HIGH PERFORMANCE COMPONENTS UTILIZING BONDED MIXES

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ABSTRACT

In order to increase the powder metal (PM) market share into new applications, material systems will need not only high mechanical performance, but the ability to hold tight tolerances. Many methods for holding tight tolerances, such as diffusion alloying of elements or bonded materials, are currently available. An improved bonding system has been developed to push the tolerance capabilities even further. The effect of the new bonding system will be evaluated in two case studies.

INTRODUCTION

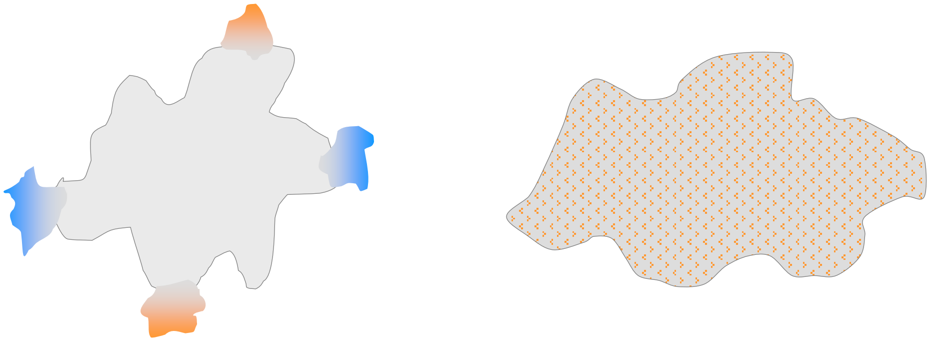
Powder metal (PM) technology offers the ability to manufacture near net-shape components to a variety of mechanical performance levels. As the PM market grows, new applications will not only require high mechanical performance, but an increasing focus on the ability to hold tight tolerances. The ability to meet the tolerance demands can be affected by a variety of factors throughout the manufacturing process. Powder handling, compaction, sintering, and secondary operations all play a role in meeting tolerance demands. However, only the aspects of the material system which play a role in dimensional stability will be discussed.

The properties of the powder system (apparent density, flow rate) can greatly influence the dimensional change of a component. Inconsistent filling of the die cavity will lead to weight and density variations throughout the production run. These variations will ultimately lead to variations in the dimensions of the final component.[1] The ability of the powder to flow can be related to the amount of fine particles in the powder mix. Fine, light particles such as graphite or lubricant can degrade the flow properties. Bonding these particles to the iron particle using an organic bonding process has been shown to increase the flow rate substantially over a similar premix.[2]

In order to achieve the required mechanical properties, alloying elements are necessary. One of the benefits of PM is the ability to customize the alloying to meet the application requirements. The method in which the alloying elements are added to the powder mix can have a large impact on the dimensional consistency of the material system due to segregation of the constituents. Thus it is important to choose the appropriate alloying technique for the required tolerance needed.

Alloying can be achieved by using elemental powders (copper, nickel, graphite), ferroalloys (Ferro phosphorus), diffusion alloying, or by pre-alloying. Each of these methods has it positive and negative aspects. Pre-mixes of iron powders with elemental additions is the most common alloying method. These mixes contain particles of differing size, morphology and density which can lead to segregation if proper powder handling procedures are not followed.[3] For this reason, diffusion alloyed and pre-alloyed iron powders were developed.

Diffusion alloying consists of metallurgically bonding fine elemental powders to a base iron particle through a secondary annealing procedure. This process results in a highly compressible steel powder with the necessary alloying to achieve high sintered strengths. These powders also show good stability because of the reduced risk of alloying segregation.[4] Another alloying option is the pre-alloying process. Here the alloying elements are added during the melting process. The melt is then atomized resulted in an even distribution of alloying throughout the iron particle. While this process reduces the risk of elemental segregation, the compressibility of the powder is reduced as a result.[4]



Diffusion Alloyed Powder **Pre-alloyed Powder**

Figure 1. Depiction of diffusion alloyed and pre-alloyed powder.

In order to facilitate growth into new applications, the Starmix® BOOST lubricant was introduced.[5] This bonded material system has the unique characteristics of a high apparent density and fast flow rate. This combination results in a highly efficient filling performance. Results of the study demonstrated the benefits achievable in a laboratory setting. In this paper, three (3) commercial success cases will be presented to show the benefits of using the Starmix® process in a production environment.

