EFFICIENT P/M PART PRODUCTION THROUGH BONDED MIXES HAVING UNIQUE POWDER PROPERTIES

Hilmar Vidarsson, Jeanette Lewenhagen and Björn Johansson
Höganäs AB, Sweden

ABSTRACT

Several key factors dictate the quality and economical outcome of the pressing operation in P/M parts production. Among these, productivity, filling performance and dusting are influenced by the properties of the powder mix. The concept of Starmix powders makes it possible to improve all these key factors by utilization of organic binders and high quality lubricants. The versatility of these powders is demonstrated in this paper through case studies, where improvements in parameters such as weight scatter and dimensional tolerances are shown. Examples are also given of filling behavior and productivity of bonded mixes as compared with plain powder mixes.

INTRODUCTION

The quality and economy of powder pressing for production of P/M parts is dictated by several factors. Of these, the powder properties of the mixes used are often found to influence the outcome in several ways, such as during powder transport from a bag or hopper down to the filling shoe, and transport of the powder from the filling shoe into the die cavity. A poor flow rate of a powder mix is often seen as an indication of slow filling of a die cavity, and may also result in filling problems in cavities of complex geometry and with narrow spacings.

Previously reported studies of powder mixes in a filling simulator have shown how the filling performance can be more accurately described in the laboratory [1]. Using this equipment it is possible to distinguish between powders with different filling performance, such as non-bonded mixes (premixes) with different lubricants and bonded mixes. It was demonstrated that bonding of powder mixes could facilitate faster and more even filling, which in production terms should mean higher productivity, more even density distribution and more consistent dimensional control.

A full-scale trial in P/M parts production, where a premix and a bonded mix were tested in terms of filling behavior and dimensional scatter, showed the production improvements possible with bonded mixes [2]. The bonded mix had superior filling performance and less scatter in green dimensions, dimensional change and final component tolerances compared to the equivalent non-bonded mix.

In this work, mass production trials were conducted, focusing on the productivity improvements obtained when comparing a bonded mix, Starmix, with the equivalent Premix. These trials were performed at a P/M Parts producer. The components were ring-shaped and had a green density of approximately 7.1 g/cm^3. The scatter in compacting force, sintered density, phosphorus, weight, dimensions, and the dusting of the mix in the press were measured.

EXPERIMENTAL PROCEDURE

Materials

Two mixes with the same composition, a non-bonded Premix and a Starmix, were used in a total of three trials. The composition of the mixes was:

Astaloy Mo + 0.50% P (as Fe_3P) + 0.30% MnS + 0.75%Amide Wax

Testing

Powder properties were analyzed prior to the production trials. The Hall Flow was measured according to ISO 4490-1978, and the Apparent Density (AD) was measured according to ISO 3923-1979. The Filling index for the mixes was calculated using a die-filling simulator, thoroughly described in previous papers [2,3]. The die-filling simulator consists of a series of rectangular dies of different widths (1-20 mm), having a fixed length (30 mm) and height (30 mm). In this study, the dies were oriented in parallel to the travel of the filling shoe. The cavities were filled automatically at different speeds and the powder was subsequently collected on a balance for calculation of filling densities from the weight and measured volumes of the cavities. From the results, a Filling Index was calculated as shown in Equation 1 as the relative difference in powder density for two cavities of different width (2 mm and 13 mm).

$$Filling\ Index = \frac{AD_{13mm} - AD_{2mm}}{AD_{2mm}} \times 100 \quad [\%] \qquad \text{Equation 1}$$

A relatively large difference in powder density gives a large Filling Index, indicating a pronounced dependence on cavity geometry. With increasing filling shoe speeds, the narrower cavity eventually

reached a point where it was not completely filled. This resulted in an apparent increase in Filling Index, giving a measure of maximum filling shoe speeds for the studied powder mixes.

During the trials the part weight and compacting force were measured for every 5 parts out of 50, the sintered density was measured for 3 parts out of each 1000 (beginning, middle, end), cutting each compact into 4 sections and evaluating the sintered density for each section. The phosphorous content was determined from specimens sampled in the same pattern as for sintered density.

The variation of green and sintered height for the parts was measured on 50 parts out of 1000 parts produced. The variation in green and sintered height was determined by measurements of the height with a special device through the whole circumference of the ring, as shown in fig. 1a. The variation of green and sintered wall thickness was measured on 20 parts out of 1000 parts produced. The variation in wall thickness was measured continuously along the inner and outer diameter in a similar manner as the height, figure 1b.

