IMPROVEMENTS IN DIMENSIONAL CONSISTENCY USING STARMIX™ BONDED PRODUCTS

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ABSTRACT

Many factors influence the productivity and efficiency of the powder metal process. Among these are segregation of the mix constituents and filling performance. STARMIX™ products address these issues by bonding ingredients to reduce segregation and increase filling performance. This paper describes the improvements in dimensional stability attainable with STARMIX™ products by using case studies comparing the performance of premixes made with conventional blending to STARMIX™ products. The results of laboratory based testing will also be discussed.

INTRODUCTION

The demand of close dimensional tolerances is and will be a key factor for successful P/M production. In a time when precision parts for the automotive industry gets more and more complex in geometry, resulting in deep and narrow filling spacings, the use of a powder mix and handling system, providing excellent filling performance and no or limited segregation are essential.

In the ferrous P/M industry the Fe-Cu-C system has been the most common one for a long time. The low melting point of copper provides a liquid phase at conventional sintering temperatures resulting in a fast diffusion into the iron matrix, and by that, a fairly homogenous structure and high strength when carbon is present. However, due to the liquid phase formation, the use of copper cause swelling during sintering. Due to density, size, and morphology differences between elemental alloying particles and the base powder, there is always a risk for segregation [1], which in the case of copper may result in significant scatter in dimensional tolerances. The above issue of copper segregation was the incitement for the development of diffusion bonded powder grades D.Cu and D.ACu, where 10 w/o of fine copper powder are bonded on sponge iron (NC 100.24) and water atomized (ASC 100.29) iron powder, respectively. The use of diffusion bonded copper serves for minimal segregation, and by that, closer tolerances [2-4].

While diffusion bonding is restricted to bonding of fine metal alloys the STARMIX™ allows for bonding of organics and graphite. In unbonded mixes small particles may cause erratic flow behavior in the filling system and poor air permeability. Bridging and rat hole formation during the filling cycle may cause not just segregation of fine particles, but also uneven filling densities in deep or narrow cavities, which negatively affects the final tolerances. In previous studies [5-8], the benefits of the STARMIX™ system regarding fillability, weight variation and increased productivity during compaction have been demonstrated by comparing unbonded PREMIX with bonded mixes.

In the present study, the combined effect of using the STARMIX™ concept in addition to diffusion bonded copper powders on dimensional tolerances and filling performance are shown. Comparisons regarding filling performance and final tolerances between bonded mixes and corresponding PREMIX, with and without the use of diffusion alloyed copper, are presented.

EXPERIMENTAL PROCEDURE

Material

Composition of the mixes used in this study is presented below. Bonded STARMIX™ contained 0.8% SL Amide wax and the non-bonded PREMIX 0.8% Acrawax.

1. PREMIX	ASC100.29 + 2% Cu-165 + 0.8% C-1651
2. STARMIX™	ASC100.29 + 2% Cu-165 + 0.8% C-1651
3. PREMIX	ASC100.29 + 2% Cu (D.ACu) + 0.8% C-1651
4. STARMIX™	ASC100.29 + 2% Cu (D.ACu) + 0.8% C-1651

Testing

Powder properties, Hall Flow and Apparent Density were measured according to ASTM standard B 233-03 and B 212-99.

Bonding

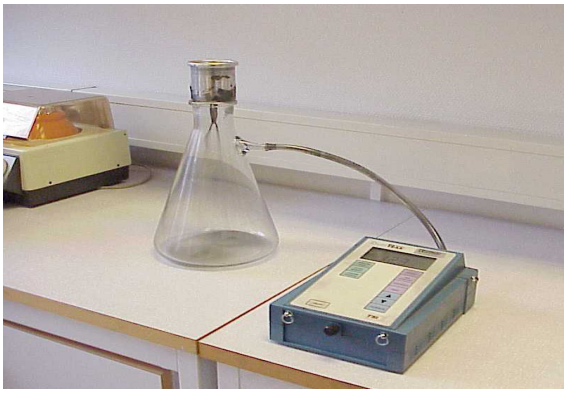
The bonding degree of graphite was measured with an air classifier, Roller Air Analyzer from Aminco. The parameters were set to separate graphite particles with a particle size of 4µm. The sample weight was 50g. The graphite content was measured before and after operation in order to calculate the bonding degree as follows (1):