CASE ONE – BELT PULLEY[3]

Experimental

In this case study, belt pulleys (Figure 2) were manufactured from FC-0205 materials using diffusion alloyed copper for the copper addition. The mixes evaluated are shown in Table 1.

Table 1. Materials Investigated for Belt Pulley.

Mix ID	Mix Type	Iron	Copper	Graphite	Lubricant
A	Pre-mix	ASC100.29	10% D.ACu[1]	0.5%	0.8% Amide Wax
B	Starmix® BOOST	ASC100.29	10% D.ACu[1]	0.5%	0.8% SL Boost

1. Note D.ACu contains 10% copper, for 1% total copper addition

The powder properties of the mix are shown in Table 2. The mixes were measured for apparent density and flow rate.[6,7]

Table 2. Powder Properties.

Mix ID	Mix Type	Apparent Density (g/cm^3)	Flow Rate (s/50g)
A	Pre-mix	3.02	30.3
B	Starmix® BOOST	3.24	24.4

Belt pulleys were manufactured from each mix according to the normal production parameters. The pulleys were compacted to a green density of 6.70 g/cm^3 and sintered for 20 minutes at 1120 °C in an endogas atmosphere with a carbon potential of 0.6 %. After sintering, the pulleys, thirty (30) pulleys were sampled from each mix and measured for scatter in dimensions (overall height and tooth height). The pulleys were also measured for plane parallelism (difference in tooth height) and run out (out of roundness and centering of hole).

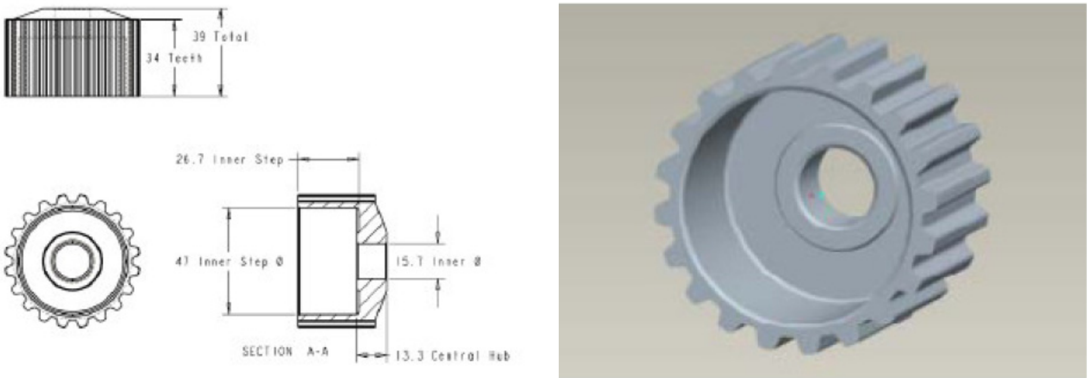


Figure 2. Drawing and picture of belt pulley.

Results

The results of the pulley evaluations on scatter in dimensions are shown in Figure 3. By switching to the SL Boost lubricant, an improvement in dimensional scatter was observed. In both tooth and total height, a 50% improvement in the standard deviation was observed. This improvement is due to the superior fill characteristics of the SL Boost based material. The faster fill rate allows for powder to fill the die more consistently, resulting in a more dimensionally stable component.