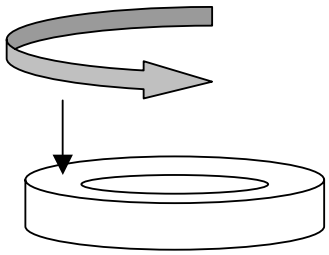


Fig. 1a. Height variation

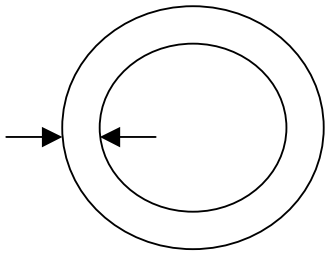


Fig. 1b. Variation in wall thickness

The dusting was measured with a Dust Track Aerosol Monitor. The air is extracted into the Dust Track with a flow of 1.7 dm^3/min. The extracted air is analyzed for particles with a diameter less than 10 µm. During the mass production trials the plastic tube, the inlet to the Dust Track analyzer, was placed on the upper punch. The dusting was measured at the beginning, middle and end of the compacting trials.

Trials

Two different mass production trials were performed. The first trial was a comparison between Premix and Starmix at 14 and 16 strokes/min, which was close to the maximum productivity possible for the Premix under optimal conditions. In the second trial, the production rate was increased further for the Starmix to 16, 18, 20 and 22 strokes/min. Before the start of the second trial, the settings of the press and filling shoe for the Starmix were optimized.

The components were ring-shaped with an approximate OD of 75 mm, ID of 55 mm and height of 11 mm. The target green density of the components was 7.1 g/cm^3 and the weight approximately 160 g. The mixes were compacted in a Dorst 200-tonne mechanical press at production rates between 14 and 22 strokes/min. One thousand components were pressed of each mix. The sintering was done at 1120 °C for 20 min in Endogas in a production belt furnace. Measurements were made of the compacting force, sintered density, phosphorus content, weight scatter, dimensional scatter, and the dusting of the mix in the press was measured.

A third and final trial was performed. Tensile test bars and Impact energy bars according to ISO standards (ISO 2740 and ISO 5754) were pressed to a density level of 7.1 g/cm^3 in a hydraulic Result 125-tonne laboratory press and sintered in the same production belt furnace as the components in the mass production trials. The mechanical properties of the specimens of the Premix and the Starmix were compared.

RESULTS

Powder Properties

The results from measurements of Hall Flow and AD for the two mixes are shown in Table 1. While the AD-level is similar for both mixes, the Hall Flow is much faster for the Starmix compared to the Premix. The results of the determination of the Filling Index, which were obtained from studies of the powder mixes in the filling simulator, are shown in Fig. 2. Two features can be noted in which the Starmix performs better: The filling is more even, giving a lower Filling Index according to the definition in Equation 1, and the maximum filling shoe speed, where complete filling still is achieved, is greater. These results indicate that the Starmix should give better performance than the Premix in terms of dimensions and production rate.

Table 1. AD and Hall Flow

	Starmix	**Premix**
Hall Flow s/50 g	23.5	27.9
AD g/cm^3	3.16	3.16

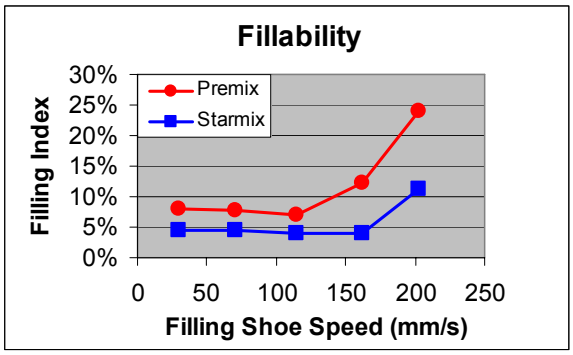


Fig 2. Filling Performance

First Trial

The results from the pressing trials, performed close to the maximum allowable production rate for the Premix, are shown in Figs. 3-10. The measured weight scatter, shown in Figs. 3 and 4, reveals that attempting to increase the production rate for the Premix from 14 to 16 strokes/minute brings about an unacceptable increase, while the Starmix remains at an acceptably low level. Thus, compared with the Starmix, the consistency of the powder filling for the Premix is seriously affected when a certain filling shoe speed is exceeded. This is well in accordance with the prediction given by the studies of powder filling from the filling simulator, Fig. 2.

