IMPROVED DIMENSIONAL PRECISION BY HIGH PERFORMANCE BONDED MIXES AND ADVANCED COMPACTION PRESSES

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ABSTRACT

One of the main strengths of PM technology is its ability to make near net shape components with a cost efficient process. There is, however, variability in the dimensions of the sintered parts that often calls for sizing or machining to reach the desired tolerance class.
High performance bonded mixes and state-of-the-art compaction presses are able to contribute to operational excellence. Precision in the dimensions of the pressed parts can be improved and parts can be made to higher tolerance classes. In this paper results are presented from compaction of a multi-level component in an advanced hydraulic press. A high performance bonded mix is benchmarked with elemental mixes of the same nominal alloying composition. Improvements in productivity as well as quality of sintered components are presented.

INTRODUCTION

Over the recent years the PM industry's demand for the production output of precise and complex structural parts has steadily increased. Previously the now attained level of precision seemed to be out of reach. To get to this level the improvements of powder compacting presses with their corresponding die set systems were essential, aside from other research.

The key factors to reach these advancements were the application of the latest multiplaten technology and the use of innovative electronic and hydraulic components. All movements of the press and die sets are closed loop controlled. This assures that the actual values of pressure, speed and position of platens and punches are transmitted to the control system, where they are compared with the programmed reference values and corrected if necessary. Dorst Technologies has coped with these new requirements through the introduction of the hydraulic powder compacting press generation type TPA-HP.

The hydraulic system is based on pumps which are closed loop controlled relative to the power requirements of the machine and the multiplaten die set. The machine operates through an energy management system that employs only a fraction of the maximum power available, thereby ensuring a most efficient, smooth and energy saving operation. The attained level of precision not only results from the sensitive controls, but also from the careful combination of essential components by considering their most effective performance state.

With Starmix™, graphite as well as lubricant and other additives of fine particle size are bonded to the iron powder particles by utilizing an organic binder. By adhering the graphite and other additives control of carbon content is improved. With better carbon control, scatter in dimensions of the sintered parts and mechanical properties can be minimized. The working environment in press shops is also improved by decreasing the dusting of fine particulate additives.

Benefits from using bonded mixes have previously been evaluated and reported. For instance, less influence on the fill density by the cavity size is described in [1] and in [2] decreased scatter in weight is reported.

This paper presents results from trials with the latest generation of bonded mixes, Starmix™ BOOST. Lubrication has been enhanced and powder properties have been further improved to give excellent filling behaviour. The lubricant and binder system is Zn-free and burns off without forming stains in the surfaces of the sintered parts.

This paper covers a benchmark between Starmix™ BOOST and two premixes of the same nominal composition, FC-0208, with amide wax and zinc stearate as lubricant respectively. The results emphasize the potential improvements in productivity as well as dimensional precision.

EXPERIMENTAL

Press Technology

The press used in this investigation was a hydraulic CNC press TPA 160/3 HP, see Figure 1 for illustration. This press has a maximum press force of 1600 kN and can operate at stroke rates up to 15 spm. Maximum filling height is 200 mm. Connected load is 55 kW.

During the trial the press was equipped with a multiple platen adaptor HMA 160.01, see Figure 2. This adaptor has three upper platens with 1200 to 1600 kN maximum pressing force and four lower platens with 800 to 1600 kN maximum pressing force. All upper and lower platens are closed loop controlled.

Figure 1: Dorst hydraulic CNC Press TPA160/3 HP

Figure 2: Multiple platen adaptor HMA160.01

Setting of the press was carried out using the control software IPG®, see Figure 3. This software features a menu guided part development by entering nine parameters in six steps:

1. Part geometry
2. Tool specific data
3. Ejection/release
4. Spring back
5. Upper ram, die and filler tracks
6. Filler programming

