

EFFICIENT BONDING FOR DIMENSIONAL STABILITY

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ABSTRACT

In production of P/M components sizing or machining operations are often used to meet the demands for narrow tolerances. These additional operations increase the production costs.

By improving the dimensional stability after sintering more components will be possible to produce without these secondary operations. Bonding technique affects the dimensional stability by several mechanisms. Segregation of alloying elements, variation in fill weight and warping of component are factors that deteriorate the dimensional stability of P/M components. With efficient bonding technique mixes less inclined to segregate and with superior filling of press tools are obtained. Less dusting is another benefit of the bonding technique that improves the working environment in P/M production. Results are presented showing the improved dimensional stability obtained by efficient bonding technique.

INTRODUCTION

Two types of bonding are commonly used in powder for P/M part production, organically bonding technique and diffusion bonding of metallic alloying elements. Diffusion bonded powders with Cu, Ni and Mo have proven to be very dimensionally stable high strength materials. These have been available on the market since early seventies [1]. In the mid-eighties organically bonded Starmix™ powder was introduced [2]. This type of mixes improves dimensional stability by avoiding segregation of graphite and other light elements.

This paper presents an investigation of organically bonded mixes with improved flowability. The experimental mixes are compared with an ordinary mix with respect to filling behavior and particle segregation. Evaluation in a production press is carried out to quantify how the properties of bonded mixes can improve the dimensional stability of sintered components.

By the bonding technique, segregation of alloying elements should be minimized. The improved flowability is beneficial for the filling of tool die. Less dusting of fine particles is improving the working environment when handling the powder and during pressing of components.

MATERIALS

Three mixes with same nominal chemical composition were prepared for the investigation. All three mixes were based on ASC100.29 atomized iron powder with 2% Cu, 0.5% C-UF4 graphite and 0.8% amide wax added.

1. ASC100.29 + 2% Cu -200 mesh + 0.5% C-UF4 + 0.8% Amide wax
2. ASC100.29 + 2% Cu (fine) + 0.5% C-UF4 + 0.8% Amide wax
3. ASC100.29 + 2% Cu (fine) + 0.5% C-UF4 + 0.8% Amide wax

Mix 1 is an ordinary mix while mix 2 and 3 are organically bonded experimental mixes. Mix 2 and 3 only differ in flowability but are similar in other respects. In table 1 powder properties of the mixes are presented. A clear difference in flowability, measured as Hall flow, is seen. The two bonded mixes have to different extent improved flowability. Mix 2 and 3 are lower in apparent density compared to mix 1. No significant differences in compressibility is found.

Table 1. Powder properties of powder mixes

Mix	Hall Flow (s/50g)	AD (g/cm ³)	GD @600MPa (g/cm ³)
1	31.7	3.19	7.09
2	28.0	3.00	7.13
3	24.7	3.05	7.11

To illustrate the degree of bonding, particle size distribution of the mixes was measured by laser diffraction (Sympatec). In figure 1 the cumulative particle size distributions for the mixes are presented. By bonding the fine particles to the coarser a significant decrease of free fine particles is obtained.

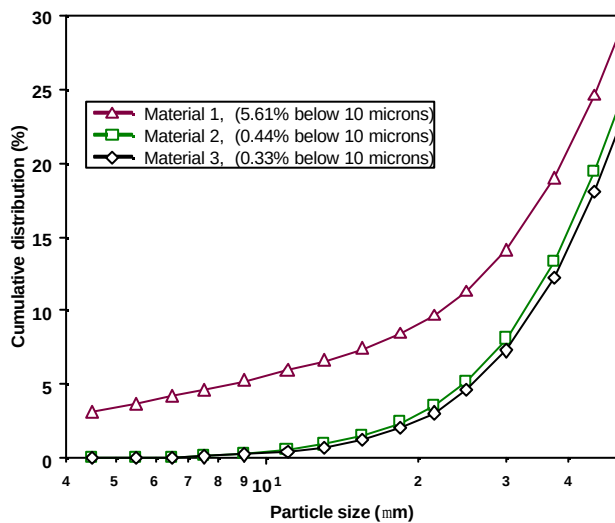


Figure 1 Cumulative particle size distribution by laser diffraction

EXPERIMENTAL

Die filling simulation

An equipment simulating filling of die cavities of different size was used to evaluate the filling characteristics of the investigated mixes, see figure 2. The equipment includes 8 cavities with rectangular cross section with width varying between 0.04 inch (1 mm) and 0.79 inch (20 mm). Length and depth is 1.2 inch (30 mm) for all eight cavities. Filling of the cavities is made in a sequence by an automatic filling device. In this investigation different speed of the filling shoe was used as a parameter. By weighing the powder in each cavity the fill density can be calculated and plotted versus the width of the cavities. The fill density is normally higher for a cavity with a larger width compared to a cavity with smaller width. A material with good filling characteristics exhibits small difference in fill density versus the cavity width.