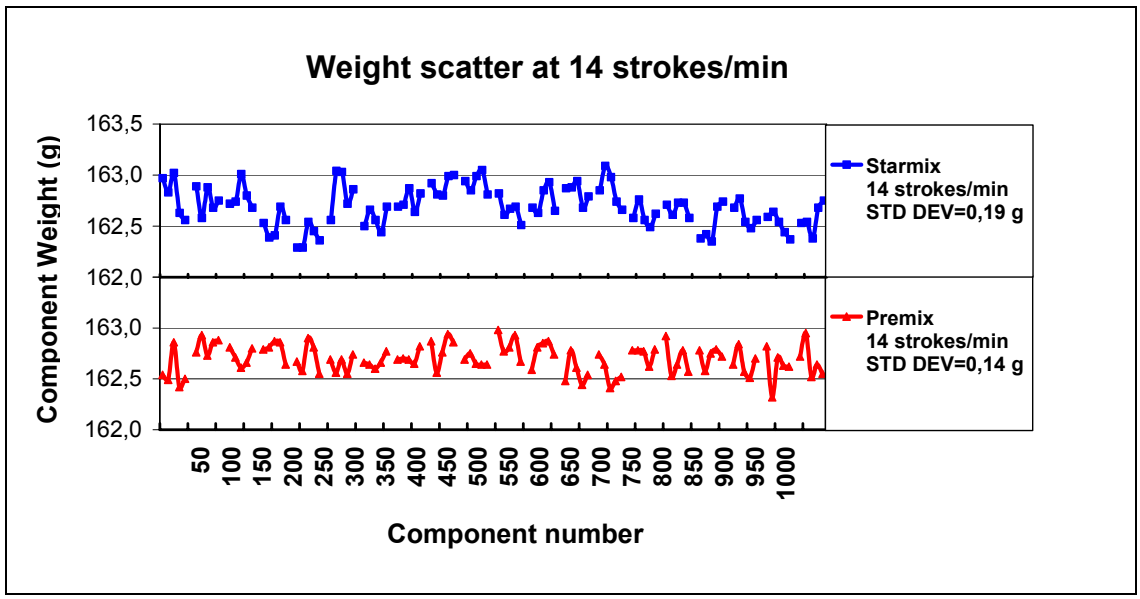


Fig 3. Weight scatter at 14 strokes/min

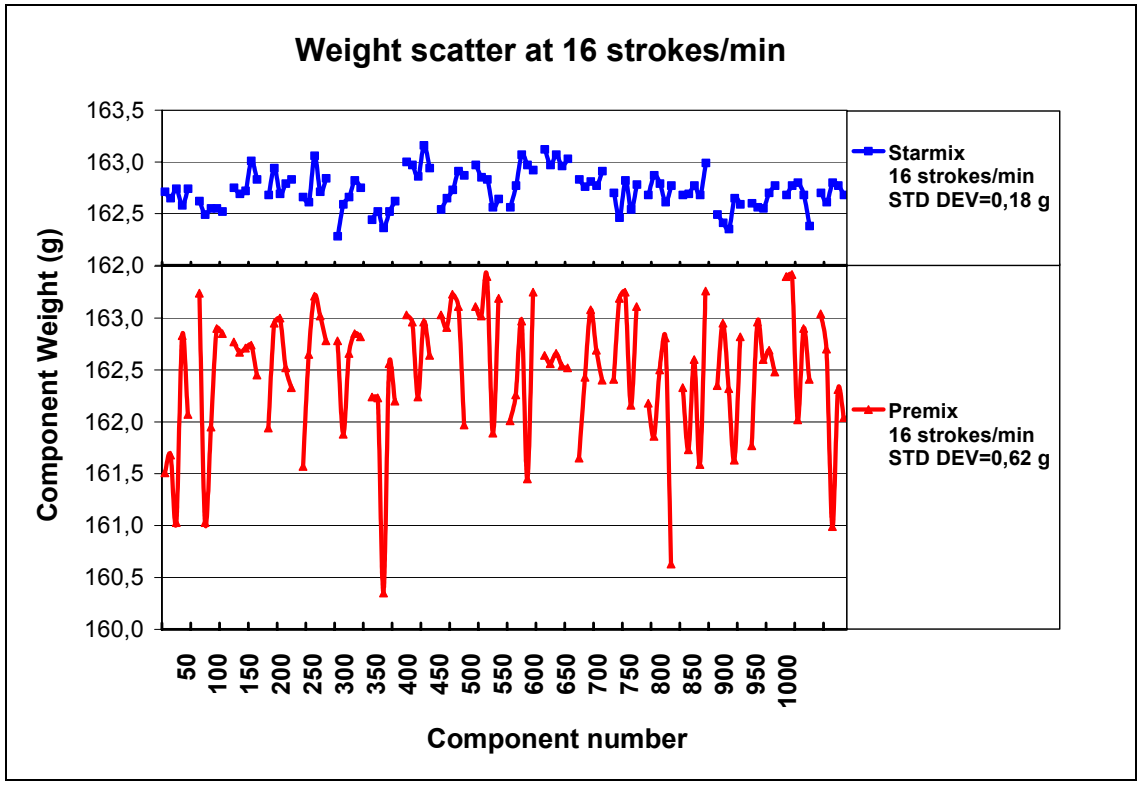


Fig 4. Weight scatter at 16 strokes/min

The behavior observed in the weight scatter measurements in Figs. 3 and 4 is clearly reflected in the variations in compaction force shown in Fig. 5. The dramatic increase in standard deviation for the Premix upon increasing the compaction rate from 14-16 strokes/minute illustrates in this case the practical limit in productivity for non-bonded mixes. In contrast, the consistent performance of the Starmix at these press rates shows that there is more potential in productivity for these types of mixes. This observation is the background for trial 2.

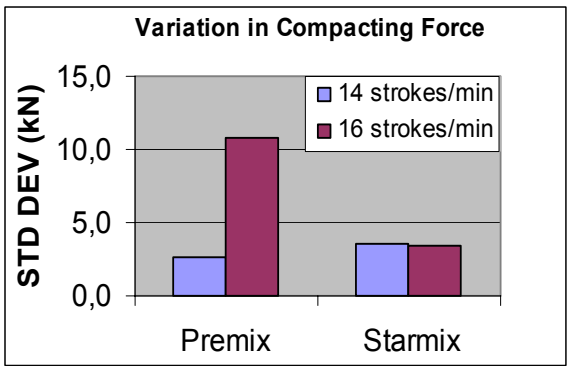


Fig 5. Compacting Force

To a certain extent, the sintered density variations shown in Fig. 6 follow the pattern of the compaction force and the measured weight of parts. This indicates that the consistency in filling is one of the parameters that influence the consistency in sintered density, when compaction is made to a fixed level in a