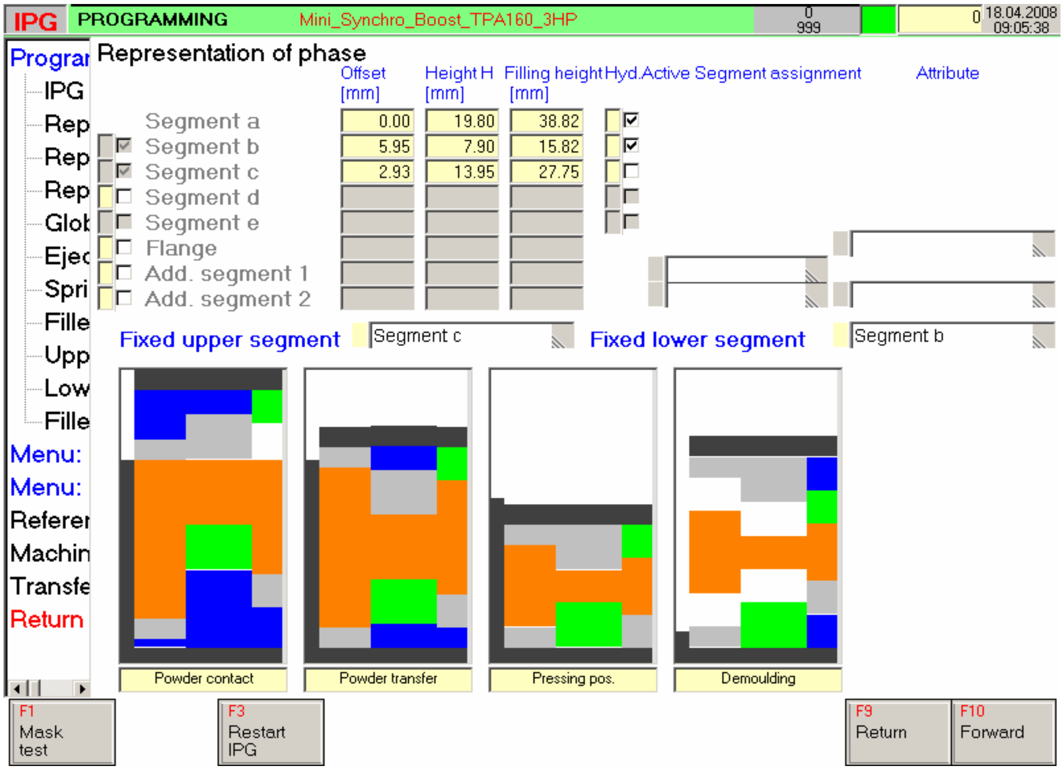

Figure 3: Press control software IPG® interface

The filling cycle is crucial for the quality of the pressed parts as well as for the productivity of the press. In the IPG® software a filler program is defined by setting parameters for six phases, see Figure 4. The phases are:

- Rapid forward (position)
- Slow forward (position)
- Dwelling (time)
- Vibrate (position)
- Slow backwards (position)
- Rapid backwards (position)

