LUBRICATION FOR DEMANDING APPLICATIONS

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ABSTRACT

A major advantage of powder metallurgy (PM) compared to other manufacturing technologies is the inherent near net shape capabilities. As PM continues to expand and material costs continue to rise, applications continue to increase in complexity. The increase in complexity will require PM component manufacturers to have an understanding of current lubrication technologies available in the industry to maximize productivity of complex components. In this paper, several lubricant systems are tested on current production components. Different component geometries are evaluated to show the limitations of each lubricant system on weight scatter, density, ejection, surface finish, and staining after sintering.

INTRODUCTION

Lubricants are used in the powder metal (PM) industry to facilitate the compaction process. Without lubricants, the compaction process would be very difficult if not impossible. Lubricants serve a number of

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functions including decreasing inter-particle friction, permitting ejection of the component from the die, and reducing wear on the die and tooling.[1] The lubricant also affects the powder properties of apparent density, flow rate, and green strength which are important manufacturing parameters.

An important aspect of lubrication which is often forgotten is the function of reducing inter-particle friction during compaction. This function is usually focused on when high densities are required for high performance applications. However, even at traditional density levels, reducing friction between the particles is critical to manufacturing a consistent component. If the lubrication is not sufficient to overcome inter-particle friction, large density gradients, cracks, excessive weight fluctuation, premature tool wear and loss of precision can occur.[2]

Flow and apparent density have been demonstrated to affect a component weight stability over a production campaign.[3,4] In these studies, bonded material solutions were compared to premix materials. The higher apparent density and faster flow rate of the bonded materials led to consistent filling of the die. The end result was a more consistent component with improved precision.

Components with large surface areas can be challenging to manufacture due to the ejection forces they will experience. When a large amount of surface area is ejected, heat related to the friction between the component and the die wall is generated. The amount of heat generated is related to the lubricity of the lubricant used in the material system. Studies have shown larger particle size lubricants can reduce the ejection forces a component experiences. However, these large particles reduce the density which can be achieved, lower green strength, and decrease sintered strength.[5]

Due to the many roles a good lubricant must perform, the design of said lubricant can be challenging. The perfect lubricant would accomplish all of the above functions. However, optimization of lubricant properties is required to provide a balance between the different performance criteria. New lubricant systems have been developed in recent years to provide advanced performance compared to industry standard lubricants.[3] Challenging component geometries require better lubricants to increase the competitiveness of PM and allow for the expansion of PM into new markets.

In this paper, the performance of different lubricant systems was evaluated on a laboratory and production scale. Commercially available lubricants were evaluated on simple rings and a challenging VVT component. The lubricants were evaluated for standard properties and also their ability to provide a consistent, precise component in a manufacturing environment.

EXPERIMENTAL PROCEDURE

Engineered Sintered Components (ESC) selected a current production component for the trial (vane rotor). The vane rotor is manufactured from a FC-0208 material system. The current mix composition was compared against three commercially available lubricant systems. Mixes were manufactured in the North American Höganäs pilot mixing center. The compositions of the mixes are shown in Table 1.

Table 1. Composition of Mixes

Mix ID	Base Iron	Copper (%)	Graphite (%)	SM3 (%)	Lubricant (%)
Baseline (B)	ASC100.29	2	0.8	0.2	0.8% BAP-1
Acrawax (A)	ASC100.29	2	0.8	0.2	0.75% Acrawax
Intralube E (I)	ASC100.29	2	0.8	0.2	0.75% Intralube E

Starmix® BOOST (SB)	ASC100.29	2	0.8	0.2	0.75% SL BOOST

Mixes B, A, and I were manufactured as premixes. Mix SB utilized the Starmix® BOOST resin bonding process. All of the mixes were manufactured in a 500 kg (1,100 lb) quantity.

The mixes were tested for apparent density and flow rate according to MPIF standards. A compressibility curve was generated for each mix at pressures of 415, 550, and 690 MPa (30, 40, 50 tsi) using a 12.7 mm (0.5 inch) thick transverse rupture strength specimen.

Rings measuring 34□ x 21□ x 11 mm length were compacted at a force of 286 kN. The rings were measured for outer and inner diameter and overall length after compaction to determine green expansion. The peak ejection pressure was measured during the compaction process. Sintering of the rings was conducted in a production mesh belt furnace at 1182 °C (2070 °F) in a 90/10 N_2 / H_2 atmosphere at a belt speed of 6.0 inch/minute. After sintering, the rings were again measured for dimensions to determine dimensional change through the sintering process. The rings were also measured for apparent hardness and radial crush strength.