mechanical press. Other parameters that may influence the consistency in sintered density include variations of added alloying elements, in this case phosphorous (here added as Fe_3P). The positive influence from the bonding of additives is seen when comparing the variation in the P-content of the sintered compacts from the Premix and the Starmix, Fig. 7. The improvements in terms of standard deviation that are obtained are between 30-50%.

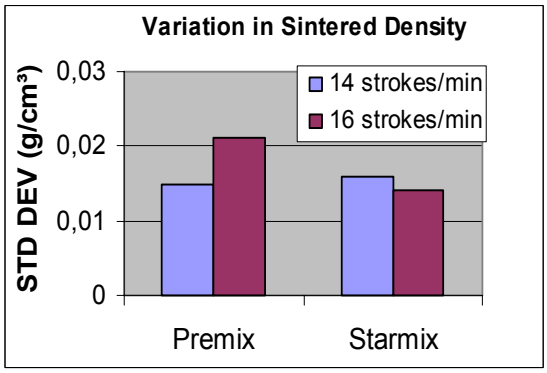


Fig 6. Sintered Density

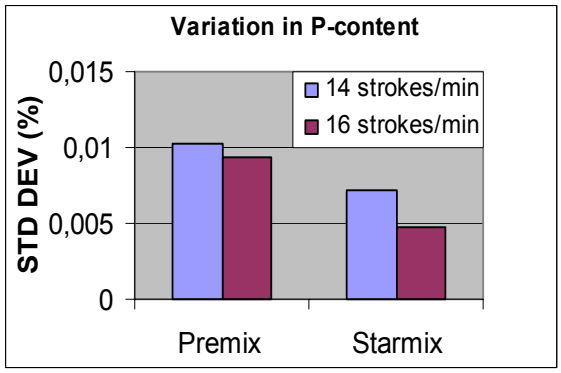


Fig 7. Phosphorous Scatter

The effect of bonding on the powder mix regarding green and sintered dimensions is shown in Figs. 8a-9b. While the Premix performs well in terms of consistency in green and sintered height for the relatively slow filling speed at the lower production rate (14 strokes/minute), its performance deteriorates markedly upon increasing the production rate to 16 strokes/min. The Starmix is, however, not influenced by this factor. An overall better performance for the Starmix is also noted on the green and sintered wall thickness.

