Close Dimensional Stability at High Production Rates

Hilmar Vidarsson*, Sigurd Berg*, Daniel Edman*, Björn Johansson*,
Peter Thorne**.
* Höganäs AB, S-263 83 Höganäs, Sweden
**North American Höganäs, USA

ABSTRACT

In production of P/M parts, dimensional stability is one of the most important quality parameters. While the contributions from powder handling, pressing operation and sintering are known to influence dimensional stability, powder properties also play an important role. Bonding of powder mixes can be used to as a means to improve dimensional stability of green and sintered components. Although the primary reason for bonding is to avoid dusting and segregation, it also influences powder properties, especially the flow behaviour. The bonding system used in Starmix™ powders is optimised to achieve maximum bonding efficiency in combination with superior die filling performance and at high production rates. This is demonstrated by comparing Starmix™ powders with non-bonded powder mixes in both laboratory studies and full-scale production.

INTRODUCTION

Of the parameters that are known to influence performance and outcomes during production of P/M parts, few are as important as the flowability of the iron powder mix. While poor flow behavior may result in unwanted effects such as insufficient dimensional control, unacceptable weight scatter and relatively low productivity, better powder flow will delivers improvements in these parameters. This will in turn lead to decreasing quality costs and better production economy.

The benefits of maintaining good flowability are therefore obvious, and emphasize the need for knowledge and understanding of the factors involved. One of the main causes of poor flowability in iron powder mixes is the nature and the amount of micronised additives that are used. In relatively large amounts graphite and lubricants in particular may have detrimental effects and leads to formation of powder bridges that can cause erratic flow. In powder handling systems for production presses, these disturbances are often experienced in the hoppers and filling shoes, and even as poor filling performance in die cavities. Furthermore, owing to the relatively low density of graphite and lubricants, they are

especially prone to dusting. Besides causing unwanted environmental effects in the workshop, graphite dusting can for example also cause instabilities in the composition of the mix, which in turn may increase the dimensional scatter of the sintered P/M parts.

Bonding of iron powder mixes is the most efficient method to improve flow behavior. The use of organic binders for this purpose has been shown to give these desired effects as well as maintaining important parameters such as compressibility and mechanical properties at required levels. This has been demonstrated with Starmix™ powder mixes in both laboratory studies and production trials [1,2,3]. Considerable improvements in die filling performance have thus been shown using a die filling simulator, where for instance the filling density of Starmix™ exhibited less dependence on cavity geometry than corresponding non-bonded premixes. Furthermore, complete cavity filling was obtainable at faster filling shoe speeds with Starmix™ as compared with premixes. In a production trial, a specific case showed a 40% increase in the productivity as a direct result of the flowability improvement obtained from the bonding process used for the Starmix™ [4].

In the present study, the focus is on comparing the performance of a non-bonded Premix and a bonded Starmix™ as production rates are increased. As background, a laboratory evaluation involving powder properties and die filling performance is conducted, and the bonding efficiency of graphite is reported. Production trials conducted at a P/M parts producer for a gear component compacted at different production rates are reported. Density, height and diameter scatter for variation both in green state and as sintered are presented.

EXPERIMENTAL PROCEDURE

Material

Mixes with the same composition, non-bonded Premix and Starmix™, were investigated.
The composition of the mixes was:

1. ASC100.29 + 2% Cu (100 mesh) + 0.6% C-UF4 + 0.8% Amide wax.
2. AHC100.29 + 1% C 1651 + 0.5% MnS + 0.8% Amide wax.
3. D.AF + 0.5% C-UF4 + 0.5% MnS + 0.8% Amide wax.

Testing

Powder properties

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. Compressibility and mechanical properties were evaluated according to ISO 3927 and ISO 2740-1986. Mechanical properties were evaluated at 43.5tsi (600 MPa). Sintering at 2050°F (1120°C) was performed in a laboratory belt furnace for 30 minutes in 90/10 N_2/H_2. Cooling rate was 1.4°F/s (0.8°C/s).