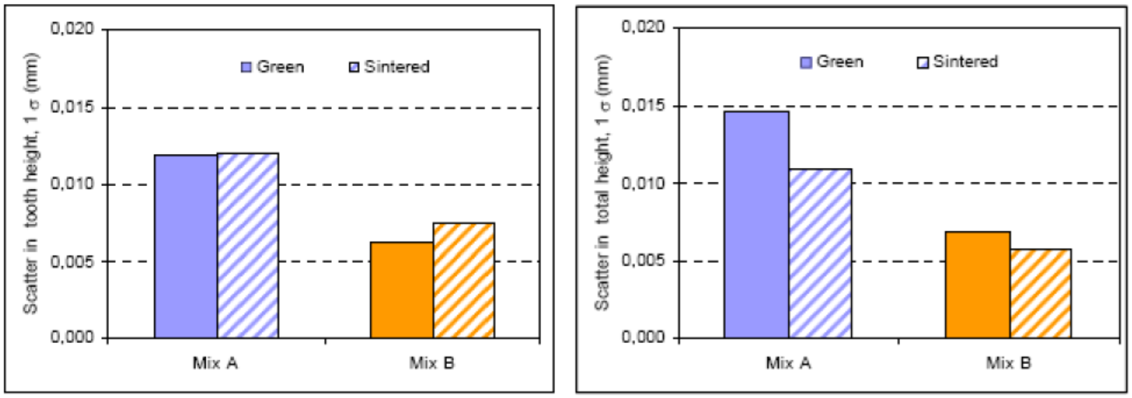


Figure 3. Results of dimensional evaluation.

The results of the plane parallelism and run out measurements are shown in Figure 4.

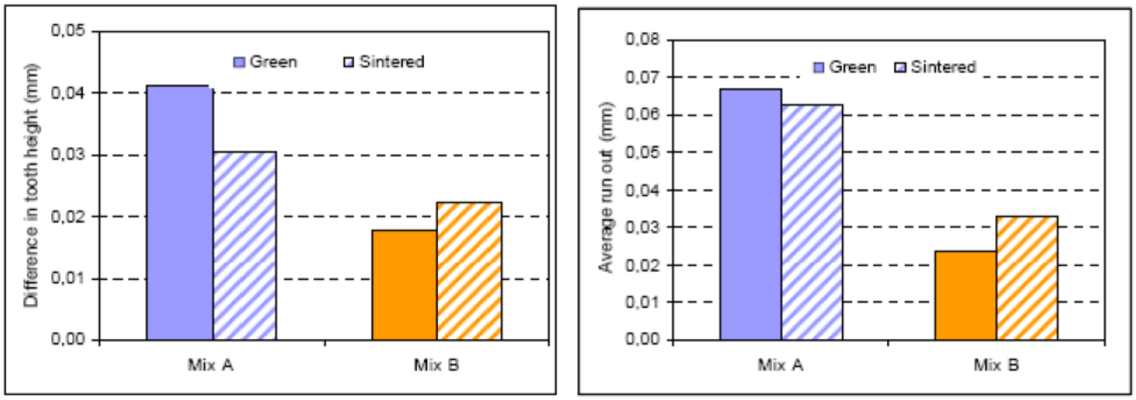


Figure 4. Results of plane parallelism and run out evaluation.

The SL Boost mix shows a large improvement in plane parallelism in the green state compared to the pre-mix. The difference was smaller in the sintered condition, but still an improvement was observed. When evaluating run out a large improvement was observed using Mix B. The improvement is due to a more consistent filling of the die cavity. As this measurement takes into account the placement of the center hole, having a consistent fill will lead to better run out. If the die cavity was not filled consistently, the core rod could have a tendency to shift toward the area with the least amount of fill. By using the SL Boost lubricant, an even fill was achieved improving the run out by over 50%.

CASE TWO – SLIP CRACKS

In this case study, a component in production was experiencing issues with slip cracks. The area of the component affected is sketched in Figure 5. If was felt that the slip cracks were due to uneven filling in the affected region causing low density areas susceptible to the cracks. The component was manufactured from a FC-0205 premix. The same composition was trialed using the Starmix® lubricant system in order to achieve uniform filling of the die cavity.

Experimental

The mix compositions evaluated are shown in Table 3. The mixes were measured for apparent density and flow rate.[6, 7] From these mixes, components were manufactured according to current production parameters and equipment. The components were compacted to a green density of 6.80 g/cm^3. They were then sintered under standard conditions and evaluated for cracks in the known affected region.

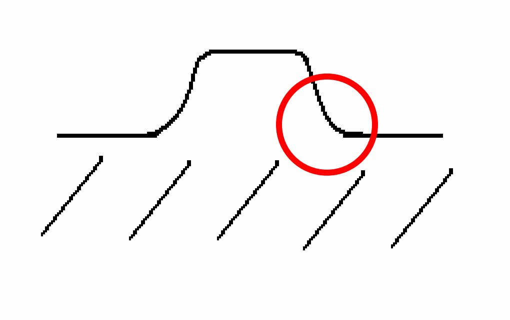


Figure 5. Region where slip cracks occur.

