# Improving Compaction Performance and Compact Quality Through Advanced Powder Mixes and Latest Press Technologies

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## Abstract

In order to improve final product quality and reduce expensive machining operations, part-makers are striving to improve process robustness and reduce dimensional variations of compacted components. In addition, better flow and cavity-fill characteristics of advanced powder concepts, as well as the latest improvements in press technology and control systems, are pushing the limits of achievable tolerances to new levels. This paper describes the relevant aspects, contributions and possible improvements for improved compact quality.

## Keywords

Compaction technology, Powder mixes, Tolerances

## Introduction

The requirements of close tolerances of PM components are increasing year by year. By improving the as-sintered dimensions, machining of the parts can be avoided, which makes the PM technology more competitive.

The scatter of the parts height is closely related to the compaction and is, in general, more difficult than the lateral dimensions. In many cases today, a tolerance of ±0.05 mm is required, which is very challenging.

Most important are the weight consistency of the filling, and the elasticity and accuracy of the press. With modern, state-of-the-art, closed-loop controlled presses, the accuracy of the positioning of the upper ram is not a limiting factor; the precision of the positioning of the upper ram is normally accurate to within one micron. Even with very rigid press and tool designs, there will be some elasticity in the press-frame, the tool adaptor and the tool itself. To control the press movement, the position of the upper ram is measured accurately; however, due to the elasticity of the system, the measured value can differ by several millimetres compared to the actual position of the punch faces. If there are variations in the amount of powder filled in the tool cavity, this will lead to variations in the press force, and consequently variations in the offset between the measured position of the upper ram and the actual position of the punch faces; this will give rise to variation in the height of the pressed parts.

Ideally, the position of the punch faces should be measured and used for the control of the movements. Unfortunately, this is not possible in practice.

To improve the height-control of pressed parts, Dorst Technologies has developed an improved system for height control called Netshape®. Netshape utilises an improved measurement system in combination with an advanced control algorithm implemented in the control system, which compensates for the elasticity of the system by calculating an individual press-position for every part.

On the other hand, Höganäs has developed a high performance powder mix, Starmix® BOOST, to improve filling and reduce weight variations. With better consistency of the filling, height scatter can be significantly improved [1] and [2].

To reach the highest possible height-tolerance of pressed parts, improvements in both powder mixes and presses are needed. In this paper, the maximum achievable tolerance level by combining the latest developments in press control systems and powder mixes is presented.

## Experimental

Two mixes with the same nominal compositions were made (see *Table 1* for details).
Nominal composition: Distaloy AQ+ 0.3% Graphite + 0.8% Lubricant.

Distaloy AQ is a pure atomised iron powder with 0.5% Mo and 0.5% Ni diffusion-bonded.

*Table 1: Mixes used in the trials*

| Mix | Trade name | Type | Lubricant | Mix size |
|---|---|---|---|---|
| 1 | Premix | Elemental mix | Amidewax | 1000 kg |
| 2 | Starmix® BOOST | Bonded mix | Boost lube | 500 kg |

Press trials were carried out in a Dorst TPA800/2HP press equipped with a system for improved height-control called Netshape®.

Trials were carried out with the two mixes, with and without the Netshape® system activated. Different amplification factors for the system were also used. The press-rate was in the range 7.8 to 9 strokes/min, except for trial M. Finally, Trial M was carried out with Mix 2, where the press rate was increased by increasing the speed of the movements, including the filler; a press rate of 11.3 strokes/min was achieved. The green density of the parts was 7.1 g/cm³ for all trials. See *Table 2* for an overview of the trials of the investigation.

*Table 2: Overview of trials*

| Trial | Mix | Control mode | Amp. Factor |
|---|---|---|---|
| C | 1 | Standard | |
| D | 1 | (Netshape®) connected | |
| E | 1 | (Netshape®) controlling | 1 |
| F | 1 | (Netshape®) controlling | 1,5 |
| G | 1 | (Netshape®) controlling | 2 |
| N | 2 | Standard | |
| H | 2 | (Netshape®) connected | |
| I | 2 | (Netshape®) controlling | 1 |
| K | 2 | (Netshape®) controlling | 1,5 |
| L | 2 | (Netshape®) controlling | 2 |
| M | 2 | (Netshape®) controlling, High speed | 1 |

The part was a two-level gear, pressed in a tool with two upper and two lower punches and a core rod (see *Fig. 1* for illustration of cut section of the gear). The nominal height of the outer section was 15 mm and the height of the inner section was 10 mm. The outer diameter of the gear was 94 mm and the diameter of the hole was 42 mm.