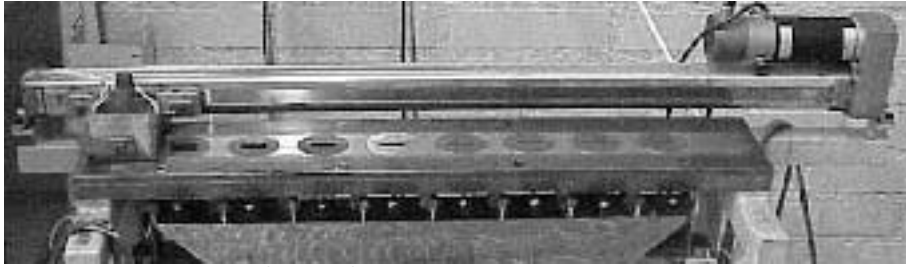
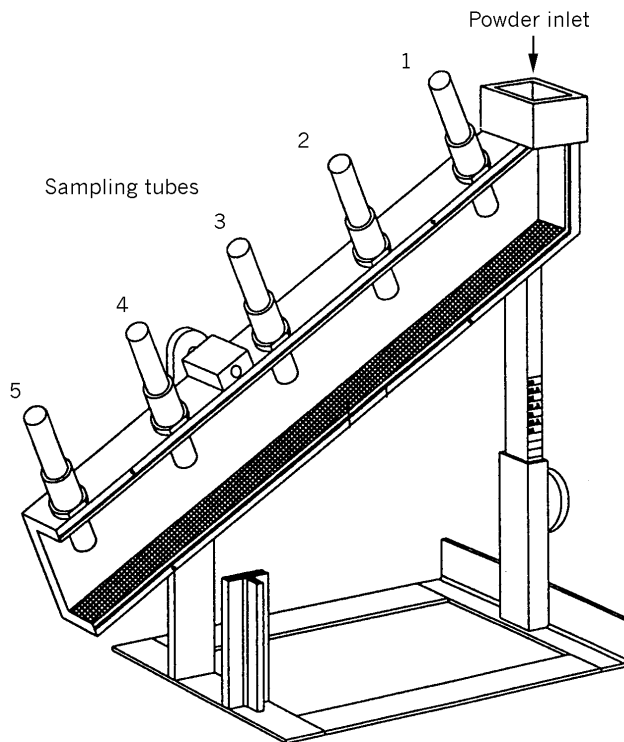


Figure 2: Equipment for die filling simulation

Segregation tester



The segregation tester consists of an inclined plane where the powder slowly flows from a powder inlet on the top, see figure 3. The angle of the plane is adjusted to match the angle of repose of the powder to be tested. A layer with uniform thickness is forming on the plane as the powder is flowing into the tester. Samples are taken on five different positions with the sampling tubes. Particle size distribution for the five samples was measured by laser diffraction. Since flow rate is a parameter important for particle segregation two inlets have been used in this investigation, one with a width of 0.08 inch (2 mm) and 0.2 inch (5 mm) respectively. Results obtained with this equipment are useful to compare the sensitivity of (heap) segregation of powder.

Figure 3: Segregation test equipment

Trials in production press

Trials have been carried out in a 45 ton mechanical Dorst TPA 45 press. The components was a ring with diameter 1.4/1.0 inch (35/25 mm) and height 0.4 inch (10 mm), pressed to a density of 7.1 g/cm³. The press rate was 16 parts/minute corresponding to a cycle time of 3.75 s. Fill depth was kept constant during the pressing of each mix. 100 lb powder was used of each mix which resulted in approximately 1500 rings. Figure 4 illustrates how the designations “front” and “rear” sides of the rings are correlating to the fill shoe movement.

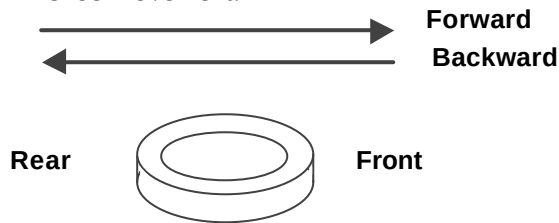


Figure 4: Fill shoe movement

Density variations within ring were evaluated for 12 rings per mix. Rings were cut in four pieces, see figure 5, that were evaluated by weighing in air and water.

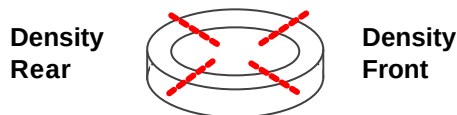


Figure 5: Variation in density within ring

Height of rings, in green and sintered state, were measured in two position of 55 rings of each mix, see figure 6.