Table 3. Mix Compositions

Mix ID	Mix Type	Iron	Copper	Graphite	Lubricant
C	Pre-mix	AHC100.29	1.75%	0.45%	0.75% Amide Wax
D	Starmix® Mix	AHC100.29	1.75%	0.45%	0.75% SL BOOST

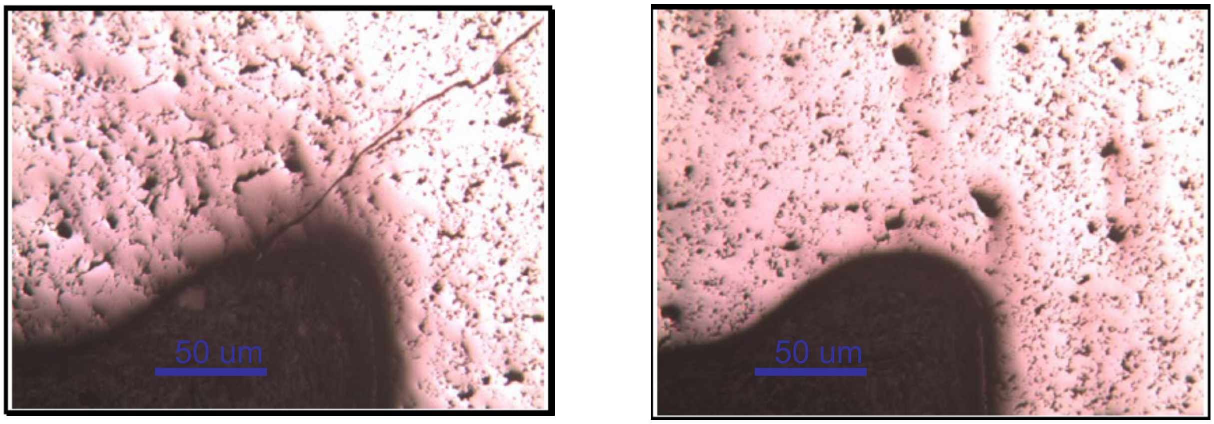
Results

The results of the powder property testing are shown in Table 4.

Table 4. Powder Properties

Mix ID	Mix Type	Apparent Density (g/cm^3)	Flow Rate (s/50g)
C	Pre-mix	3.00	34.9
D	Starmix® Mix	3.28	25.2

By switching the lubricant system, the apparent density increased dramatically. A faster flow rate was also observed. When evaluating the finished components, the effects of these changes were noticed. An elimination of the slip cracks were observed in the components manufactured from the SL BOOST lubricant. By achieving better fill in the affected area, the large difference in density seen in the pre-mix was eliminated. Of the components evaluated, no slip cracks were observed in the components manufactured from Mix D. Photomicrographs of the affected area are shown in Figure 6.



Mix C

Mix D

Figure 6. Difference in affected region.

CASE THREE – CUTTING INSERTS

A challenging application where Starmix® BOOST is currently utilized is in the manufacturing of saw tooth inserts for industrial grade chainsaws. Pictures of the inserts from various views are shown in Figure 7.