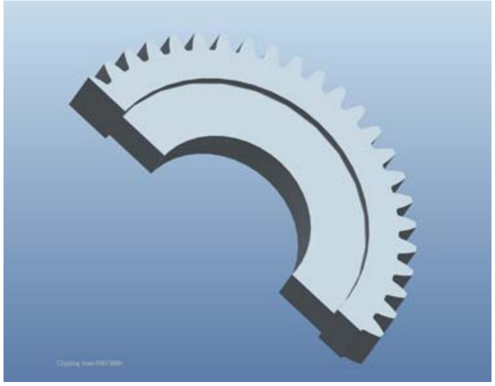


*Fig. 1: Illustration of the sample part used in the trials*

For each trial, press settings were adjusted and the press was run for 10-20 parts to avoid weight variation from the start up. Thereafter, 50 consecutive parts were sampled and the force for each part was registered. Each sampled part was weighed and the height was measured by a coordinate measurement machine, the Zeiss DuraMax 5/5/5 VAST-XXT.

It is crucial to have an accurate method to measure the trial parts in order to correctly assess the results of the investigation. The heights were measured both of the outer segment, nominally 15 mm high, and the inner segment, nominally 10 mm high. Since the height-scatter of the two segments correlated very well, only the results of the outer segment will be presented. To investigate the repeatability of the height measurement method, 25 sample parts were measured twice. The difference in the measured height between the two measurements for each part was calculated. One standard deviation of the differences between the two measurements was 0.0009 mm.

The sample parts from trails C, F, N, K and M were sintered in a laboratory belt furnace. The sintering temperature was 1120°C, 20 minutes at temperature in 90 $N_2$/ 10 $H_2$ atmosphere. After sintering, the height of the sample parts was measured again.

**Results and discussion**

The physical properties and chemical analyses of the mixes are presented in *Table 3*. Compressibility was similar for the two mixes and all chemical analyses were very close to the nominal contents. The major difference in the properties of the mixes was in Flow and Apparent Density, where Mix 2 had 0.21 g/cm³ higher apparent density and 6 s/50 g faster flow.

*Table 3: Physical properties and chemical analyses of mixes*

| Property | Mix 1 | Mix 2 | Unit | Method |
|---|---|---|---|---|
| Compressibility at 600 MPa | 7,03 | 7,04 | g/cm³ | ISO 3927 |
| Apparent Density | 3,07 | 3,28 | g/cm³ | ISO 3923-1 |
| Hall Flow | 31,3 | 25,3 | s/50 g | ISO 4490 |
| Cu | 0,07 | 0,07 | % | ASTM E 572 |
| Mo | 0,51 | 0,51 | % | ASTM E 572 |
| Ni | | | % | ASTM E 572 |
| Graphite | 0,30 | 0,33 | % | ISO 15350 |
| Lubricant | 0,81 | 0,81 | % | ISO 13944 |

During compaction of the two mixes, typical filling height and withdrawal force were recorded (see *Table 4*). With the higher apparent density of Mix 2, the fill height was lower. Due to a more efficient lubricant system, the withdrawal force was 15% lower for Mix 2 compared to Mix 1.

*Table 4: Typical fill height and withdrawal force for the two mixes*

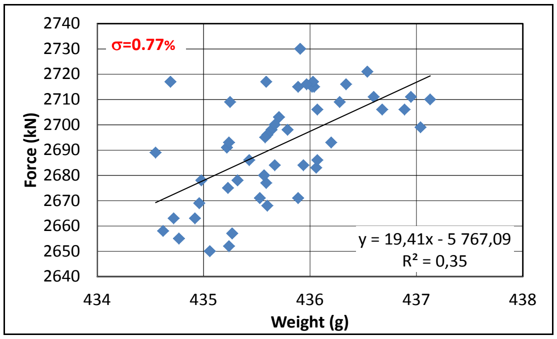
| Parameter | Mix 1 | Mix 2 |
|---|---|---|
| Fill height outer segment | 32.26 mm | 29.99 mm |
| Fill height inner segment | 20.79 mm | 19.84 mm |
| Withdrawal force | 270 kN | 230 kN |