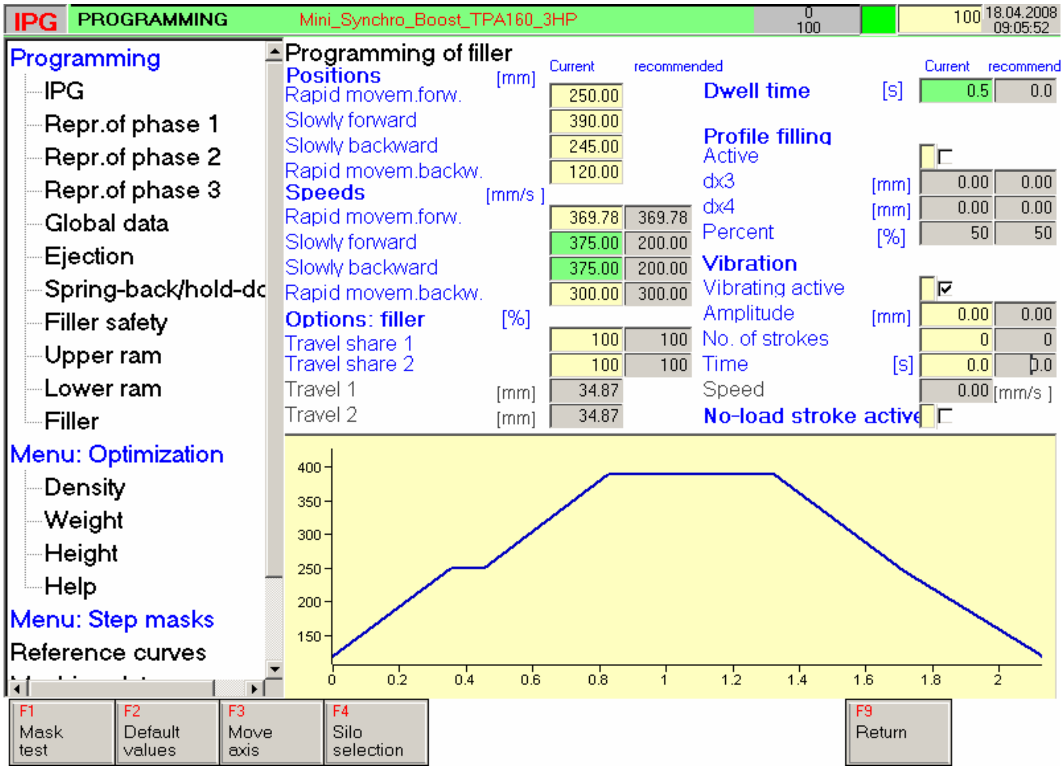

Figure 4: IPG® interface – six phase filler program

To evaluate the filling performance of the powder mixes to be compared, the filler settings were varied while the rest of the pressing cycle i.e. powder transfer, pressing and ejection were constant. In Table 1 the initial filler settings are presented. To increase the press rate the velocity of the filler was increased by increments of 50 mm/s, the velocity of the forward and backward movement of the filler was similar at all settings.

Table 1: Initial filler settings

Parameter	Initial settings
Velocity forward	100 mm/s
Velocity backwards	100 mm/s
Dwell time	0.5 s
Vibrate	Not used
Fill shoe travel	160 mm

Besides the filler movement, the fill height was the only parameter that differed between the trials with the three different mixes. No loop control was used during the trials to keep the weight constant, all variations in the filling cycles and powder mixes will thus be reflected in the weight scatter of the pressed parts.

<u>Materials</u>

Three mixes were included in the investigation, see table 1 for designations of the mixes. The three mixes were of the same nominal composition according to FC-0208 and were based on high compressible pure iron powder ASC100.29 and copper added as Distaloy ACu. Distaloy ACu is a pure atomized copper powder where 10% of fine particulate copper is diffusion bonded. The lubricant content was 0.8% in all three mixes.

Table 2: Designations of powder mixes

Designation	Type of mix	Lubricant	AD (g/cm³)	Flow (s/50 g)
B	Starmix™ BOOST	BOOST lubricant	3.44	23.8
A	Premix	Amide wax	3.03	34.0
Z	Premix	Zinc stearate	3.30	35.1

Mix B was manufactured in full production scale of 10 tons. Mixes A and Z were manufactured in 1 ton scale. Mix B, the latest generation of bonded mix, was developed to give excellent filling performance, also manifested by high AD and fast flow.

Component

The part used in this investigation was a small synchronizing hub, see Figure 5. In the figure the designations used for segments and the directions in relation to the fill shoe movement are shown. During the filling cycle the fill shoe moved from the rear to the front position and back again.