(1) $$\frac{C_2}{C_1} \times 100 = \text{Bonded graphite (\%)}$$

C_1 = Analyzed graphite before test

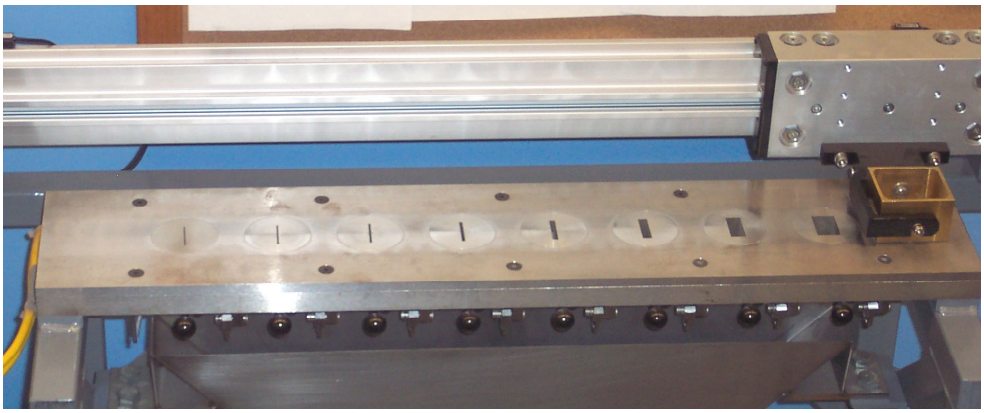
C_2 = Analyzed graphite after test

Dusting
A Dust Track Aerosol Monitor, figure 1, was used to measure the dusting of the powder mixes. A sample weight of 5g is dispersed through a Hall flow cup into a sample container. Air, at a flow of 1.7 dm^3/min (1.8 qt/min), is extracted into the equipment and particles less than 10µm monitored.


Figure 1. Dust Track Aerosol monitor.

Die filling simulation
The filling performance of the powder mixes was evaluated with a Die Filling Simulator, described in detail in previous publications [5,9]. The equipment, figure 2, consists of eight cavities with varying widths between 1 mm (0.04 inch) and 20 mm (0.79 inch), having a fixed length and depth of 30 mm (1.2 inch). The cavities are filled in sequence at different speeds and the powder from each cavity is subsequently collected and measured for filling density. To simplify the presentation, of the filling behavior for a powder mix, a Filling Index (2) is defined and plotted against the filling speed.

(2) $$\frac{AD_{13mm} - AD_{2mm}}{AD_{13mm}} \times 100 = \text{Filling index (\%)}$$


Figure 2. Die Filling Simulator

Ejection performance
Ring shaped parts, outer diameter 55 mm (2.17 inch), inner diameter 45 mm (1.77 inch) and 10 mm (0.39 inch) height were compacted at 400 MPa (29 tsi), 600 MPa (43.5 tsi) and 800 MPa (58 tsi) in a laboratory press. The parts were measured for ejection energy and green density.

Production trial
A small 28 teeth gear, figure 3, was compacted in a 100 ton Gasbarre press to a green density of 7.0 g/cm^3 and an approximate weight of 76 g. The outer diameter of the gear is 43 mm (1.69 inch), the inner diameter 23 mm (0.91 inch) and the height was set to 12 mm (0.47 inch). 750 components were compacted for each mix at 16 strokes/minute. After compaction the components were sintered in a production furnace for 20 minutes in 90% N_2/ 10% H_2 at 2050°F (1120°C). 5 components every 25 strokes were collected and measured for weight and dimensional scatter.



Figure 3. Compacted gear

RESULTS AND DISCUSSION

Powder properties
Hall flow and apparent density are presented below. The flow rate is considerably faster for the bonded mix compared to the corresponding Premix. Previous investigations [6-8] concludes that the enhanced filling rate make a productivity increase in the compaction process possible.