Standard tensile and transverse rupture test specimens were compacted at 415, 550, and 690 MPa (30,40,50 tsi). Green strength was determined on the transverse rupture strength specimens. The test specimens were sintered in a continuous mesh belt furnace in the NAH sintering laboratory. The specimens were sintered for 20 minutes at 1121 °C (2050 °F) in a 90 % nitrogen / 10% hydrogen atmosphere with a conventional cooling rate of 0.5 °C/s (1.0 °F/s) cooling rate. Mechanical property testing was then completed on the test bars.

To evaluate the effect of the different lubricant systems in a production setting, ESC chose a vane rotor for which they had a significant history (Figure 1). The rotor was 25 mm (1 inch) high and the target weight was 348.5 g (0.75 lb). The overall green density of the rotor was 6.85 g/cm^3. The rotors were compacted on a 200 ton mechanical press at a stroke rate of 8.1 parts/minute which is the current production standard.

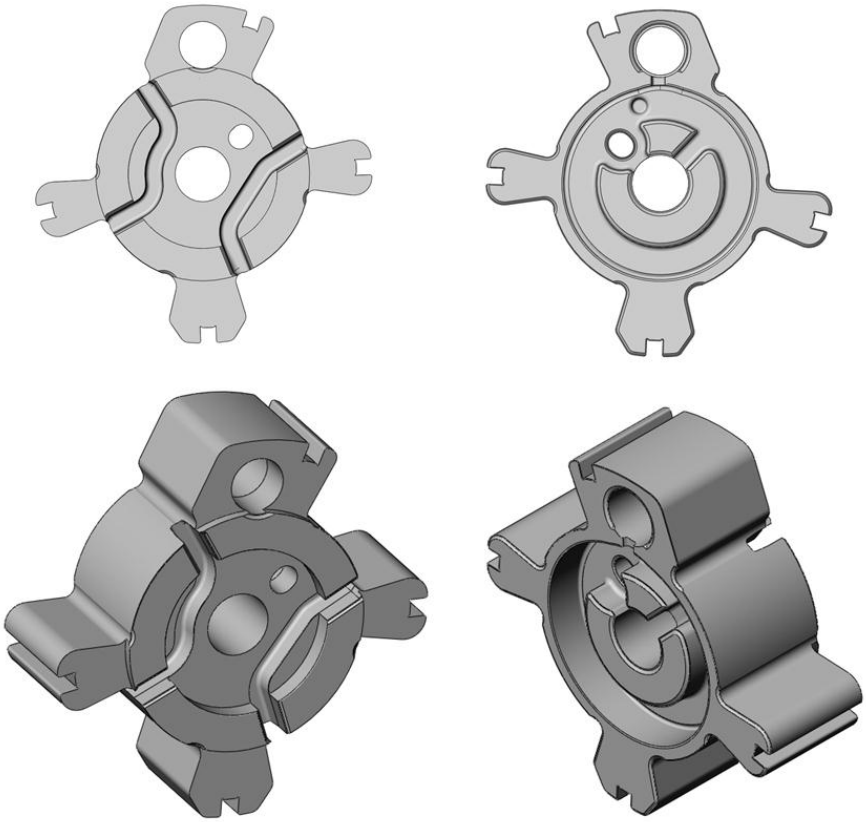


Figure 1. Vane rotor used for production evaluation

The weight of each rotor was automatically measured by an inline scale. The rotors were also evaluated for surface finish. The surface finish measurements were taken according to the diagram in Figure 2.

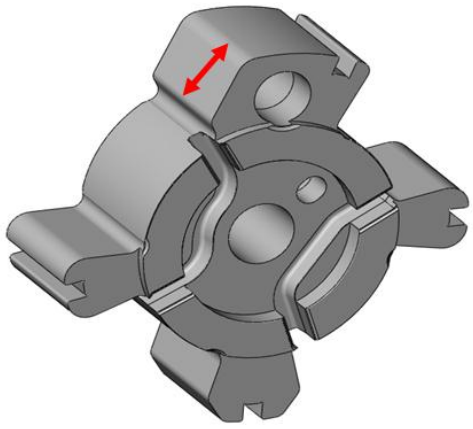


Figure 2. Surface finish measurement schematic

Rotors were then selected from the beginning, middle and end of the run for sintering. They were sintered in a production continuous mesh belt furnace under the same conditions used for the ring specimens. The

sintered vane rotors were evaluated for crush strength, dimensions, apparent hardness and metallography. A schematic describing the vane rotor crush strength testing is shown in Figure 3.