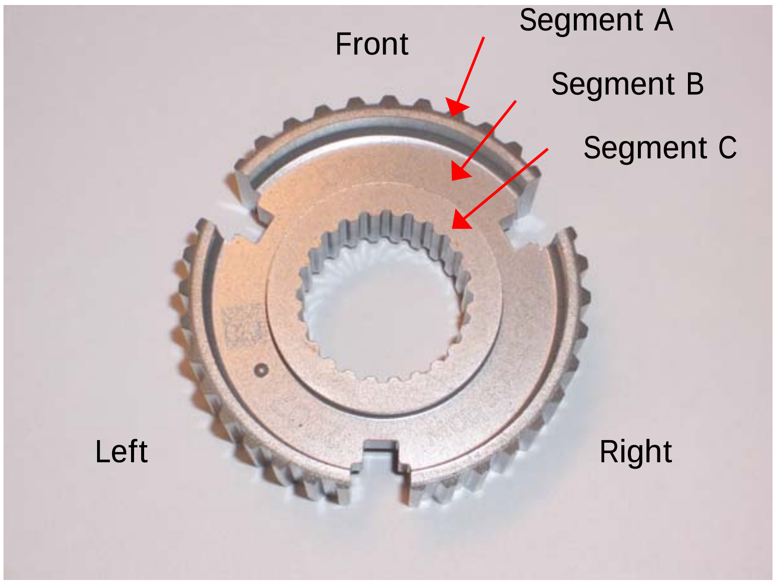

Figure 5: Small Synchronizing hub

The nominal density of the synchronizing hubs was 7.0 g/cm³ and the weight was 125 g. The outer diameter was 52 mm and the height of segment A was 20 mm.

Test sequence, sampling and measurements

Each test run included a continuous run of 250 parts. Groups of 5 parts were sampled after 20, 45, 70, 95, 120, 145, 170, 195, 220 and 245 parts had been pressed. Altogether 50 parts were sampled from each test run. Compacting force of each component was logged by the control system of the press.

All sampled parts were weighed. Height of each segment (A, B and C) was measured in three positions (front, left and right) on 15 parts of each trial. Parallelism was calculated as the difference between the highest and lowest height measured for each segment. Ten sampled parts were used for measuring the overall green density. One part from each trial was cut into nine segments and green density of the segments was measured by weighing in air and water.

The parts were sintered in belt furnace Cremer 25-115/E at a temperature of 1120°C for 30 minutes in 90/10 N_2/H_2 atmosphere.

After sintering, all sintered parts were weighed and overall sintered density was measured on 10 parts. The height was measured in the same way as before sintering and on the same samples as before sintering. Run-out was measured on five parts from each trial

RESULTS

The weight scatter of the pressed parts versus the press rate is presented in Figure 6. It can be seen that the weight scatter with mix A was approximately twice the scatter of mix Z and B. Mix Z was inferior regarding the highest possible press rate with complete filling of the tool die while mix B achieved the highest press rate with complete filling, 12 parts per minute. An interesting feature of mix B was that excellent weight stability was obtained at the highest press rates.

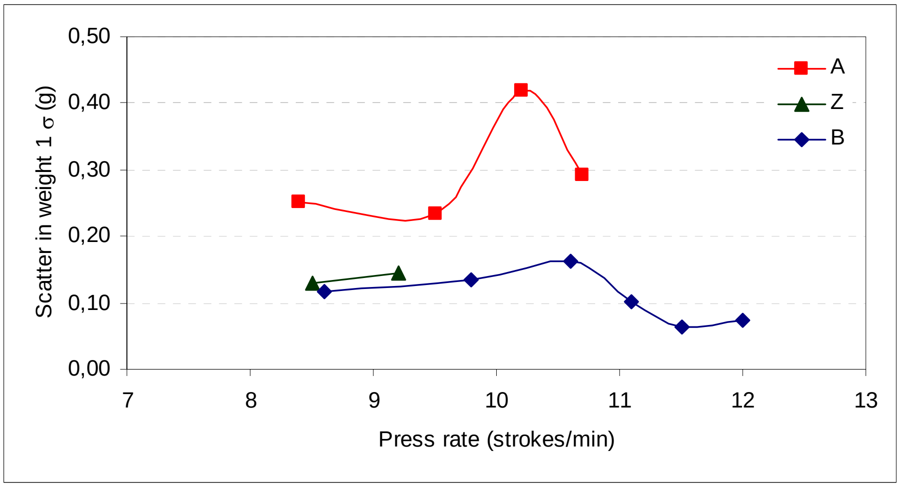

Figure 6: Weight scatter of green components

The scatter in press force reflects the weight scatter of pressed parts, compare Figures 6 and 7. With accurate position control of the press strokes, the force was correlated to the weight of the parts pressed.