Table I. Powder properties

	1. PREMIX	2. STARMIX™	3. PREMIX	4. STARMIX™
Flow (s/50g)	32	24	33	25
AD (g/cm^3)	2.94	3.08	2.94	3.00

Die filling simulation
Kondoh and Takemoto [10] as well as Cocks and Wu [11] have visually observed that removal of entrapped air to a considerable extent influence the filling mechanism of deep or narrow cavities. Also, non-bonded graphite and lubricants may cause bridging and erratic flow behavior. This, in combination with a faster flow for STARMIX™ compared to corresponding PREMIX can, explain the obtained results from the Die filling simulation, figure 4.

In the figure below, the Filling Index is plotted against the speed of the filling shoe. A low Filling Index concludes even density levels between narrow and wider cavities, while a higher Filling Index may imply in poor filling performance. From the Die filling simulation it is obvious that the bonded mix performs better than the non-bonded, especially at enhanced filling rates.

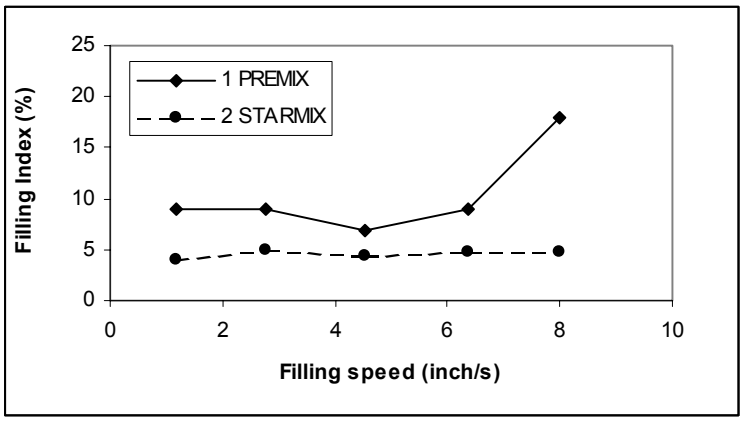


Figure 4. Die filling simulation

Bonding
The bonding of graphite, measured in the Roller Air Analyzer, is presented in table II.

Table II. Bonding of graphite

	1. PREMIX	2. STARMIX™
Bonded graphite (%)	55	98

STARMIX™ serves for a close to complete bonding of graphite, which is a prerequisite for optimal tolerances.

Dusting
A low dusting powder mix serves for improved working behavior in the compaction process. In figure 5 below, it is shown that the STARMIX™ provides for a considerable reduction in dusting. This is due to a superior bonding of graphite and lubricants.

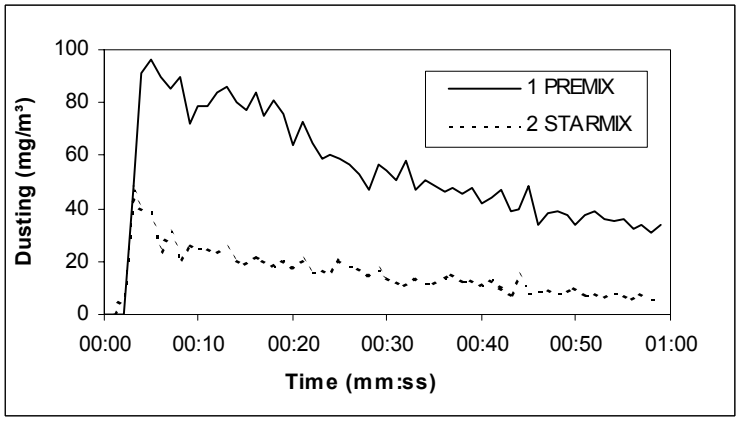


Figure 5. Dusting – Dust Track Aerosol Monitor

Ejection performance
In figure 6, the ejection energy for corresponding bonded and non-bonded mix are presented.