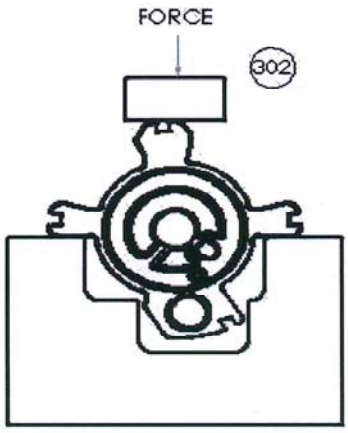


Figure 3. Vane rotor crush strength testing schematic

RESULTS

Powder Properties

The results of the powder property testing are shown in Table 2.

Table 2: Powder Property Testing Results

Mix ID	Flow Rate (s/50 g)	Apparent Density (g/cm^3)
Baseline (B)	34.0	2.99
Acrawax (A)	36.0	2.95
Intralube E (I)	32.1	3.00
Starmix® BOOST (SB)	25.5	3.25

Adjusting the lubricant system had an effect on the powder properties of the mix compared to the baseline mix. Mix A exhibited a lower apparent density and the slowest flow rate. Mix I had a similar apparent density to the current material, but with increase flow rate. The best material for apparent density and flow rate was the bonded material.

Compressibility curves were generated for each lubricant system. The results are shown in Figure 4.

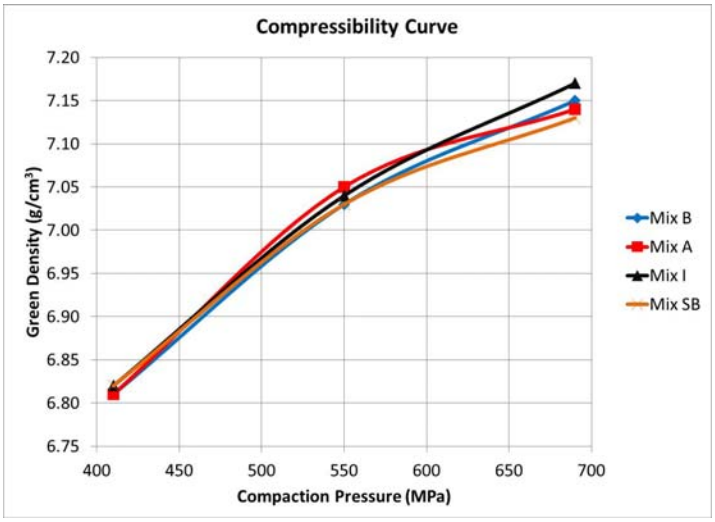


Figure 4. Compressibility curves for the different material systems

The compressibility of the materials was almost identical at the lower compaction pressures. A difference between the material systems was not observed until the 690 MPa (50 tsi) compaction pressure. At this pressure, Mix I had the best compressibility.

Green expansion was measured on the ring specimens at different compaction pressures. The results are shown in Figure 5.

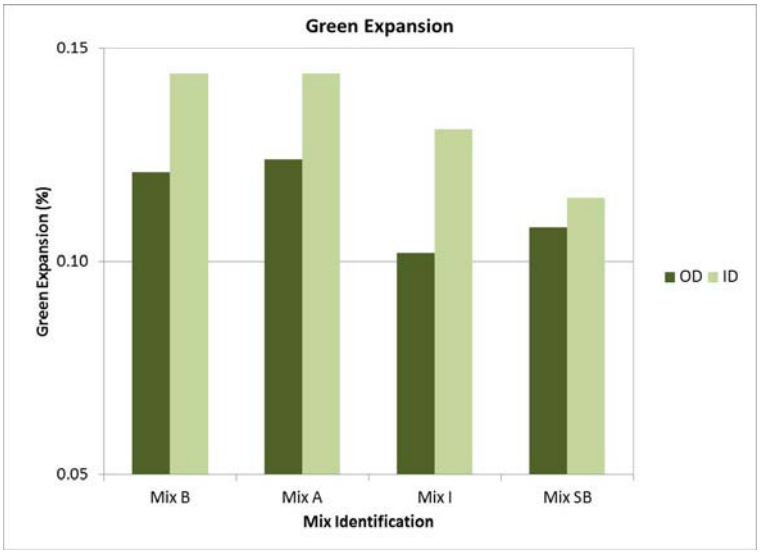


Figure 5. Green expansion of lubricant systems

Mix I and Mix SB has the least amount of green expansion in both the outer and inner diameter. The decrease in green expansion was measured to be 20%. This can be attributed to the improved lubrication