Bonding

Roller air analyzer

The part bonded graphite and lubricant in a powder mix are measured with the Roller Air Analyzer or Roller Particle Size Analyzer from Aminco. The instrument is an air classifier, which separates material by diameter and density. In this case, the parameters are set to blow off graphite with a mean particle size of 4 µm. The sample amount used was 50g. After this operation the content of carbon and lubricant in the sample are analysed and compared with the content before the test. The fraction of bonded C is then calculated as :

$$C_2/C_1*100 = \% \text{ bonded graphite}$$

C_1 = analysed carbon in mix before the blowing test

C_2 = analysed carbon in mix after the blowing test.

The equipment for dust measurement is shown below.

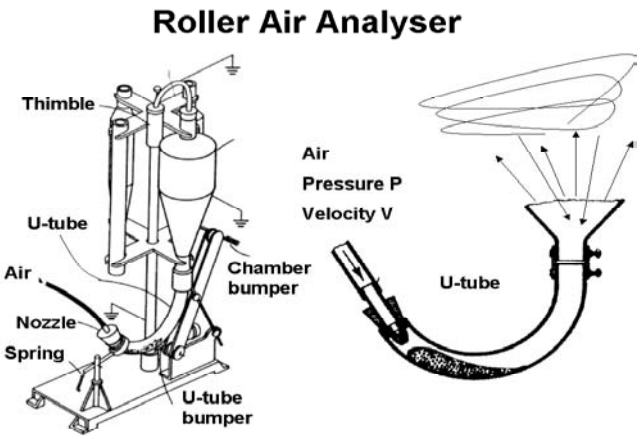


Figure 1. Equipment for dust measurement, Roller Air Analyzer.

Production trials, mix 1.
A small gear, figure 2, was compacted in a mechanical press at Pennsylvania Powdered Metal, density range 7.00 to 7.05 g/cm^3.



Figure 2. Part for production evaluation.

Outer diameter of the gear was 1.693 inch (43 mm), inner diameter was 0.906 inch (23 mm) and the height was 0.472 inch (12 mm). Performance at 16, 20, 24 and 26 strokes/minute was investigated regarding weight, height, diameter and density variations.
The variation of green and sintered height (four investigated positions) and diameter (two investigated positions) for the gears was measured for 5 gears in sequence of 50. Weight variation was measured continuously during compaction. Gears were sintered in a production furnace, 90/10 N_2/H_2 at 2050°F (1120°C) for 20 minutes.

RESULTS AND DISCUSSION

Powder properties

The results from measurements of Hall Flow and AD for the mixes are shown in table 1. AD level for Starmix™ is ~0.2 g/cm^3 higher and flow is ~8 seconds faster compared to a Premix. A faster filling in combination with an even filling [4] makes increased productivity possible.

Table 1. AD and Hall Flow Mixes 1 – 3

Mix	AD g/cm^3		Hall Flow s/50 g	
	Premix	Starmix™	Premix	Starmix™
1	3.01	3.25	32	24
2	3.03	3.24	34	24
3	3.06	3.23	28	23

Bonding

Bonding is evaluated by use of a roller dust analyzer. In table 2 the degree of bonding of graphite for mix 1, Premix/Starmix™ is shown.

Table 2. Bonding of graphite for the investigated mixes 1, Premix/Starmix™.

	Before rolling (%)	After rolling (%)	Remaining graphite (%)
Premix	0.63	0.28	45
Starmix™	0.61	0.60	98

Graphite is bonded to 98% in Starmix™ compared to an apparent bonding of 45 % in Premix.

Dusting

Measurement of dusting is shown in figure 3.