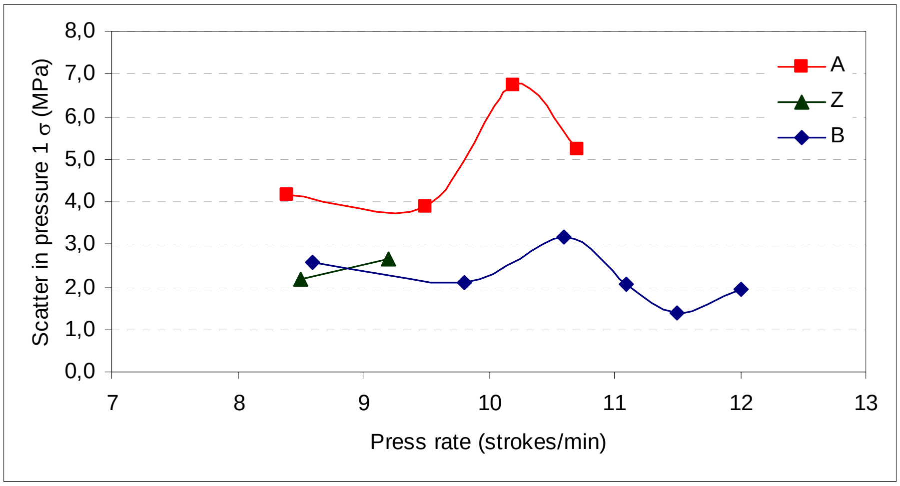

Figure 7: Scatter in compacting pressure

In Table 3 some key data on the performance of the three mixes at the highest press rate are presented. Higher stroke rates were achieved by increasing the velocity of the filler. With better filling performance of the mix, higher velocity of the filler could be used. For mix B it was also possible to shorten the stroke of the filler and still have complete filling of the tool die which also improved the press rate. One characteristic of the mixes which influenced the performance twofold was the apparent density. Higher apparent density decreased the fill height, which was positive for the filling, but also shortened the movements during the powder transfer and compaction of the parts. Shorter movements also enable design of more compact tools with shorter punches.

Table 3: Highest possible press rates and some key parameters for the filling cycle

Mix	Highest press rate (strokes/min)	Velocity of filler (mm/s)	Travel of filler (mm)	Fill height of segment A (mm)	Fill factor of segment A
B	12.0	375	140	38.82	1.96
A	10.7	250	160	45.06	2.26
Z	9.2	125	160	40.97	2.08

Further results on the properties of the synchronizing hubs are presented later in this report based on the parts pressed according to the settings shown in Table 3. Weight scatter of the green parts was similar to the weight scatter of the sintered parts, see Figure 8.

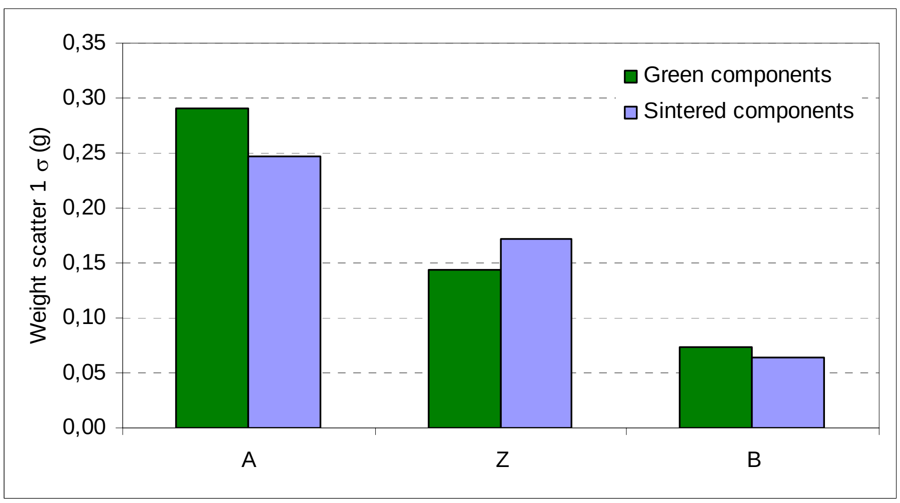

Figure 8: Weight scatter of green and sintered parts

The green density measured on the parts divided into nine segments is presented in Figure 9. The horizontal lines in the diagram are average values ± 3 σ. The values showed a similar trend to that of the weight scatter of the parts, mix B was most consistent and mix A was least consistent in green density. By improving the filling characteristics of the mix not only was the weight scatter improved but also the variation in density within the parts.