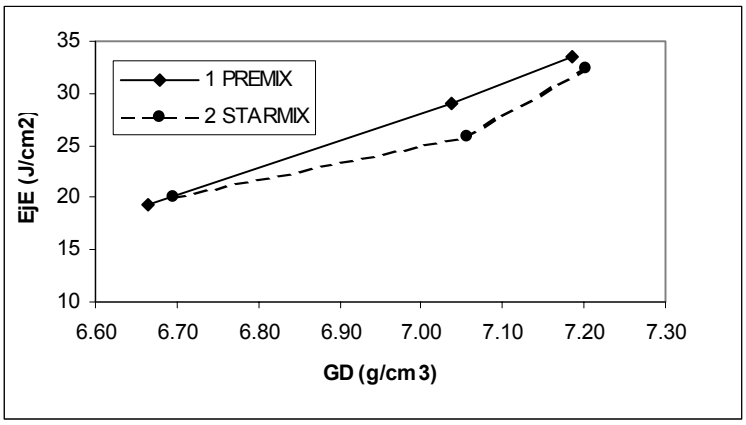


Figure 6. Ejection energy

In previous papers [5-8] the benefit of increased compaction productivity by the use of bonded mixes has been presented. Higher compaction speeds may increase the die temperature, which may place high demands on the lubricity of the powder mix. The lubricant system utilized in STARMIX™ matches or even improves, the ejection properties compared to a corresponding PREMIX.

Production trial
The green weight scatter is presented in figure 7, below. The good filling behavior of STARMIX™, illustrated in the die filling simulation, serves for a decreased weight variation during compaction. Still, the compaction speed applied in these trials was at a level, where the filling characteristic for the PREMIX is acceptable. The positive effect of using a bonded mix would be even more pronounced at higher compaction speeds [7,8].

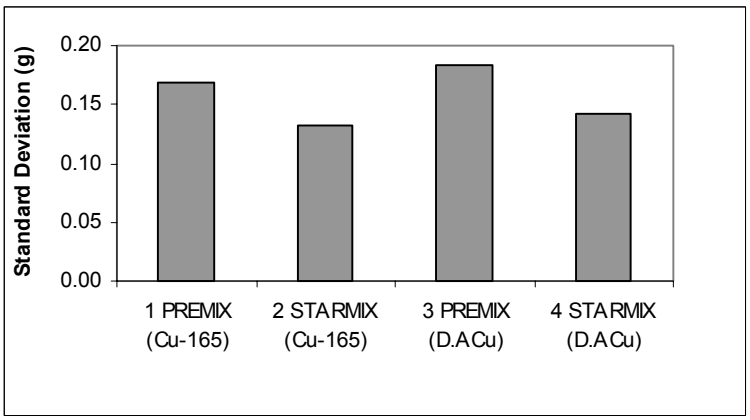


Figure 7. Green weight scatter

The superior fillability of STARMIX™, compared to corresponding PREMIX, could also be seen in the decreased out of roundness, presented in figure 8. The out of roundness, in this case, is defined as the length difference between two perpendicular diameters. The better roundness for the bonded mix may be explained by a more homogenous density distribution, among others due to easier removal of entrapped air and less bridging effects during filling.

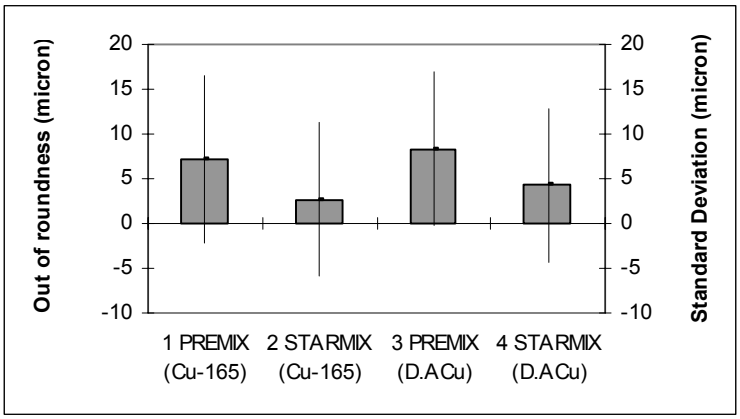


Figure 8. Out of roundness, green parts. Diameter 1 – Diameter 2.

