowder 165 copper and Acrawax. Mix 2 used the same copper, but was bonded using the STARMIX™ process. Mix 3 used the STARMIX™ bonding process combined with a diffusion

alloyed copper master alloy, D.ACu. D.ACu has an atomized iron base, ASC100.29, with 10% copper diffusion alloyed. In order to achieve 2% Cu, 20 % D.ACu was added. Each 500 kg mix was manufactured using production based test mixers at the North American Höganäs Technical Center.

**Table I: Mixes Utilized**

| Mix | Type | Cu (%) | Graphite (%) | Lubricant (%) |
|---|---|---|---|---|
| 1 | Premix | 2.0 | 0.5 | 0.8 |
| 2 | Bonded Mix | 2.0 | 0.5 | 0.8 |
| 3 | Bonded Mix | 2.0* | 0.5 | 0.8 |

* 20% D.ACu

5,000 gears (30 mm (1.2 in.) diameter x 12 mm (0.472 in.) height) from each mix were compacted to a green density of 6.8 g/cm$^3$ using a 100 t Gasbarre Mechanical press at a rate of 12 strokes/minute. Every tenth gear from each mix was separated and serialized. When all 15,000 gears were compacted, the gears were sintered in an Abbott 6" belt furnace for 20 minutes at 1120 °C (2050 °F) in 90 $^{v}/_{o}$ $N_2$/10 $^{v}/_{o}$ $H_2$.

The gears collected for evaluation for randomly sintered with the balance of the gears to simulate production sintering conditions. The serialized gears were then evaluated for out of roundness and the results for each mix compared. The out of round (OOR) was evaluated by comparing the difference in diameter of the gears perpendicular and parallel to the filling direction. The weight stability of each set of gears was also evaluated.

## RESULTS AND DISCUSSION

The degree of bonding of a premix compared to a bonded mix was evaluated using the elutriation test method. The bonded mix yielded a significantly higher rate of graphite bonding (98%) to the bonding degree for the premix (55%). There are many benefits to higher degree of graphite bonding. Improved graphite bonding reduces the potential of segregation or loss of graphite during handling. Reducing segregation results in more consistent physical properties of manufactured components. Bonded graphite also results in a cleaner work environment since the graphite does not float off to settle in the immediate area during handling[3].

The flow of the bonded mix also improved when compared to conventional premix. The Hall Flow Test yielded an improvement of approximately 4 s/50 g. The improvement in flow was also shown by the Fill Index using the Fillability Tester. When using a premix, the best achievable Fill Index was approximately 93% at fill shoe speeds up to approximately 100 mm/s. The Fill Index degraded rapidly above 100 mm/s fill shoe speed, yielding incomplete filling in the 2 mm wide cavity. The bonded mix started with a higher Fill Index, approximately 96%. The Fill Index for the bonded mix did not degrade until fill shoe speed over 150 mm/s, or 50% faster than the maximum fill shoe speed for the premix (Figure 6).

Improvements in flow can result in higher production rates and more consistent components. Powders with improved flow allow die cavities to be filled completely at higher fill shoe speeds. By increasing the fill shoe speed, the press speed can be increased, yielding higher production rates. Improved flow also allows the die cavity to be filled more completely and consistently. Die cavities that are filled consistently are less likely to have green density variations that can lead to dimensional and physical property inconsistency after sintering[3].

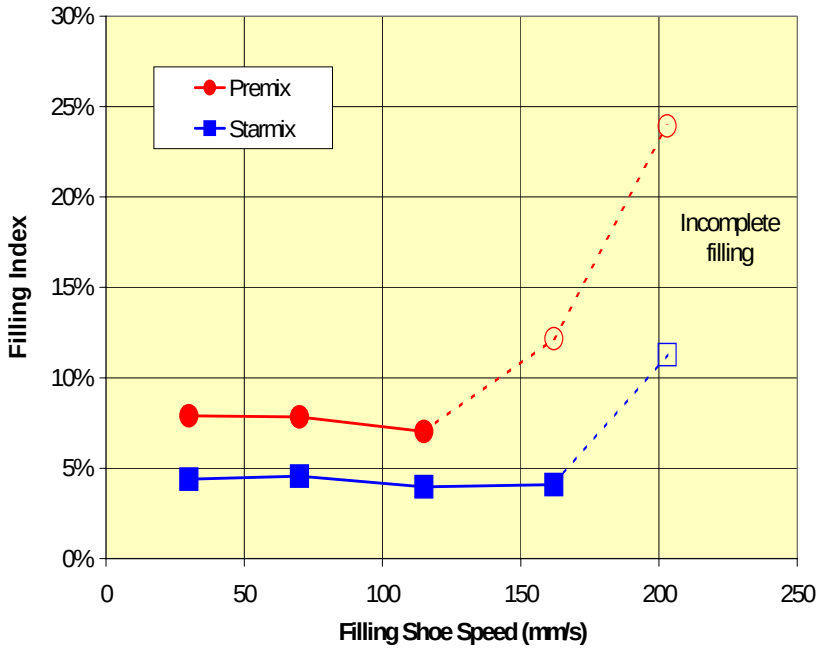



**Figure 6: Fill Index**

Improvements in bonding of mix ingredients combined with improved flow yielded improved dimensional consistency during production of gears (Figure 7). During the evaluation of the out of roundness of the gears, the premix achieved a 6s range of 25 µm (0.001”). By using a bonded mix, the 6s range was reduced by 20% to 20 µm (0.0008”). When a bonded mix was combined with diffusion-alloyed copper, the improvement in the 6s spread compared to the premix was 40%, to 15 µm (0.0006”). The combination of bonding the ingredients provides the potential for dramatically reducing the dimensional variation in the PM process (Figure 7).