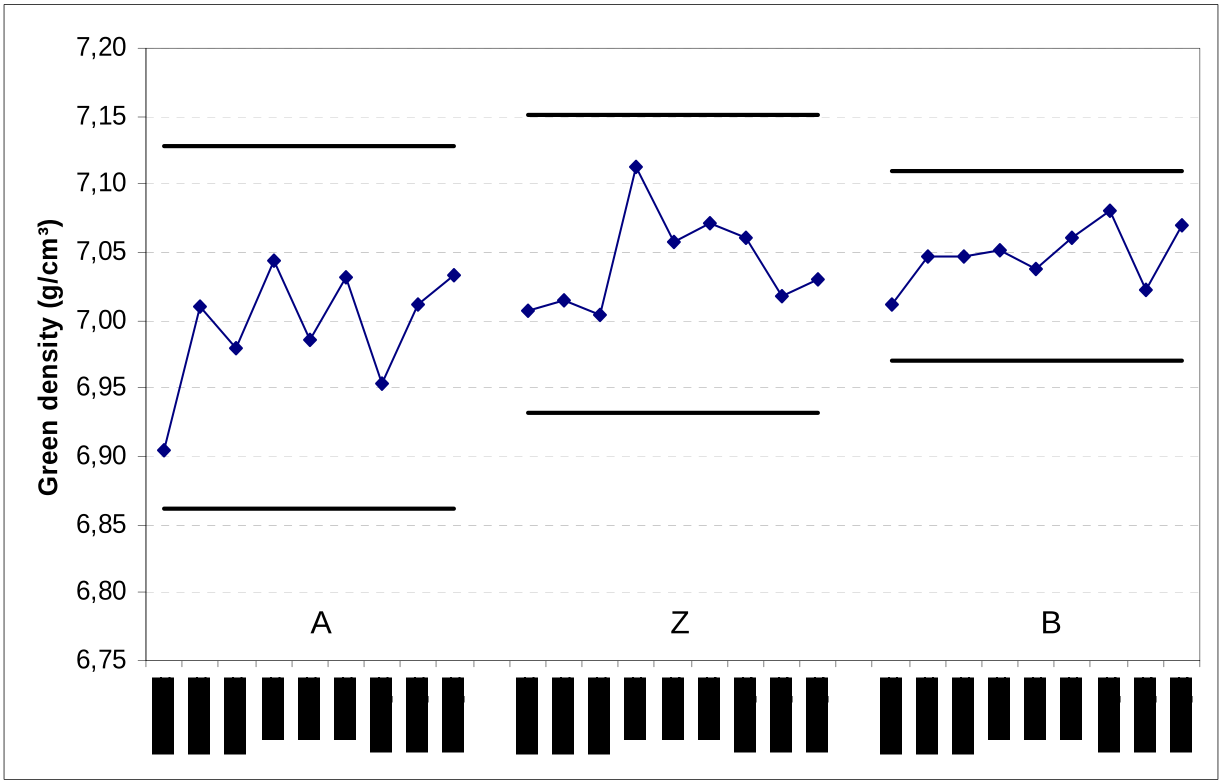

Figure 9: Green density of segments, measured values and ±3 σ

Scatter in the height of each segment of the sintered parts is presented in Figure 10. The standard deviation was calculated based on the average height of the three measurements of each segment of a part. Highest scatter was obtained for segments A and C with mix A, these two segments being geometrically the most challenging to fill. Least scatter was obtained with mix B.