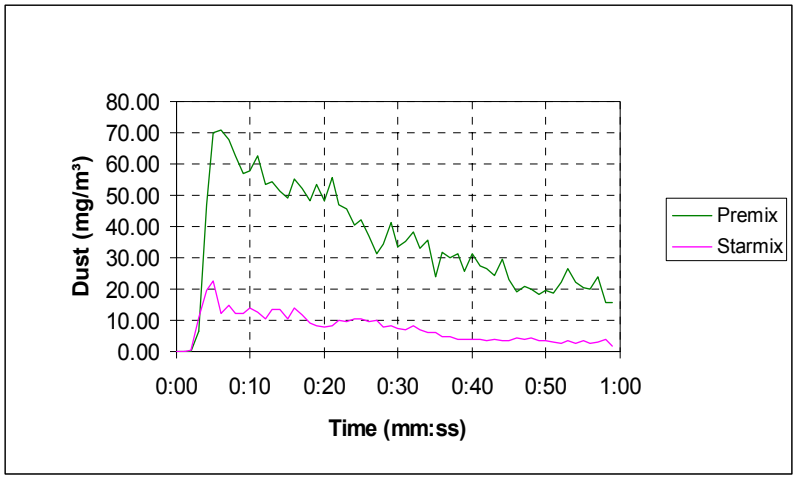


Figure 3. Dusting mix 1, Premix/Starmix™.

Dusting from a Starmix™ is reduced by ~90% compared to a Premix with the same composition. Dusting does not only improve the environment around the press, but also contribute to higher consistency in tolerances.

Mechanical properties.

Mechanical properties for the investigated mixes compacted at 43.5tsi are shown in table 3.

Table 3. Mechanical Properties.

Mix No.	Type	Green Density g/cm^3	Sintered Density g/cm^3	DC* %	UTS ksi/MPa	YS ksi/MPa	HV10	Elong %	Carbon %
1.	Premix	7.07	7.00	0.21	73.5/507	51.9/358	144	3.2	0.63
	Starmix™	7.06	6.98	0.26	71.5/493	50.9/351	146	2.9	0.61
2.	Premix	6.99	6.97	-0.02	68.0/469	42.6/294	147	2.4	0.90
	Starmix™	6.96	6.94	-0.08	67.1/463	41.9/289	145	2.6	0.89
3.	Premix	7.10	7.10	-0.14	119.5/824	57.1/394	246	2.4	0.47
	Starmix™	7.09	7.10	-0.17	119.4/823	57.1/394	239	2.4	0.47

* green to sintered.

Mechanical properties obtained at a fixed compaction pressure of 43.5tsi are in the same range for all investigated mixes.

Production evaluation, mix 1
Green density as mean value of 1 gear of 100 compacted is shown in table 4.

Table 4. Green density

Strokes/min.	16	20		24		26
Mix	Premix	Premix	Starmix™	Premix	Starmix™	Starmix™
Average	7.05	7.04	7.01	7.04	6.98	6.98
Std Dev	0.012	0.009	0.009	0.014	0.005	0.008

Starmix™ with the same amount of lubricant indicates a slightly lower green density, table 4. This implies that the size and complexity of the part has an influence on the lubricity. In order to match a Premix for compaction of complex parts a bonded mix needs either to have an increased amount of the same lubricant or modification of the lubricant composition.

The scatter in density is important for tolerances. The green density standard deviation is shown in figure 4. The slow production rate indicates an increased scatter for Premix. At 20 strokes/minute the scatter is equal for Starmix™ compared to Premix. Increased production rate of 24 strokes/minute the scatter starts to increase for the Premix while it even improves for Starmix™. Performance for Starmix™ indicates that it is possible to increase productivity to 26 strokes/minute.