The differences in out of roundness in green condition are primarily due to the filling characteristics of the powder mixes. In sintered state also the chemical distribution, in this case copper and graphite, will influence the roundness of the component. As presented in figure 9, both the ovality and the scatter decrease by utilizing the STARMIX™ mixes. Compared to the same measurements in green condition the difference between the bonded and non-bonded mixer are larger. This is explained by the more homogenous distribution of alloying elements the bonded mix serves for.

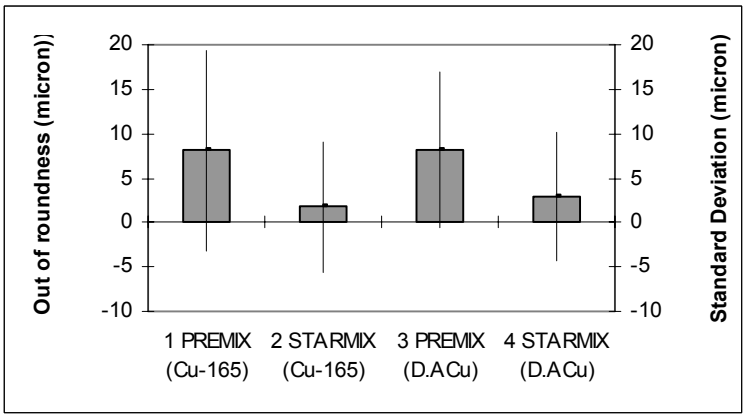


Figure 9. Out of roundness, sintered parts. Diameter 1 – Diameter 2.

In figure 10, the variation in the sintered diameter, parallel to the filling shoe direction, is presented as standard deviation. Also in this case the bonded mixes have less scatter compared to the corresponding PREMIX. The least scatter is obtained by the STARMIX™ including diffusion bonded copper, which could be explained by enhanced distribution of the alloying element.

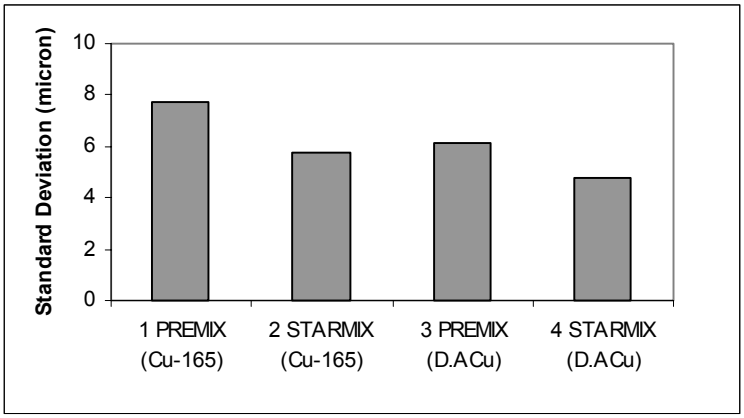


Figure 10. Sintered diameter variation

Mechanical properties

SUMMARY

Final tolerances of a P/M part are dependent on the filling performance of a powder mix as well as the chemical composition within and between components. STARMIX™ is optimized to achieve maximum bonding of alloying elements and superior filling characteristics. In the present study it is shown that utilizing a bonded mix in combination with a diffusion-bonded copper grade can optimise the final tolerances, in terms of dimensional stability and roundness. The superior fillability of STARMIX™ compared to corresponding PREMIX is illustrated in a die filling simulation. Also, a dust test proves that the bonding of primarily graphite, will lead to decreased dusting and by that improved working climate around presses.

CONCLUSIONS

- The green and sintered tolerances, in terms of dimensional scatter and ovality, can considerably be improved by utlizing the STARMIX™ concept.
- By combining diffusion bonded copper and STARMIX™, the variation in sintered diameters can be minimized.
- The superior filling characteristics for STARMIX™ compared to a non-bonded mix provides for even density distribution within and between parts.
- Close to 100% bonding of graphite will not only serve for close tolerances but also improve the working environment around the compaction operation.
- The lubricant system used for STARMIX™ provides equal or improved ejection performance compared to corresponding PREMIX.

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