which was observed for these two mixes. Ejection data supporting the green expansion measurements is shown in Figure 6.

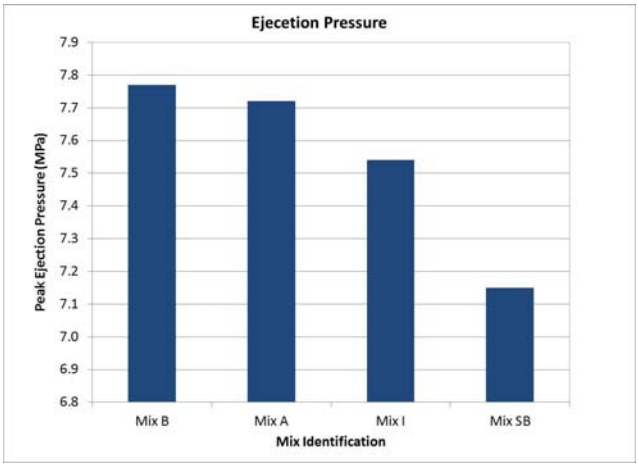


Figure 6. Peak ejection pressures for lubricant systems

Mix I and Mix SB had the lowest peak ejection pressures. Mix B and Mix A had similar peak ejection pressures. The decrease in peak ejection pressure corresponds with the decreased green expansion these two material systems exhibited. The results show Mix I and Mix SB provide superior lubrication compared to the other two lubricant systems. Both of these lubricant systems have been previously shown to have superior lubrication properites.[3,6]

The mechanical property data is shown in Table 3.

Table 3: Mechanical Property Data

Mix ID	Comp. Pressure MPa	Green Density g/cm^3	Green Strength MPa	Green Expan. %	Sintered Density g/cm^3	carbon % C	HRB	DC %	TS MPa	YS MPa	A %	IE J
B	410	6.81	12.1	0.15	6.75	0.68	79	0.30	505	401	2	9.4
B	550	7.03	14.5	0.18	6.95	0.69	84	0.37	565	428	2	10.4
B	690	7.15	15.0	0.22	7.07	0.69	86	0.42	592	455	2	11.5
A	410	6.81	10.3	0.16	6.76	0.69	79	0.28	526	410	2	9.5
A	550	7.05	13.1	0.19	6.98	0.69	83	0.35	577	456	2	10.2
A	690	7.14	13.8	0.22	7.07	0.69	87	0.40	630	476	3	11.8
I	410	6.82	12.4	0.14	6.75	0.70	80	0.30	504	399	2	9.4
I	550	7.04	15.2	0.17	6.97	0.69	85	0.37	571	432	3	10.6
i	690	7.17	15.9	0.21	7.10	0.69	87	0.41	594	457	3	12.1
SB	410	6.82	14.5	0.14	6.75	0.69	79	0.36	502	390	2	9.4
SB	550	7.03	15.4	0.16	6.96	0.70	85	0.40	556	429	2	10.5
SB	690	7.13	16.3	0.19	7.05	0.69	87	0.44	577	447	3	11.8

The green strength of Mix I and Mix SB were significantly higher than Mix A and slightly higher than Mix B. A similar trend was observed for the green expansion of the TRS bars compared to the testing on the ring specimens. Similar mechanical properties were obtained for each material system.

RESULTS – PRODUCTION TRIAL

The weight of the vane rotors was recorded over the entire run for each mix. The standard deviation of the weight is presented in Figure 7.