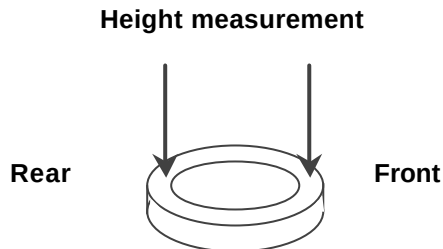


Figure 6: Position for height measurement of rings

Finally, the diameters of 120 rings were measured in two directions, along and perpendicular to the direction of the movement of the filling shoe, see figure 7. The rings were measured in green and sintered state. Ovality of ring was calculated as diameter along filling direction minus diameter perpendicular to filling direction.

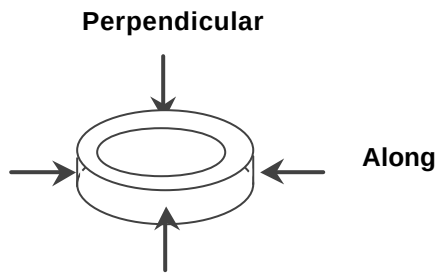


Figure 7: Measurement of ring diameter

Rings were sintered at 2050°F (1120°C) for 30 minutes at temperature in 90/10 N₂/H₂ atmosphere.

RESULTS AND DISCUSSION

Die filling simulation

In figure 8 the results for the three mixes are presented. Material 1 has the highest apparent density and is therefore reaching the highest filling density in the wider cavities. The filling density is decreasing significantly in the smaller cavities for material 1. With this behavior large variations in fill density can be expected in a tool with sections of different shape.

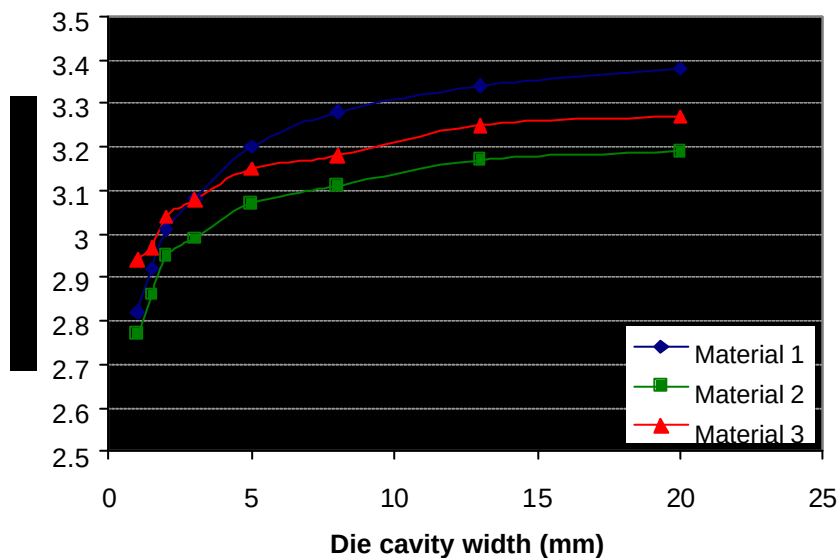


Figure 8: Die filling simulation – Fill shoe speed 30 mm/s

The influence of the improved flowability is seen on material 2 and 3. With improved flowability the decrease in fill density due to small dimensions of die cavity is smaller.

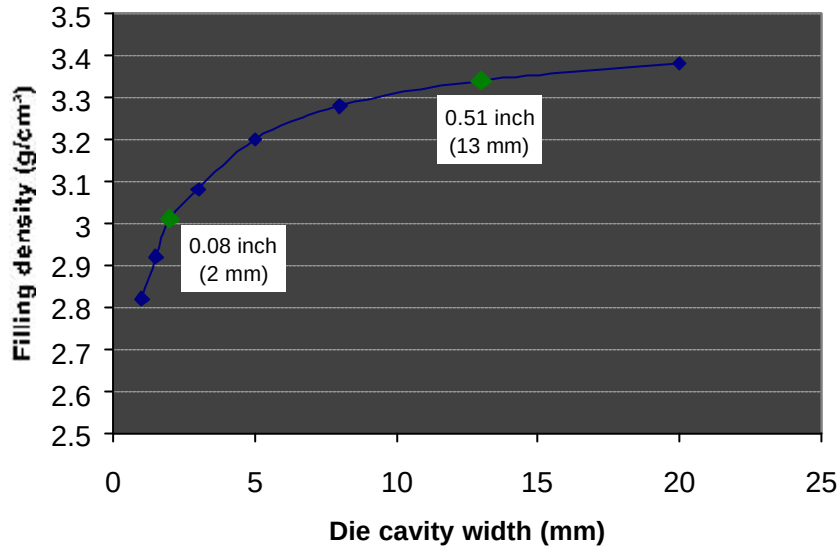


Figure 9: Calculation of filling index

From the results a filling index is calculated according to equation 1. The filling index is the decrease in filling density from the 0.51 inch cavity to the 0.08 inch cavity in percent.