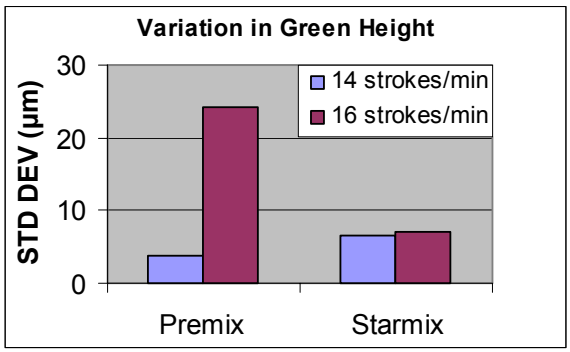


Fig 8a. Green Height

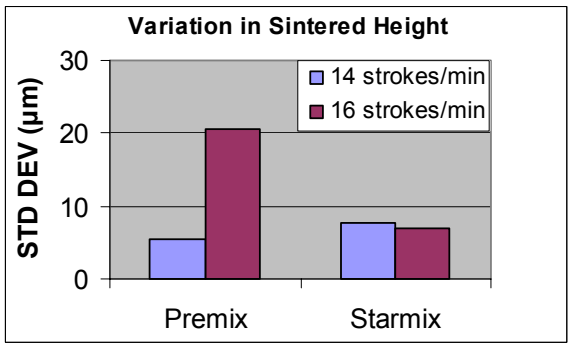


Fig 8b. Sintered Height

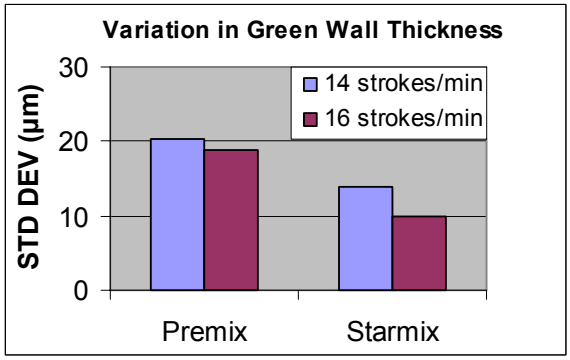


Fig 9a. Green Wall Thickness

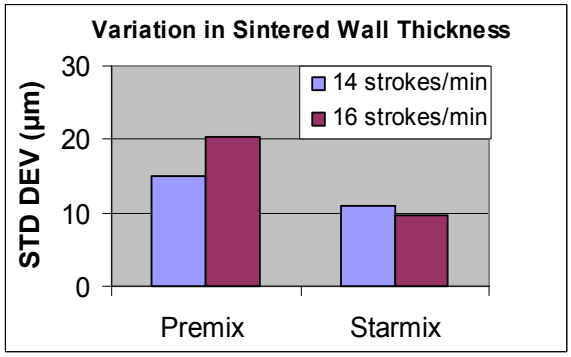


Fig 9b. Sintered Wall Thickness

The results of the dusting measurements showed that the dusting of the Premix is worse than the Starmix, Fig. 10. While the dusting for Premixes often has a tendency to increase with increasing production rates, this could however not be seen in this trial when increasing the production rate from 14 to 16 strokes/min. The dusting level measured during trial 2 for the Starmix was similar to trial 1.

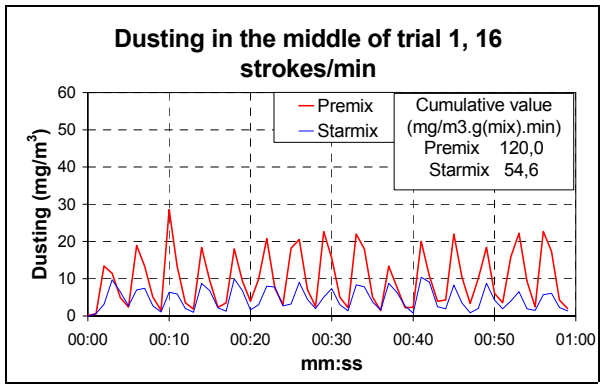


Fig 10. Dusting at 16 strokes/min

Second trial

The component weight scatter for the second trial is shown in Fig. 11. For comparison, the weight scatter for the Premix at 16 strokes/min from trial 1 is shown in the same figure. The results show that the weight scatter is low for the Starmix at all the tested production rates compared to the scatter for the Premix at 16 strokes/min. This corresponds well with the observations from trial 1. The Premix at 16 strokes/min has a standard deviation in weight that is up to 3 times higher than the Starmix at 22 strokes/min. The average 6σ-value of the weight scatter for the Starmix (16-22 strokes/min) is 0,77%, which can be compared to the value for the Premix at 16 strokes/min, which is 2,30%.