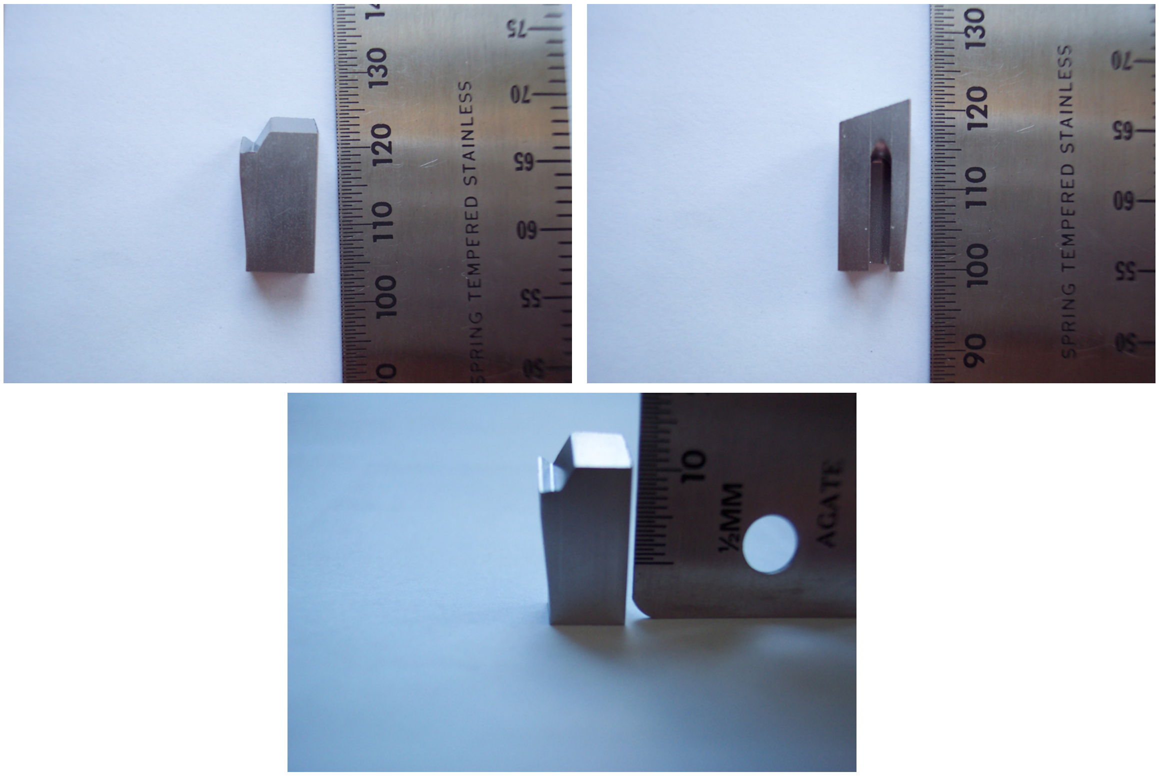


Figure 7. Cutting inserts.

The manufacture of these inserts is difficult due to the various geometries of the inserts along with the narrow die cavity. The inserts weigh approximately 7 g, so even a small variation in weight can be observed. One of the key characteristics is the ability of the tooth at accept an impact load during the cutting operation. The impact requirement requires that the inserts have as even a density distribution at possible. Large variations in density distribution will result in insert failure.

Experimental

The saw tooth inserts are currently manufactured from a FL-5305 based material system. In this experiment, a pre-mix and a Starmix® BOOST mix are compared in a manufacturing setting. The mix compositions evaluated are listed in Table 5.

Table 5. Mix compositions evaluated.

Mix ID	Mix Type	Base Iron	Graphite	Lubricant
E	Pre-mix	Astaloy CrM	0.55%	0.75% Kenolube
F	Starmix® BOOST	Astaloy CrM	0.55%	0.75% SL BOOST

The mixes were evaluated for apparent density and flow rate.[6,7] Inserts were manufactured according to current production parameters and on current equipment. From each mix, 250 inserts were compacted to a green density of 7.00 g/cm^3. The weight of the inserts was measured during the production run. The inserts were then sintered for 30 minutes at 1232 °C in a 90 / 10 N_2 / H_2 atmosphere. After sintering, the inserts were measured for sintered density distribution according to MPIF Standard 42.[8] A total of 40 inserts were used for the measurements. The density was evaluated in three (3) sections (top, middle, bottom) of the insert according to the schematic displayed in Figure 8. The density distribution was also evaluated metallographically to provide a visual depiction.

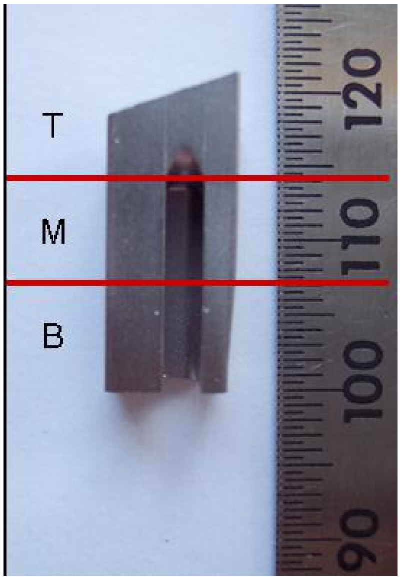


Figure 8. Sectional density measurements

Results
The results of the apparent density and flow rate test are shown in Table 6.