$$\text{Filling_index} = \frac{AD_{0.08} - AD_{0.51}}{AD_{0.51}} \times 100\% \quad (1)$$

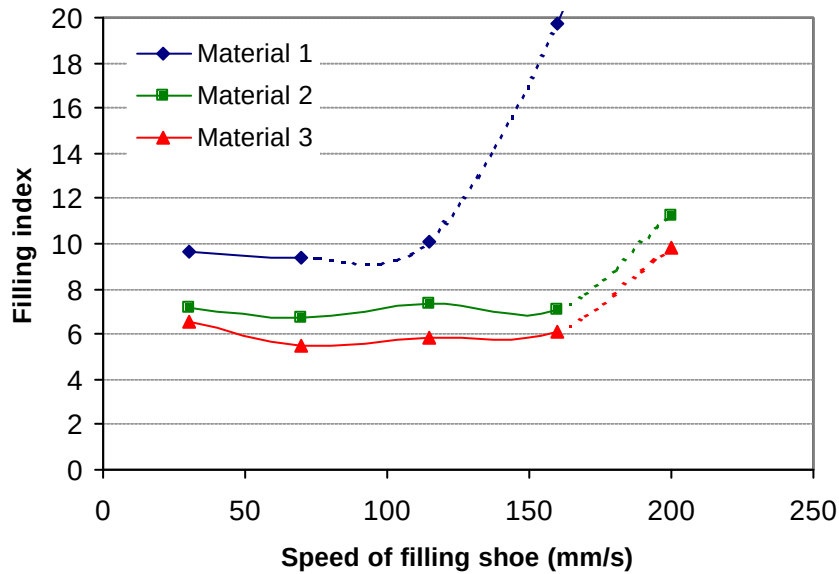


Figure 10: Comparison of filling index at different speed of filling shoe

In figure 10 filling index for the three materials are presented versus the speed of the filling shoe. Dotted lines are indicating that both cavities on which the index is calculated were not completely filled. Normally it is the smaller of the two cavities, which is not completely filled, which results in a significant increase in index.

Table 2: Indication of cavities not completely filled

Speed of filling shoe (mm/s)	Width of cavity (inch)							
	0.79	0.51	0.31	0.2	0.12	0.08	0.06	0.04
30								
70								
115						①	①	①
160	①			①	①	①	①	①②
200	①		①	①	①②③	①②③	①②③	①②③

With increased speed of the filling shoe cavities are not being completely filled. This is shown in table 2. Cavities with smaller width are the ones that first fails to fill completely.

From the filling index it is clearly seen that the improved flowability of the mixes improves the filling of small section in a tool die. Components can be produced with less variation in density between section of different geometry and size. This is beneficial to obtain uniform dimensional change for different sections.

From figure 10 and table 2 it can also be concluded that the improved flowability makes it possible to increase the pressing rate, if filling is the limiting factor. Material 1 fails to fill all cavities at a speed of 115 mm/s while material 3, with the best flowability, fails to fill all cavities at a speed of 200 mm/s. A substantial increase in pressing rate is possible by this improvement of flowability.

Segregation tests

Segregation tests were performed with two different size of the inlet, 1.2×0.08 inch and 1.2×0.2 inch. With a larger inlet a higher flow capacity is obtained which influences the results of the segregation test. Results comparing the sensitivity to heap segregation with respect to particle size for the three mixes are presented in diagram 11 and 12. An optimal result would be a horizontal line in the diagram, which would indicate that samples taken on all five positions still have the same particle size distribution. In practice difference in shape, density or, as in this case, size of particles is a driving force for segregation. Typically a larger amount of fine particles are found at the upper position and coarser particles are found at the lower position of the tester.

Diagram 11 is a good illustration of a fundamental principle for segregation. A powder with better flowability is more inclined to particle segregating compared to a powder with poorer flowability. Material 1, that has poor flowability, exhibits least particle segregation. Material 3 that has best flowability of the three mixes also is the mix that exhibits most particle segregation.

For material 3 there is more than 20% less fines in the samples taken from the low position compared to the sample from the high position. This implies that powders with good flowability must be handled with more caution than a powder with less good flowability.