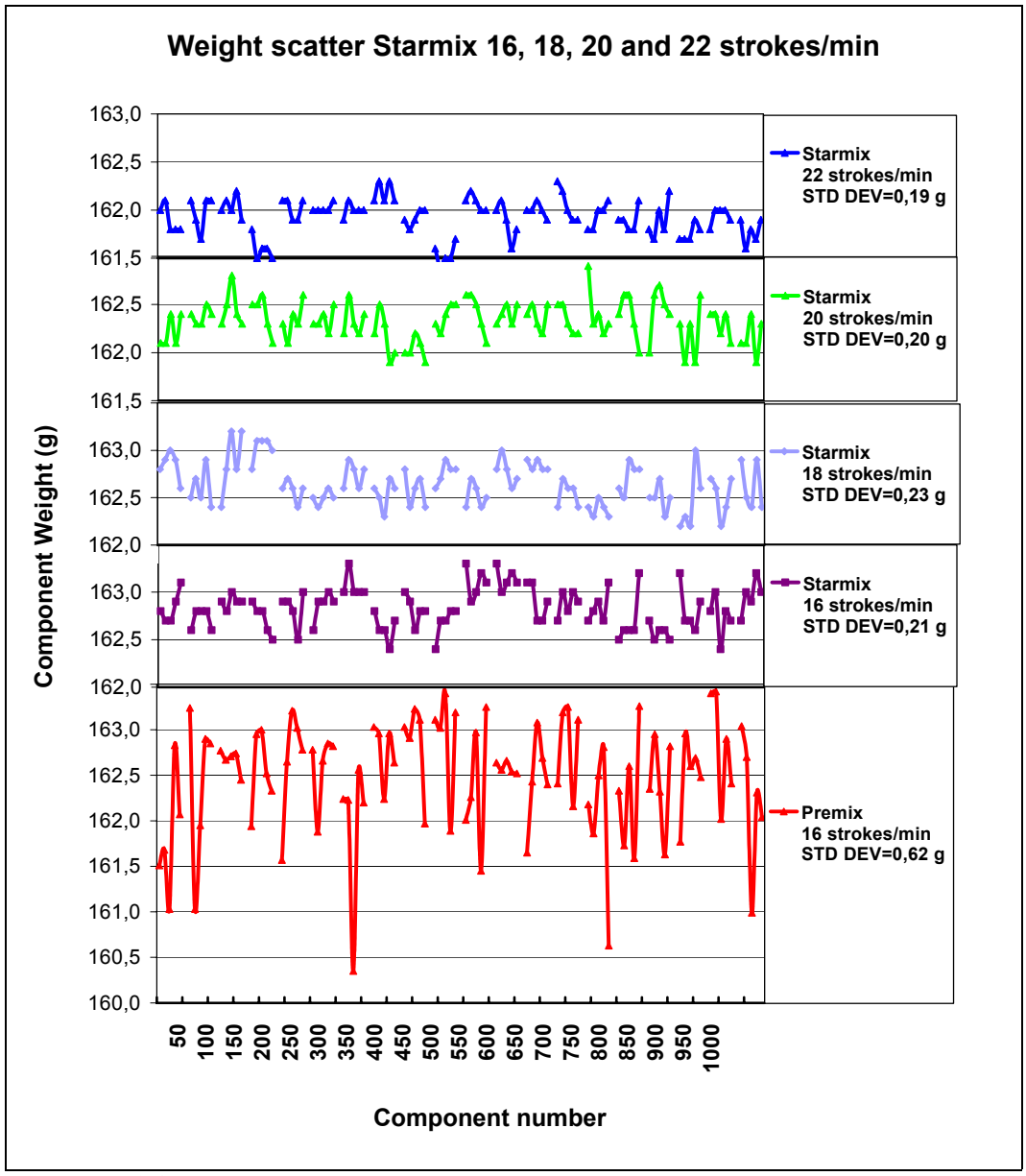


Fig 11. Weight scatter

The variation in compacting force for the Starmix at different production rates is shown in Fig. 12. The results show a stable performance for the Starmix up to 22 strokes/min, which is the maximum production rate for the press equipment used. The variations for Starmix at these high production rates are still much smaller than for the Premix at 16 strokes/min, which corresponds well with the weight scatter seen from Fig. 11.