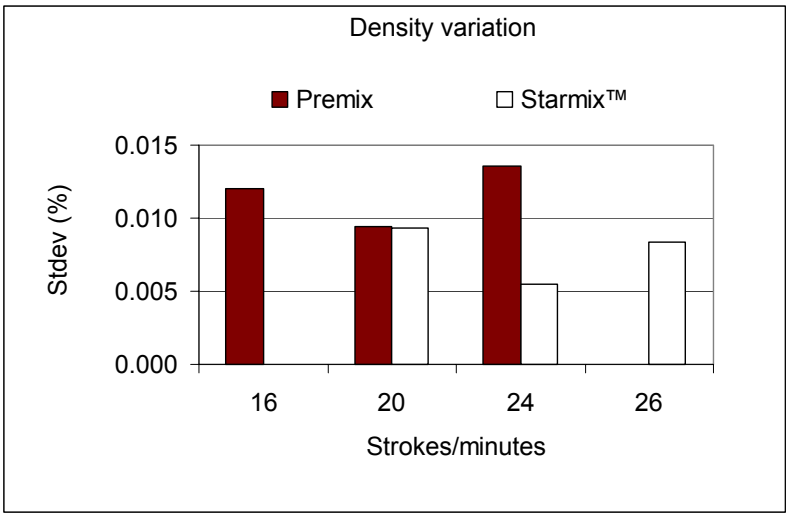


Figure 4. Density variations, mix 1 Premix/Starmix™

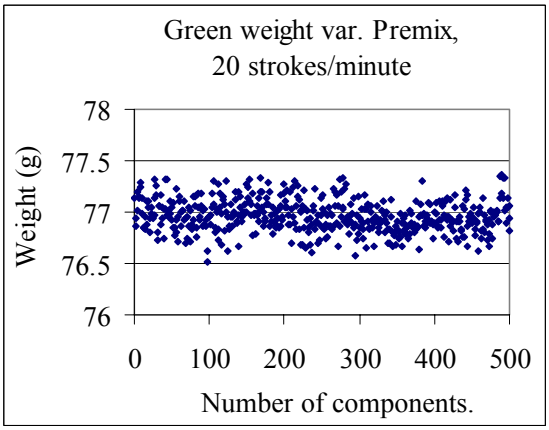
Weight measurements at different production rates are shown in table 5.

Table 5.Weight variation, mix 1 Premix/Starmix™

Strokes/min	16	20		24		26
Mix	Premix	Premix	Starmix™	Premix	Starmix™	Starmix™
Average	77.84	76.97	76.94	77.37	77.51	77.31
Std Dev	0.204	0.150	0.160	0.282	0.187	0.163
Max	78.57	77.37	77.41	77.95	78.06	77.88
Min	77.05	76.51	76.51	75.55	76.86	76.84

In the production rate interval from 16 to 20 strokes/minute Premix and Starmix™ have a weight scatter level of ~0.18 g. At 24 stokes/minute the scatter increases for the Premix to a level of 0.28 g. The weight scatter for Starmix™ is maintained at the same level ~0.17 g up to 26 strokes/minute.

In figure 5 a–e, the weight variations are shown for all compacted gears at 20, 24 and 26 strokes/minute. The number of parts compacted was more than 500 parts after stable conditions had been reached, except for Starmix™ at 26 strokes/minute due to lack of time on the press.



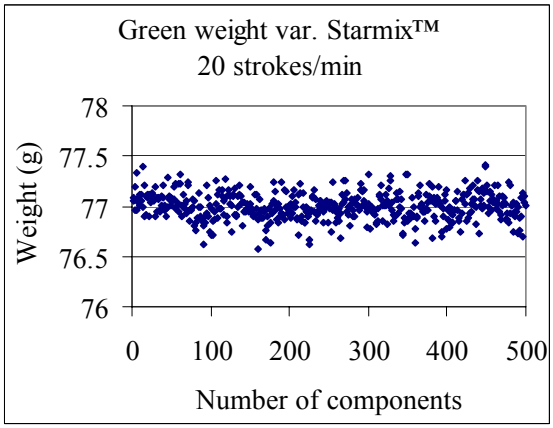


Figure 5a. Weight scatter, Premix at 20 str./min. Figure 5b. Weight scatter, Starmix™ at 20 str./min.

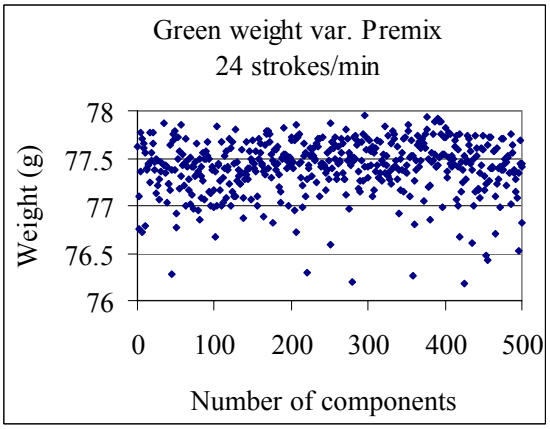


Figure 5c. Weight scatter, Premix at 24 str./min.