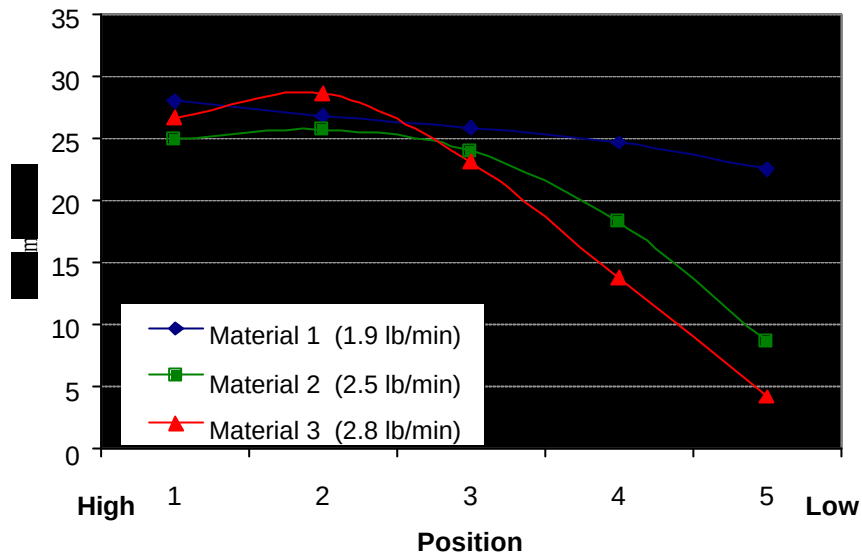


Figure 11: Particle segregation - Inlet 0.08 inch

A factor that is important is the flow rate when powder is handled. In the legend of diagram 11 and 12 the flow rate during the segregation test is indicated. These flow rates were calculated based on the time for 6 lb of powder to flow through the inlet of the segregation tester. The difference between the three materials in diagram 11 and 12 show the difference in flowability of the powder mixes. By increasing the inlet size the mass of powder per minute flowing into the tester is increased by a factor 3 - 4.

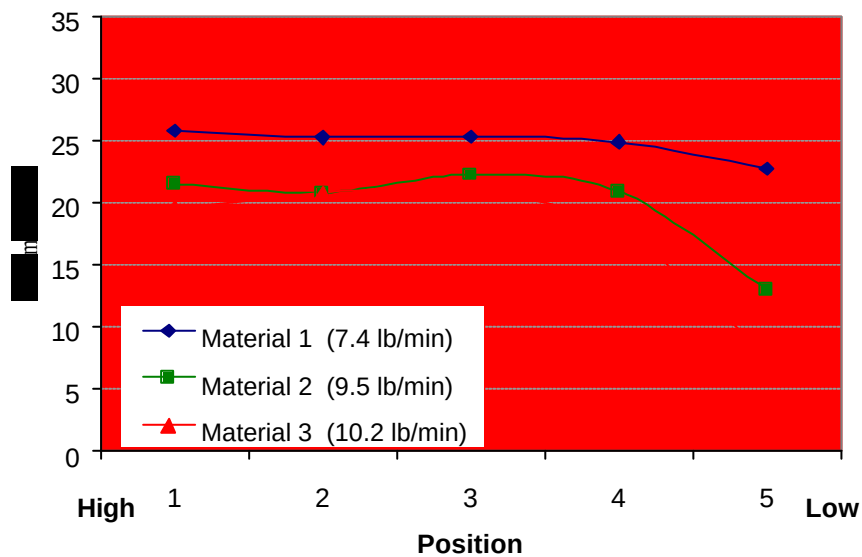


Figure 12: Particle segregation - Inlet 0.2 inch

If powder is allowed to slowly flow and forming a heap, for example when filling a hopper, particle segregation will occur. By minimizing the steps in handling of the powder and make the necessary handling in a correct way to avoid segregation a powder with improved flowability will be beneficial to improve pressing speed and to have less density variations within the parts.

Trials in production press

Table 3: Results from trials in production press

Weight scatter	Material 1	Material 2	Material 3	
Standard deviation	0.084	0.061	0.136	g
Moving range	0.047	0.039	0.047	g
Green dimensions				
Average height diff. front-rear	-27	0	26	μm
Average ovality	10	10	11	μm
One sigma of mean diameter	2	2	1	μm
Sintered dimensions				
Average height diff. front-rear	-23	8	27	μm
Average ovality	22	10	10	μm
One sigma of mean diameter	2	2	2	μm
Average density diff. Rear - front	0.109	0.079	0.060	g/cm^3

Weight scatter is presented in table 3 as standard deviation calculated on all rings for each material. Moving range is the average of difference in weight from each ring and the ring before. A difference between those two statistical values is that the standard deviation will increase if there are trends in the values. Moving range is only taking the random scatter into account, not including trends. Results are also presented graphically in diagram 13 – 15.

The weight scatter is small for all three mixes. Mix 3 has a different behavior compared to mix 1 and 2. The weight is less stable which is indicated by a higher standard deviation. Moving range, or random scatter, is not higher compared to mix 1. The explanation is found in the high flowability causing particle segregation in the handling of the powder. Variations in particle size will cause variation in apparent density.

No actions were taken to avoid segregation in handling of the powder in this experiment or in the design of the hopper and filling system of the press used in the trials.

The best result in weight scatter was obtained by mix 2.