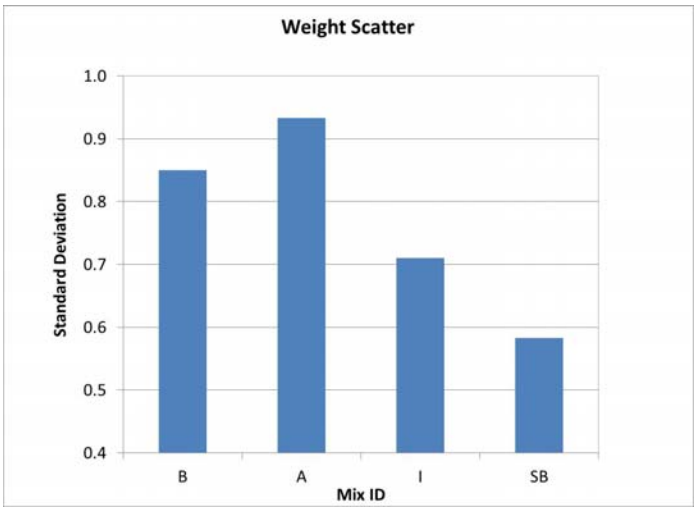


Figure 7. Standard deviation on weight scatter

Changing the lubricant system from Mix B to Mix A resulted in an increase in the weight scatter. This can be attributed to the poor powder properties that were found for Mix A. When the powder properties were improved compared to the base material, the weight scatter improved. Mix I improved the scatter by approximately 15% while mix SB improved the weight scatter by 30%. This improvement in weight scatter will result in a more consistent component and improved production capability.

The surface finish measurements for the green vane rotors are shown in Figure 8.

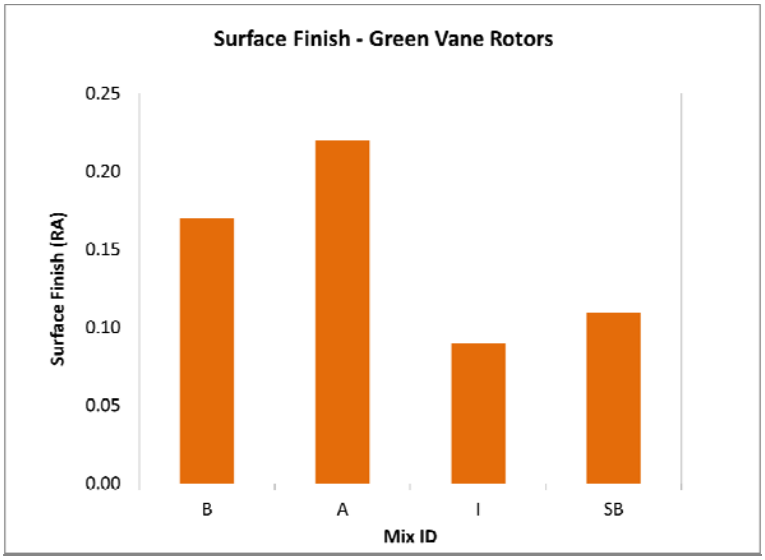


Figure 8. Surface finish measurements on green vane rotors

The surface finish of the green vane rotors was significantly improved when using Mix I or Mix SB. The improved lubrication provided by Mix I and SB results in an improved surface finish out of the die due to good lubrication between the component surface and the die wall.

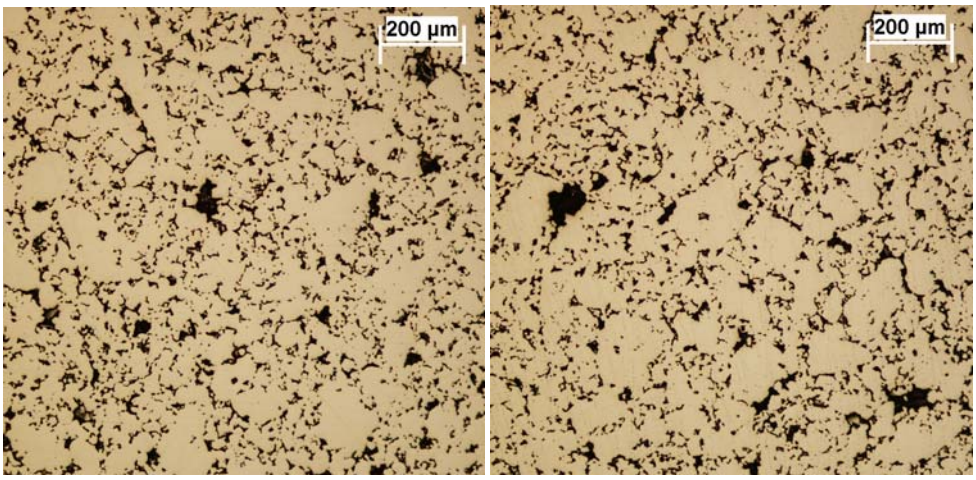
The results of the crush strength, hardness and dimensional analysis of the sintered vane rotors are shown in Table 4.