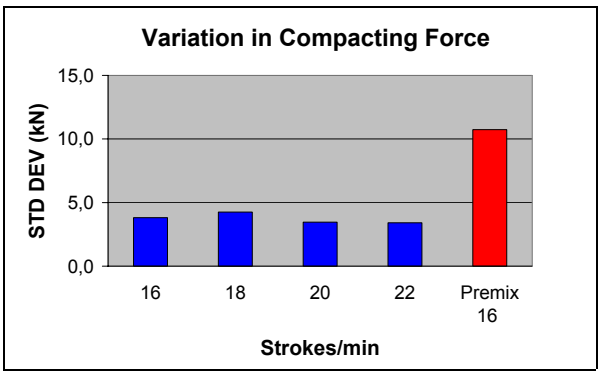


Fig 12. Compacting Force

The variation in sintered density as seen in Fig. 13 follows a similar pattern to the compacting force shown in Fig. 12. The Starmix performs better at all tested production rates in trial 2 compared to the Premix at 16 strokes/min in trial 1. The smaller variation in compacting force and sintered density is probably due to the faster, more even and consistent filling of the Starmix compared to the Premix.

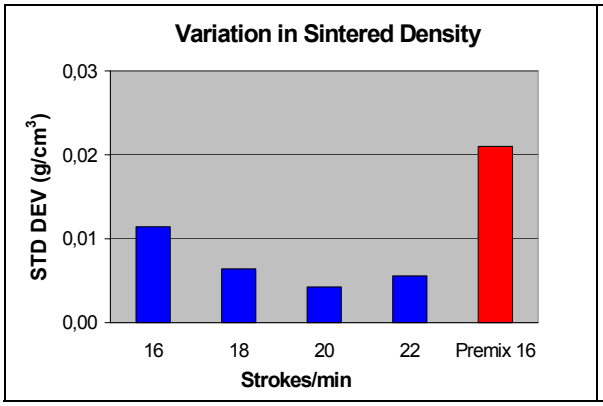


Fig. 13. Sintered Density

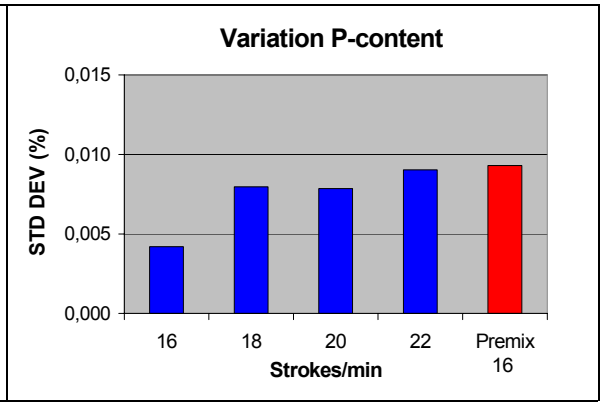


Fig. 14. Phosphorous scatter

The scatter in P-content is lower for the Starmix at production rates up to 20 strokes/min compared to Premix at 16 strokes/min. At 22 strokes/min the Starmix has approximately the same scatter in P-content as the Premix.

The dimensional scatter of the green and sintered dimensions is shown in Figs. 15a-16b. The scatter in green and sintered height is lower for Starmix at all tested production rates compared to the Premix at 16 strokes/min. The scatter in green and sintered wall thickness is, however, lower for Starmix up to 20 strokes/min compared to the Premix at 16 strokes/min. At 22 strokes/min, the wall thickness for the Starmix is not as consistent as the other measured properties. The reason for this may be that the movement of the filling shoe at these high production rates needs to be optimized further.