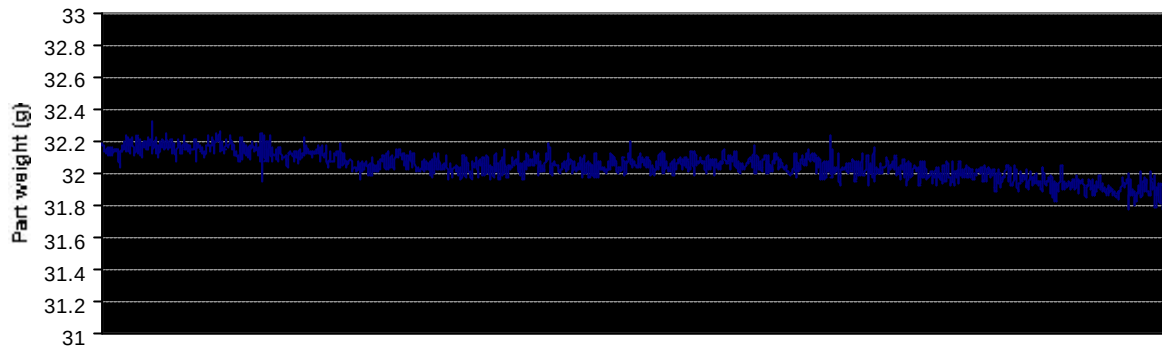


Figure 13: Scatter in part weight for mix 1

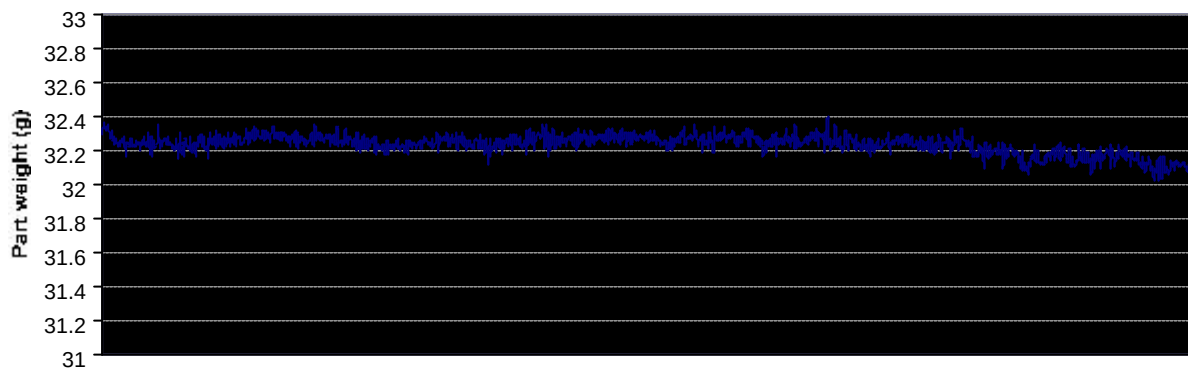


Figure 14: Scatter in part weight for mix 2

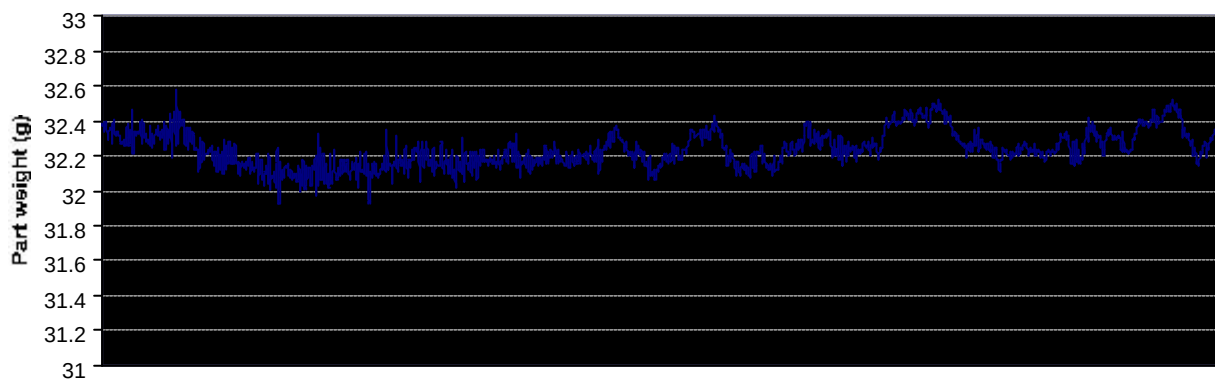


Figure 15: Scatter in part weight for mix 3

What can not be seen in the results of the weight scatter in this trial is the possibility to further increase the press rate. Even if the weight scatter for mix 1 is good the filling is poor which is seen in the density distribution within the rings. In figure 16 it is seen how the density distribution is improved by increased flowability of the powder. The difference in density between rear and front segment of the ring is almost twice as large for mix 1 compared to mix 3.