Table 4. Sintered Vane Rotor Results

Mix ID	Apparent Hardness HRB	Dimensional Change %DC	Crush Strength kg
B	77	0.376	4018
A	77	0.363	4070
I	75	0.388	4092
SB	75	0.468	4021

No difference was observed between the materials for apparent hardness and crush strength. A difference was observed in the dimensional change for Mix SB. While this mix was shown to have more growth on the laboratory scale, the difference was not as great as observed on the actual vane rotors.

Metallography was performed on the sintered vane rotors. Unetched photomicrographs are shown in Figure 9.



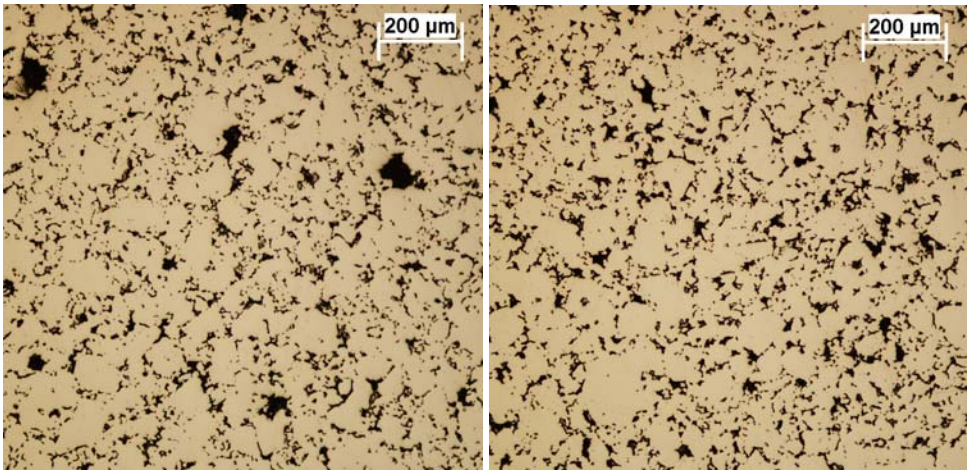
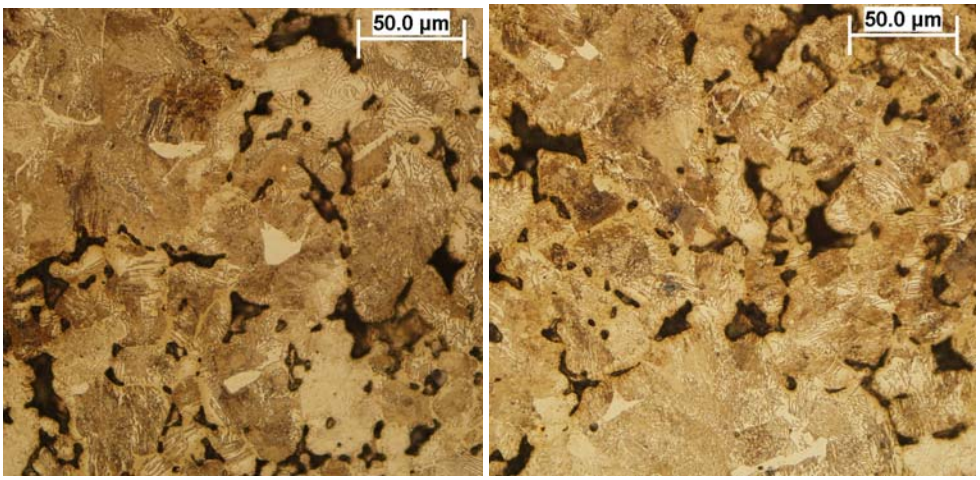


Figure 9. Unetched photomicrographs for the vane rotors

Similar particle bonding and pore morphology was observed for each material system. Mix SB appeared to have better distribution of porosity compared to the other material systems. This is due to the superior fill characteristics of the mix.