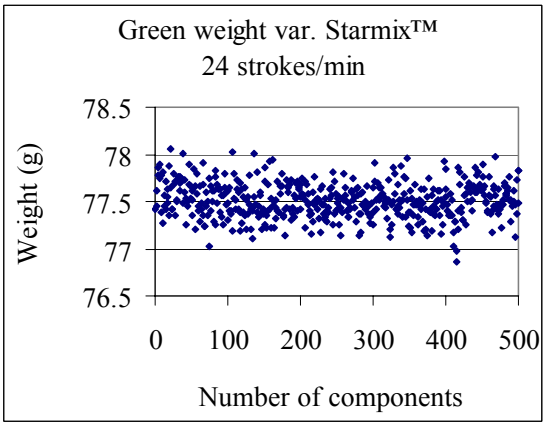


Figure 5d. Weight scatter, Starmix™ at 24 str./min.

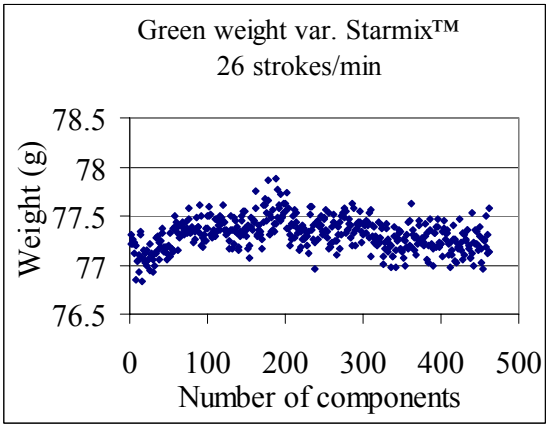


Figure 5e. Weight scatter, Starmix™ at 26 str./min.

Direct comparison is possible in figure 5 a-e between Premix and Starmix™. At 20 strokes/minute the scatter is the same. Increase productivity to 24 strokes/minute, the weight scatter for Premix increases while it remains at the same level for Starmix™. In order to investigate the performance of Starmix™, maximum compaction speed was applied, 26 strokes/minute. At this productivity level the scatter was found to be at the same level. A further gain in productivity with Starmix™ was not possible to investigate due to press limitations.

Height variation measured at four different positions and diameter variation at two positions on the gears as mean value for all measured ones is shown in figure 6 a-d.

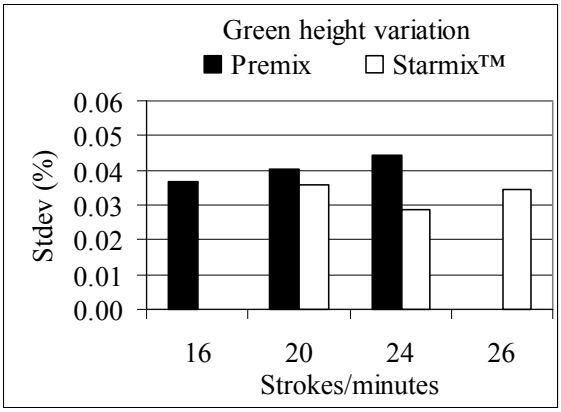


Figure 6a. Green height variation.

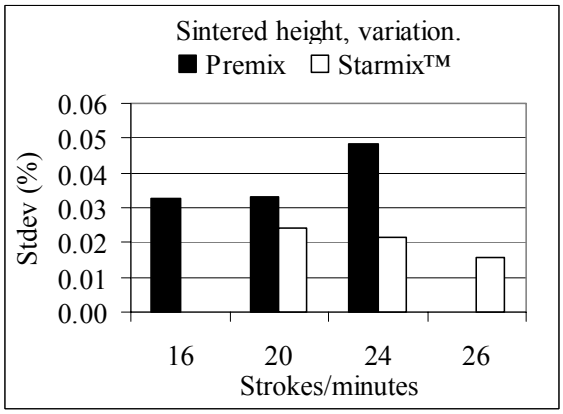


Figure 6b. Sintered height variation.