Table 6. Results of apparent density and flow rate testing.

Mix ID	Mix Type	Apparent Density (g/cm^3)	Flow Rate (s/50g)
E	Pre-mix	2.82	30.9
F	Starmix® Mix	3.23	24.0

The weight scatter of the mixes is shown in Figure 9.

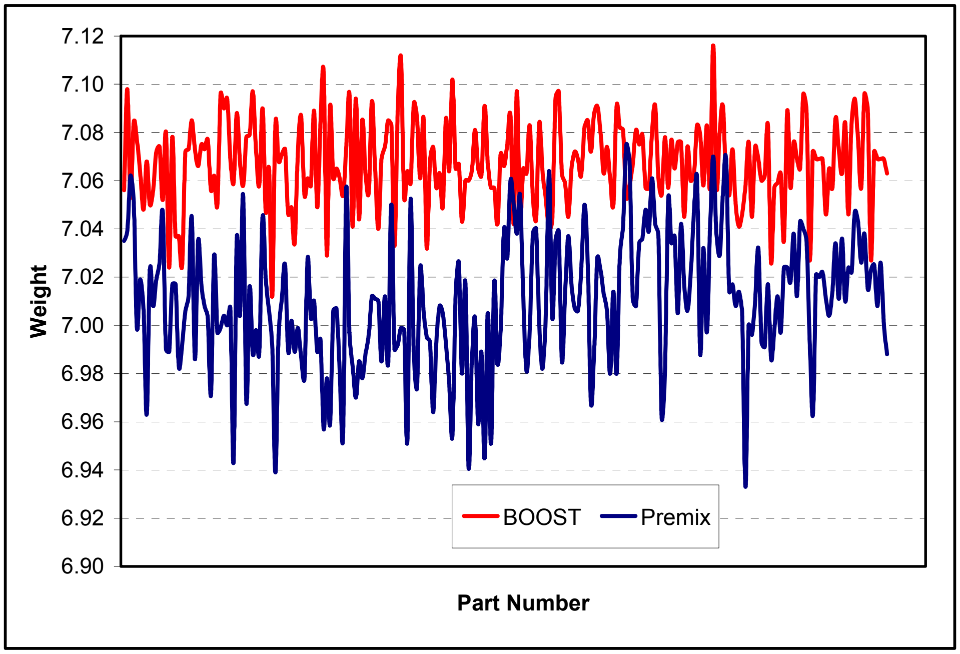


Figure 9. Weight scatter of Starmix® BOOST vs. pre-mix

The SL BOOST mix decreased the weight scatter considerably. The standard deviation of the weight is presented in Table 7. By switching to the SL BOOST lubricant system, the standard deviation on the weight was cut by over 30%.

Table 7. Standard Deviation of Weight Scatter

Mix ID	Average Weight (g)	Standard Deviation
E	7.01	0.027
F	7.06	0.017

The results of the section density measurements are shown in Table 8.

Table 8. Section density measurements.

Mix ID	Mix Type	Top	Middle	Bottom
E	Pre-mix	6.97	6.63	6.45
F	Starmix® Mix	6.98	6.91	6.86

A large variation in the density from top to bottom was observed when using the pre-mix. When switching to the SL BOOST lubricant system, the density gradient was dramatically reduced. The superior die filling capabilities of Mix F allow for a more even filling of the die as was seen earlier in the weight stability data. Without this even filling, the inserts would fail due to low density sections.

The density distribution is show metallographically in Figure 10. Here the dramatic difference in the density of the insert regions is easily seen. The SL BOOST mix uses its filling characteristics to provide an even distribution of the powder particles.