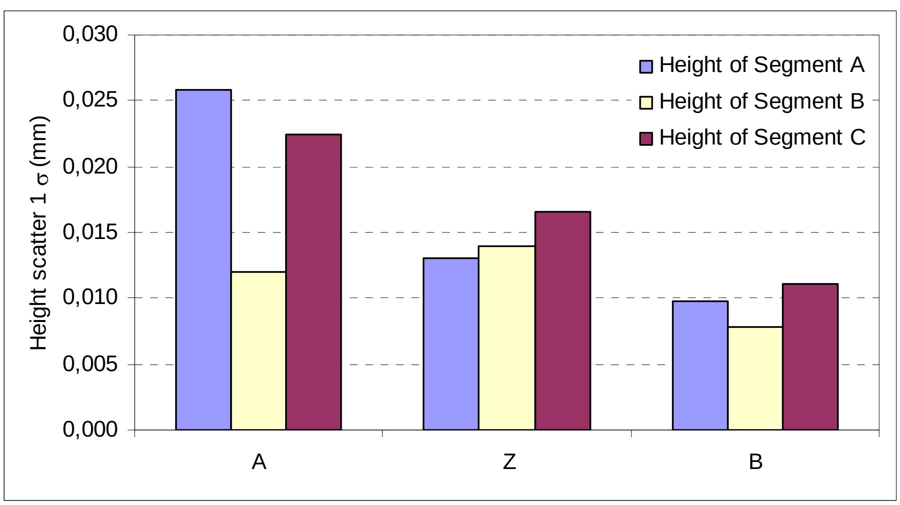

Figure 10: Scatter in height of each segment of the sintered parts

In Figure 11 the parallelism of the sintered parts is presented. For all three mixes the greatest difference in height was found for segment A and the lowest difference was found for segment C. The larger height differences for segment A was for all three mixes due to lower height in the front section. This was a logical result considering the high and narrow cavity of segment A and that in the front of the cavity filling time is shorter. For segment A, mix A exhibited the best parallelism and mix Z the worst. For Segments B and C, mix B exhibited the best parallelism, whereas mixes A and Z had twice as much difference in height as mix B.

One way to improve the parallelism, especially for segment A where the height was systematically lower in the front position, would be to utilize the profile filling feature of the press. By this feature the filling height can be increased in the front through synchronizing the die movement with the filler position during the backward motion of the filler.

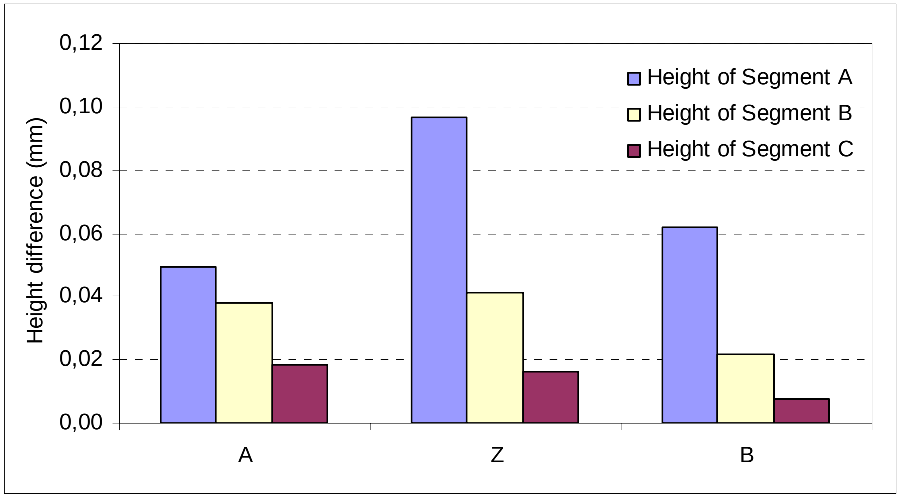

Figure 11: Parallelism of the sintered parts

In Figure 12 the total scatter in height of each segment is presented. This scatter is calculated as the standard deviation of all height measurements on the parts of each trial and includes both the lack of parallelism and part to part variation. For the total height scatter mix B was best for all three segments.