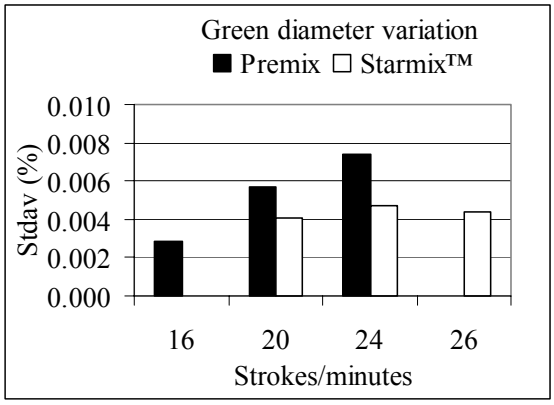


Figure 6c. Green diameter variation.

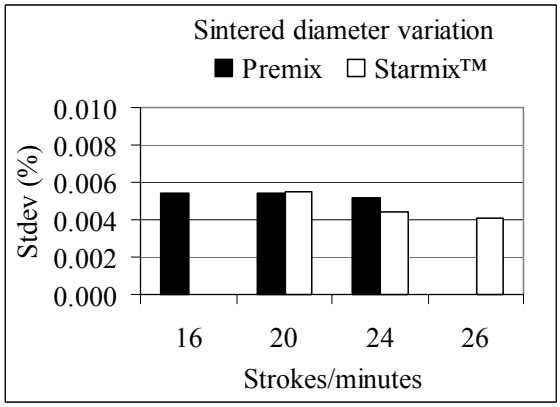


Figure 6d. Sintered diameter variation.

Standard deviation in green height variation is lower for Starmix™ compared to Premix at 20 strokes/minute. Increasing the production rate up to 26 strokes/minute does not cause change in height scatter. As sintered the scatter is lower at all production rates.

Green diameter scatter at 20 stokes/minute indicates a better performance for Starmix™. Also in this case the scatter level is maintained up to 26 strokes. For as sintered, the scatter is at the same level as Premix at 20 strokes/minute. Also in this case the performance of Starmix™ indicates that it is possible to increase the production rate at least up to 26 with maintained tolerances.

SUMMARY

The results of this study demonstrate clearly that powder properties influence performance and consistency in production of P/M parts. The improved Hall Flow values indicate a faster flow behavior for the Starmix™ compared with the non-bonded Premix. This is verified by the higher productivity obtained from the production trials. Graphite bonding is close to 100% and dusting is reduced by ~90%. An improved working environment around the press is achieved.
Mechanical properties are in the same range for Starmix™ compared to Premix.
With Starmix™, similar levels for green density variation can be maintained at increasing production rates. Thus, while the weight scatter for Premix shows an increased scatter when pressed at 24 strokes/minute, Starmix™ maintains the same level of weight scatter at up to 26 strokes/minute, which is the maximum speed of the actual press. Limits regarding productivity gain therefore not given in this evaluation. Results from green height and diameter measurements indicate smaller scatter at all investigated production rates where comparison is possible. In the as sintered state, the performance is maintained.
Taking all the above-mentioned results into account, Starmix™ enables production of P/M parts at higher productivity with maintained or even improved tolerances.

CONCLUSIONS

- Improved physical properties such AD and flow enables Starmix™ to achieve faster filling at a higher AD than a corresponding Premix.
- The Starmix™ has the equivalent mechanical properties of the corresponding Premix.

- A bonding of 98% graphite is achieved by the Starmix™ technique. Dusting is therefore reduced and the environment around the press is consequently improved.

- In this study, the Starmix™ could be compacted at a press rate up of to 26 strokes/min with the approximately the same scatter in properties as the equivalent Premix at 20 strokes/min. This corresponds to an increase in productivity of 23%. However higher production rates may be possible for this part using a faster press.

REFERENCES

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

2. 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, H. VIDARSSON, J. ARVIDSSON: *Improvements in Bonding of Press-ready Low-alloy Steel Powder Mixes*, Proceedings of Euro PM2001, Nice, France, October, 2001.

4. H. VIDARSSON, JEANETTE LEWEHAGEN, B.JOHANSSON: *Efficient P/M part Production Through Bonded Mixes Having Unique Powder Properties,* Proceedings of PM2TEC 2002, Orlando June 2002.