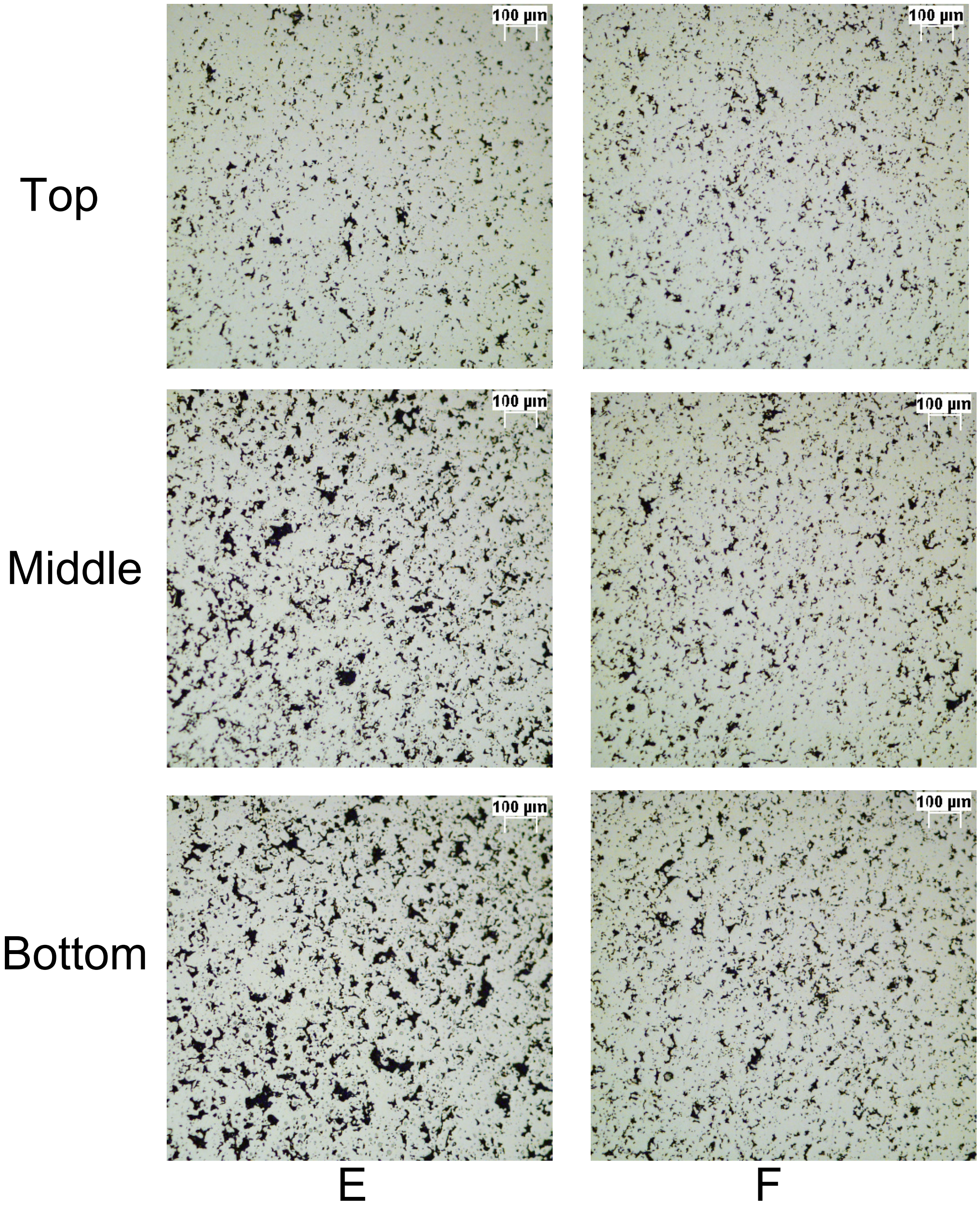


Figure 10. Photomicrographs of density from top to bottom of insert.

CONCLUSIONS

Based on the commercial cases presented, the following conclusions can be drawn:

- Starmix® BOOST offers significantly higher apparent density and flow rate compared to a pre-mix of similar composition. The two characteristics allow for superior die cavity filling capability
- The die filling capability of Starmix® BOOST allows for tighter tolerances to be held compared to a pre-mix. A 50 % reduction in dimension scatter was observed on a belt pulley trial using the Starmix® BOOST lubricant system
- Using the filling characteristics of Starmix® BOOST, production issues such cracks resulting from density differences can be eliminated. Starmix® BOOST was shown to have even filling in a small cavity which resulted in the elimination of slip cracks seen with the current pre-mix material.
- For demanding die filling components, Starmix® BOOST was shown to greatly improve density consistency over a pre-mix. By achieving even filling of the die cavity, the density gradient from top to bottom of a small cutting insert was dramatically reduced.

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