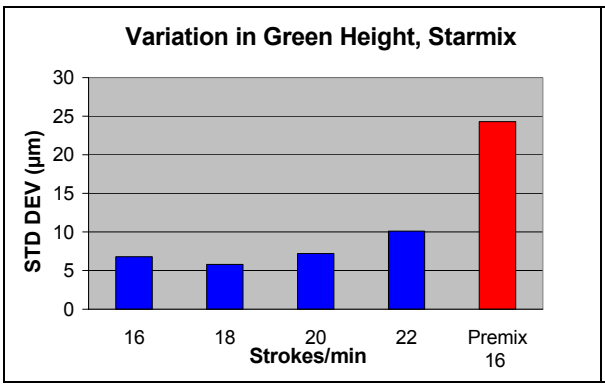


Fig 15a. Green Height

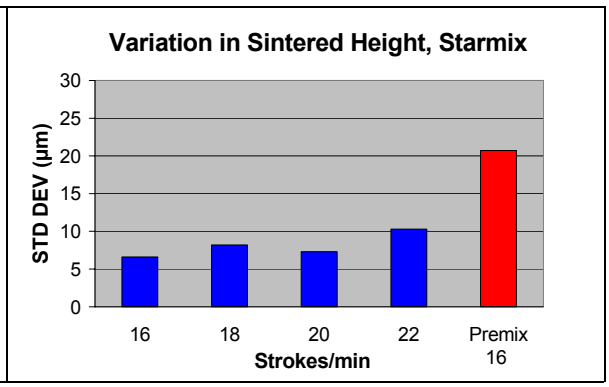


Fig15b. Sintered Height

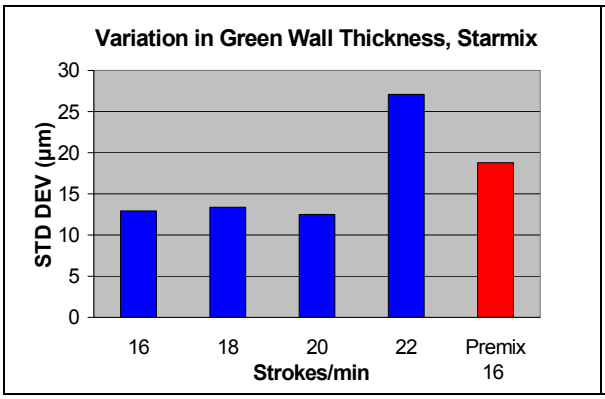


Fig 16a. Green Wall Thickness

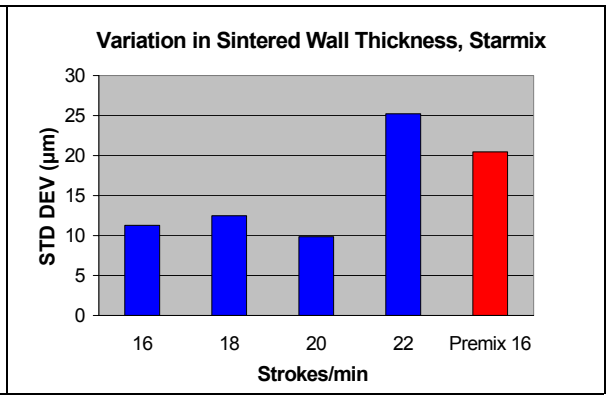


Fig 16b. Sintered Wall Thickness

Third trial

The results from trial 3 are presented in Table 2 (TS-test bars) and Table 3 (test rings, ∅55 mm outer, ∅45 mm inner). There are some small differences between Starmix and Premix. The Starmix requires higher compacting pressure than the premix to reach the same green density. However, the Starmix has a higher impact energy and sintered density compared to the Premix. The other properties are on the same level.

Table 2. Mechanical properties Starmix

	Starmix	**Premix**
Compacting Pressure (MPa)	729	686
Green Density (g/cm^3)	7.12	7.12
Sintered Density (g/cm^3)	7.29	7.26
Dimensional Change (Die-Sintered) (%)	-0.58	-0.56
Tensile Strength (MPa)	450	444
Yield Strength (MPa)	346	338
Elongation (%)	7.3	7.5
Hardness, HV10	167	164
Impact Energy (J)	72.3	66.5

Table 3. Radial Crushing Strength measured on rings

	Starmix	**Premix**
Sintered Density, Ring (g/cm^3)	7.25	7.22
Radial Crushing Strength (MPa)	1217	1204

DISCUSSION

The results in this study demonstrate clearly that the powder properties influence the performance and consistency of production of PM parts. The improved Hall Flow values and especially the results from the filling simulator indicate a faster, and a more consistent and even flow behavior on the Starmix compared with the non-bonded Premix, and this is verified by the higher productivity obtained from the production trials. Thus, for the mixes in this investigation, which was made in production, the productivity could be increased by at least 40% by using Starmix. Furthermore, the Starmix improved weight scatter and gave less dimensional scatter compared with the non-bonded Premix.

CONCLUSIONS

- The Starmix can be compacted at a press rate up to 20 strokes/min with the approximate same scatter in properties as the equivalent Premix at 14 strokes/min. This corresponds to an increase in productivity of 40%.

- Starmix powder fills more consistently than Premix powders. The filling performance of Starmix powders is superior to the corresponding Premix.

- The Starmix has equivalent or better mechanical properties than the corresponding Premix.

REFERENCES

1. M. LARSSON, Dr. H. VIDARSSON: *Efficient Bonding For Dimensional Stability,* Proceedings of PM2TEC 2000, New York, May/June 2000.

2. Dr. H. VIDARSSON AND J. ARVIDSSON: *Die Filling Capability of Powder Mixes,* Proceedings of Powder Metallurgy World Congress 2000, Kyoto, Japan, November, 2000.

3. F. VINNERBORG, U. ENGSTRÖM, Dr. H. VIDARSSON, J. ARVIDSSON: *Improvements in Bonding of Press-ready Low-alloy Steel Powder Mixes*, Proceedings of Euro PM2001, Nice, France, October, 2001.