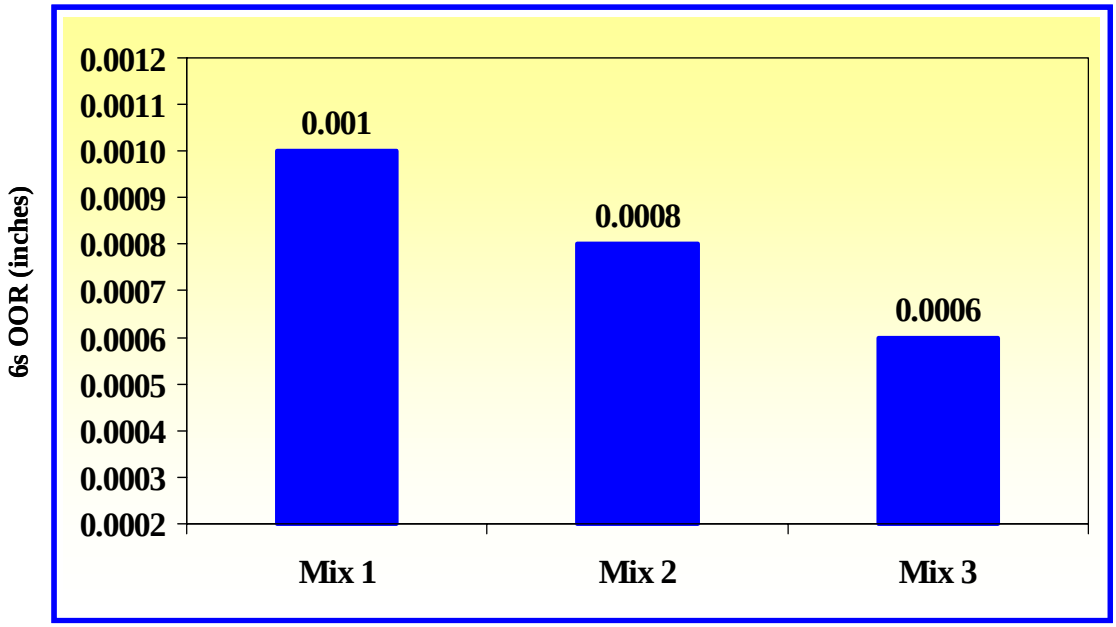


**Figure 7: Gear out of Roundness**

The weight stability of the gears was also evaluated. The 6s spread of the weight is presented in Figure 8 as a function of total weight. As can be seen in Figure 8, the bonded mix performs better from a weight stability standpoint. Improved weight stability leads to lower variation in density variation, property variation, and improved dimensional stability.

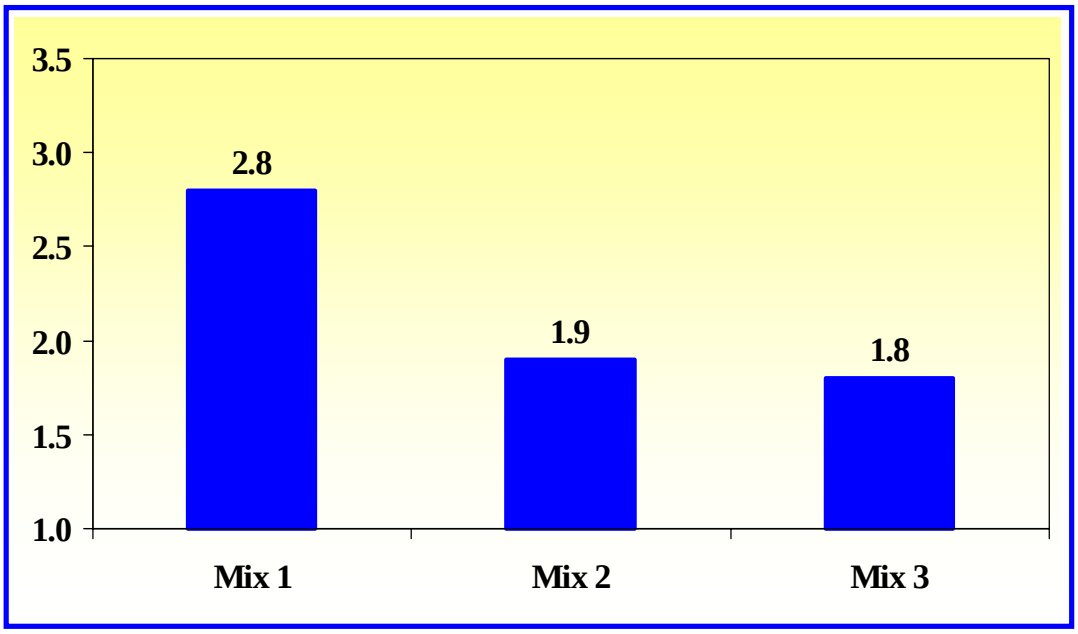



**Figure 8: Weight Stability**

## CONCLUSIONS

Based on the evaluation, the following conclusions can be made:

1. The STARMIX™ process yields graphite bonding percentages of up to 98%, compared to 55% for a conventional premix.

2. The STARMIX™ process yields improvements in the flow characteristics of mixes. Bonded mixes using the STARMIX™ process flow up to 4 s/50 g faster in the Hall Flow Test. Bonded mixes also perform better in the Fillability Tester, completely filling the die cavities at up to 50% higher fill shoe speeds.

3. Bonded mixes using the STARMIX™ process yielded a 50% improvement in the dimensional consistency of a gear compared to a premix. The improvement increased to 40% when diffusion alloyed copper was used.

4. Bonded mixes using the STARMIX™ process yielded a 50% improvement in the weight consistency of a gear compared to a premix.

## ACKNOWLEDGMENTS

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