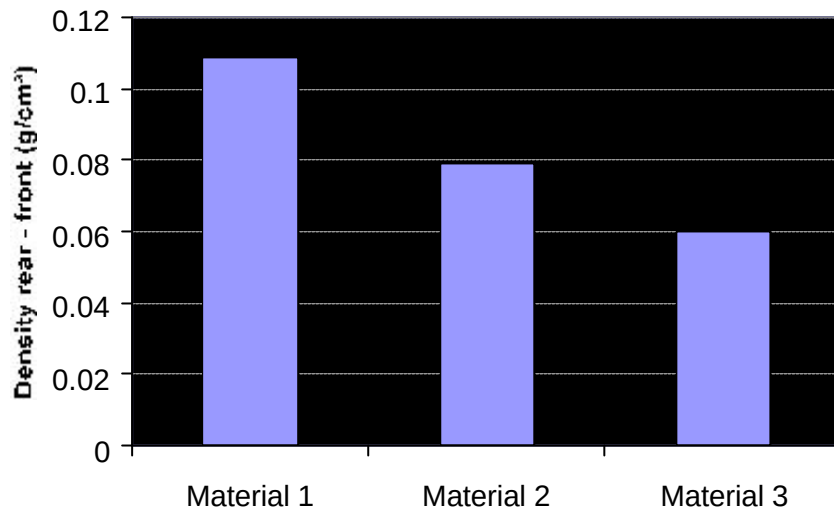


Figure 16: Difference in density between rear and front segment of ring

The improved flowability improves density distribution, which in turn also influence the height difference between rear and front position of the ring via the springback, see figure 17.

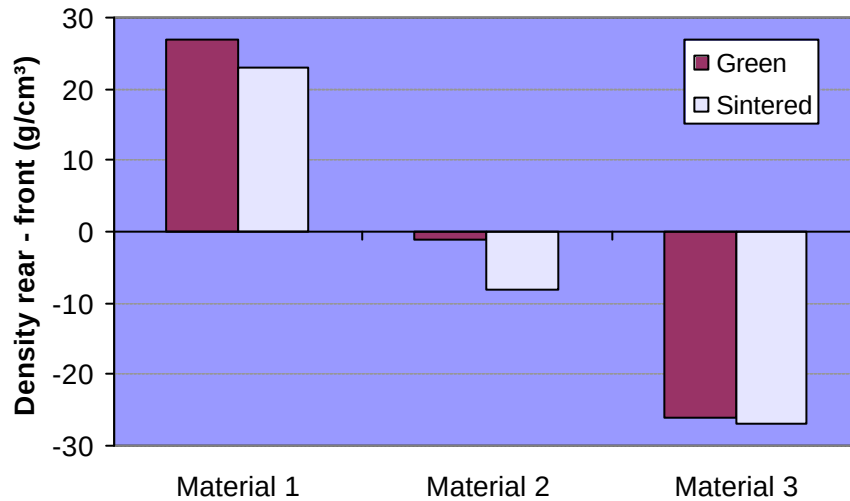


Figure 17: Difference in height between rear and front position on ring

In green state the ovality of the ring, see figure 18, is similar for the three mixes. Mix 2 and 3 keep the same ovality after sintering while mix 1 becomes more oval after the sintering.

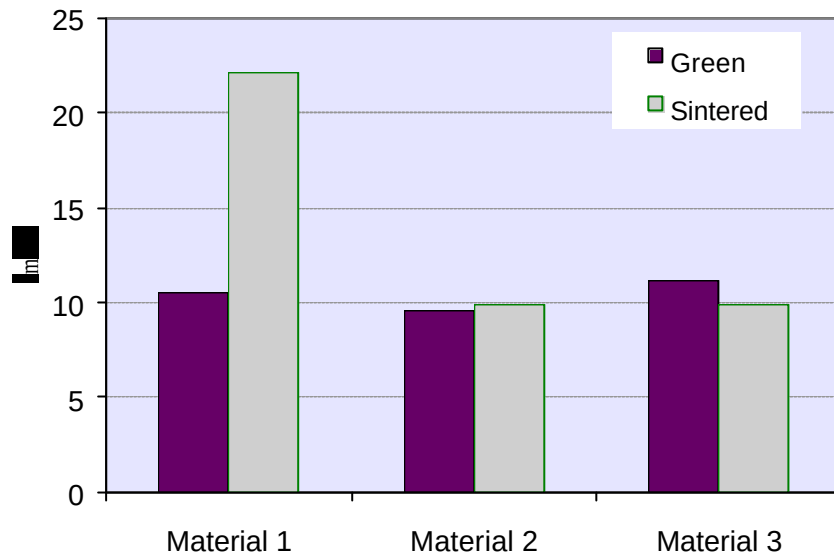


Figure 18: Diameter along – perpendicular (ovality) to the filling direction

Scatter in average diameter in green state is decreased with increased flowability of the powder, see figure 19. After sintering the scatter in average diameter has increased for mix 1 and mix 3. Mix 2 has kept the same scatter as in green state and exhibits least scatter after sintering.