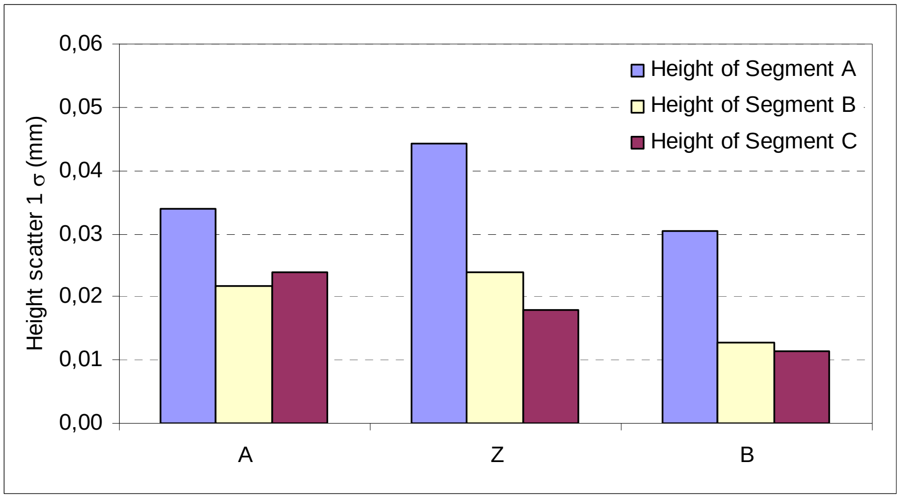

Figure 12: Total scatter in height of the sintered parts

Run-out measured on the sintered parts is presented in Figure 13. Comparing the three mixes, results are similar to parallelism. Mix B showed the best results and mix Z the worst result.

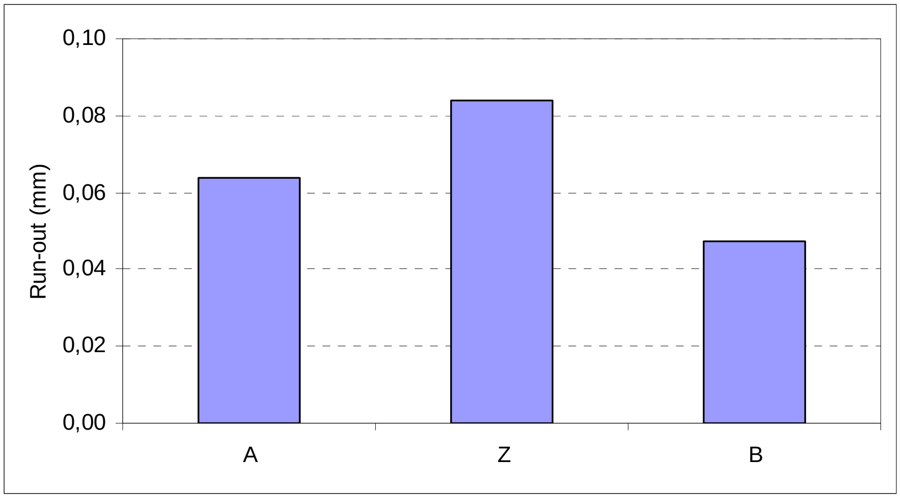

Figure 13: Average run-out of the sintered parts

CONCLUSIONS

The performance of three different powder mixes has been explored utilizing a state-of-the-art hydraulic press and pressing synchronizing hubs using tooling with three upper and three lower punches. By using the latest generation of bonded mix with optimized filling performance productivity can be increased in combination with accuracy in shape and consistency. With the latest generation of bonded mix, productivity was improved by 30% compared to a Premix with Zn-st and by 12% compared to a Premix with Amide wax as lubricant. At the highest press rate with each mix, weight scatter was two times higher for the Premix with Zn-st and four times higher for the Premix with Amide wax compared to the bonded mix. Density distribution within the synchronizing hub was also improved by the better filling performance of the bonded mix. The accuracy in shape was also improved with less height variation and less run-out for the bonded mix.

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