The etched microstructures are shown in Figure 10.



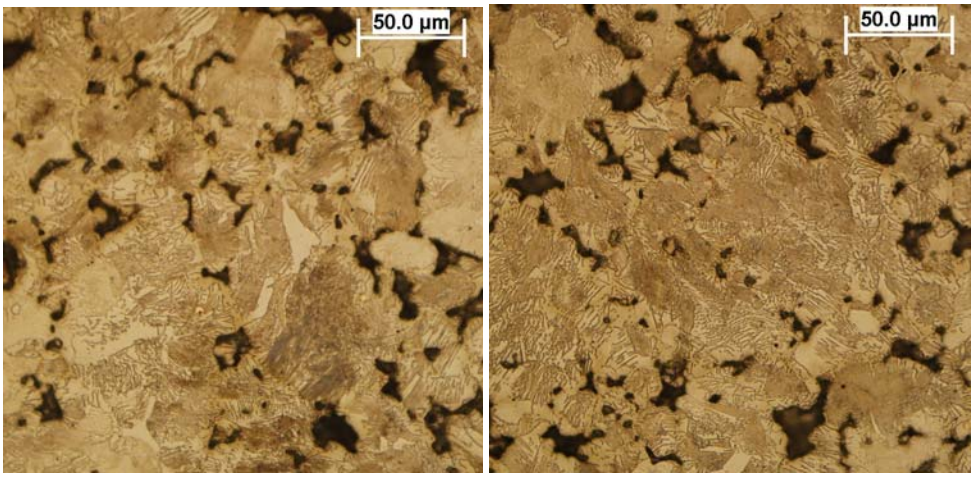


Figure 10. Photomicrographs of vane rotors, etched with Nital 1%

The etched microstructure was similar for each material. The structure was pearlitic with small amounts of ferrite present consistent with the sintered carbon values measured for each mix.

DISCUSSION

The selection of a lubricant is an important decision when designing a material system. In the PM industry today, there are a variety of lubricants available, each with their own unique aspects. This study showed that for the same component and production settings, lubricant selection can change the production capability significantly.

Past studies have shown that bonded material systems can provide an improvement in the consistency of a component over a production campaign.[3,4] Improvements in weight are achieved due to the improved powder properties which a bonded material system provides. The key to consistency and improved precision starts with the first step in the PM component manufacturing process: die filling. By bonding the fine particles, the powder will have faster flow rates and higher apparent density. These key powder properties allow for the particles to fill the die in a more consistent manner. The packing of the powder particles is more consistent, leading to decreased distance between the powder particles in the die cavity. The consistency in particle packing is not the same for all bonded mixes. Studies have shown that not all binder / lubricant systems are the same.

The design lubricant system plays a large role in achieving optimized powder properties. Highly engineered lubricant systems can provide both excellence powder properties and consistent ejection properties. The optimization of these aspects results in improved consistency of manufacture. While bonded material systems are highly engineered due to the multiple functions (bonding & lubrication) which they must perform, new lubricant systems designed for standard premixes can also provide improved powder properties compared to older lubricant systems. Mix I had similar apparent density to Mix A and Mix B, however the flow rate was faster. The improvement in flow rate resulted in an improved weight scatter and improved production process.

Ejection characteristics are also important especially when there is a large amount of surface area. Mix I and Mix SB were shown to have lower ejection pressures in the laboratory testing. While the compaction press used in the production run was not able to measure ejection forces, the surface finish of the part was

noticeably better for these two mixes. Improved lubrication will reduce wear on the tooling and decrease the likelihood for surface defects in the components.

CONCLUSIONS

Based on this study, the following conclusions can be drawn:

- Powder properties play a large role in the weight stability of a component over a compaction campaign. The design of the lubricant system is important to achieve consistent powder properties. A good design will provide improved powder packing properties in the die cavity which results in consistent fill during manufacture.

- Material systems with better flow rates and higher apparent density provide for better part to part repeatability, especially for weight. Mix I improved the weight scatter by 15% using just an improved flow rate. The bonded material, Mix SB, improved the weight scatter by 30% using the combination of better flow rate and higher apparent density.

- Mix I and Mix SB reduced the ejection force compared to the base material. The reduction in ejection force resulted in less green expansion for these mixes compared to Mix B and Mix A. Mix I and Mix SB also improved the surface finish out of the die compared to the other mixes.

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