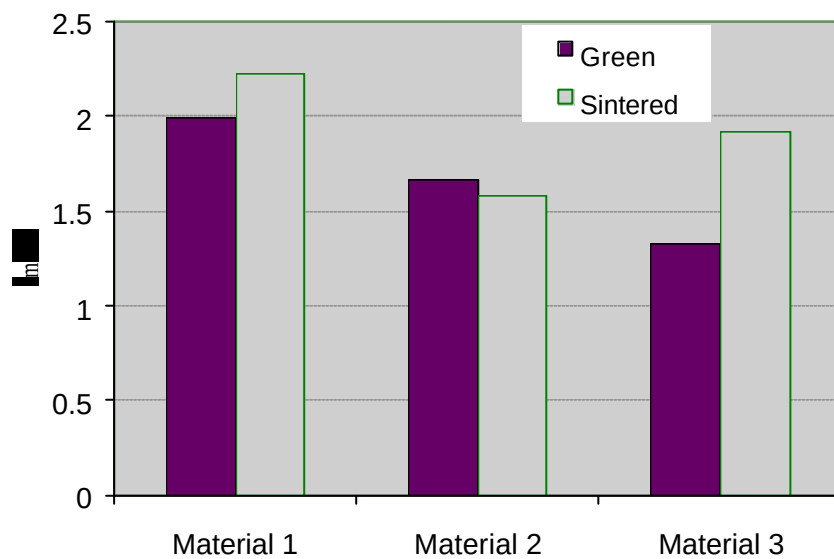


Figure 19: Standard deviation in average diameter

In diagram 20 the results from dust measurements in the press during compaction of the three mixes is presented. A major difference is seen between the ordinary mix (mix 1) and the bonded mixes (mix 2 and 3). The peaks have the same frequency as the movements of the filling shoe. With mix 1 dust is measured each time the filling shoe move. This dusting is eliminated by the bonding technique.

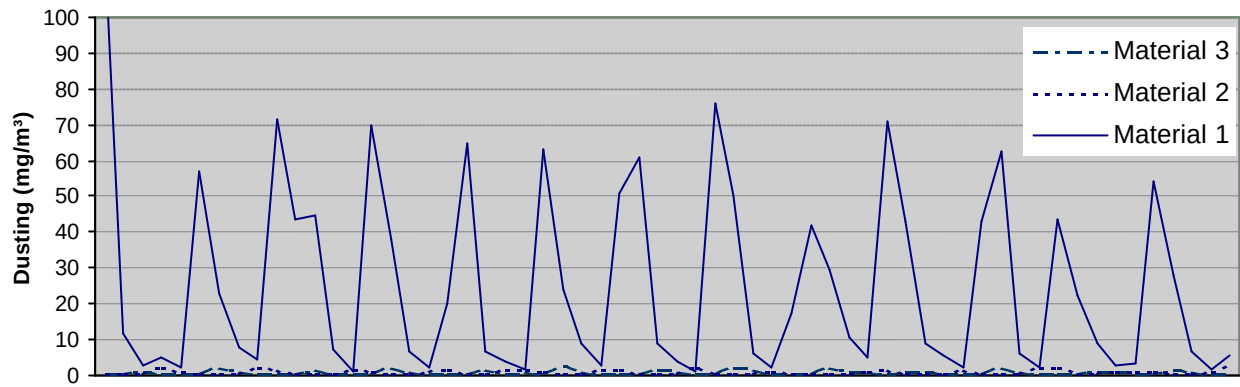


Figure 20: Dust measurement in press

CONCLUSIONS

Die filling simulation

Bonded mixes with improved flowability have superior filling behavior. This makes it possible to increase the rate of production during pressing, if filling is the bottleneck. In parts with complicated shape less density variations within the parts is possible to obtain. Less internal density variations is beneficial to achieve uniform springback and dimensional change during sintering.

Segregation test

The drawback of improved flowability is that the powder is more inclined to particle segregation. Rapid and streamlined handling of powder minimizes particle segregation and should be used to have optimal result. Higher production rates are made possible, and is actually improving the result giving less variation in filling (weight scatter between parts).

Trials in production press

The improvement in filling behavior that is found in the die filling simulation equipment is confirmed by decreased density variation within the rings.

Bonded mixes with improved flowability give better roundness for the sintered rings. The scatter in diameter in green state is decreasing with the bonded mixes with improved flowability. Also in sintered state the least scatter was obtained by one of the bonded mixes.

Dusting during pressing is almost completely eliminated by utilizing the bonding technique.

REFERENCES

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2. J. Tengzelius and U. Engström, "Powder mixes for precision components", Paper presented at the 1983 Powder Group Meeting, Edinburgh.