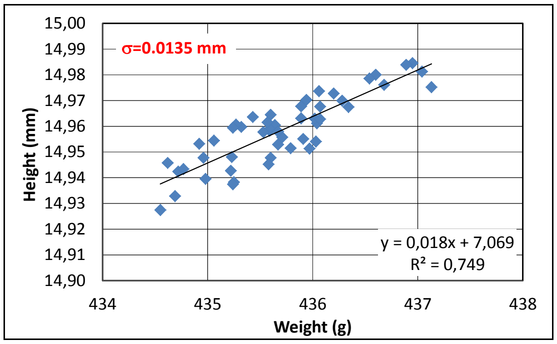
In *Table 5*, the results from the compaction and measurement of the green parts are summarised. *Scatter* is expressed as one standard deviation. In relation to *force*, the scatter is expressed as a percentage of the average force. To facilitate the analysis of the data, linear regression lines were calculated for force and height, respectively, as functions of the weight. In *Table 5*, scatter in weight, force, height, as well as $R^2$ values and slope coefficients of regression lines are tabulated.

*Table 5: Summarised results of green parts*

| | | | | | Force scatter | | | Green height scatter | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Powder | Trial | Control mode | Amp. Factor | Weight scatter | Force | Linear regression | | Outer segm. | Linear regression | |
| | | | | (%) | (%) | $R^2$ | Slope coeff. | (mm) | $R^2$ | Slope coeff. |
| Mix 1 | C | Standard | 0 | 0,15% | 0,77% | 0,35 | 19,4 | 0,013 | 0,75 | 0,018 |
| Mix 1 | D | Connected | 0 | 0,12% | 0,55% | 0,92 | 27,3 | 0,009 | 0,80 | 0,015 |
| Mix 1 | E | Controlling | 1 | 0,14% | 0,67% | 0,94 | 28,8 | 0,008 | 0,84 | 0,012 |
| Mix 1 | F | Controlling | 1,5 | 0,13% | 0,68% | 0,94 | 31,0 | 0,006 | 0,66 | 0,009 |
| Mix 1 | G | Controlling | 2 | 0,17% | 1,00% | 0,96 | 34,6 | 0,007 | 0,83 | 0,009 |
| Mix 2 | N | Standard | 0 | 0,06% | 0,45% | 0,23 | 23,0 | 0,005 | 0,72 | 0,018 |
| Mix 2 | H | Connected | 0 | 0,07% | 0,26% | 0,8 | 23,1 | 0,005 | 0,47 | 0,012 |
| Mix 2 | I | Controlling | 1 | 0,06% | 0,38% | 0,74 | 33,9 | 0,005 | 0,72 | 0,016 |
| Mix 2 | K | Controlling | 1,5 | 0,06% | 0,40% | 0,84 | 37,7 | 0,006 | 0,68 | 0,017 |
| Mix 2 | L | Controlling | 2 | 0,06% | 0,45% | 0,77 | 41,8 | 0,006 | 0,63 | 0,016 |
| Mix 2 | M | Controlling (High speed) | 1 | 0,06% | 0,32% | 0,9 | 32,3 | 0,005 | 0,80 | 0,017 |

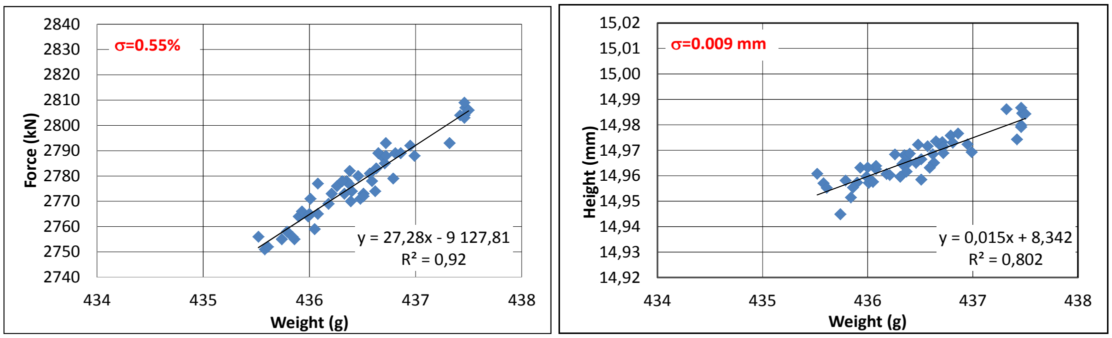
The results will now be scrutinised in greater detail, starting with Trial C (Mix 1, Standard control mode) as a starting point (see *Figs. 2 – 3* for plotted data). As can be seen, there was a closer correlation between height and weight than between force and weight. Variation in fill weight is thus mainly translated into height scatter in the compaction.





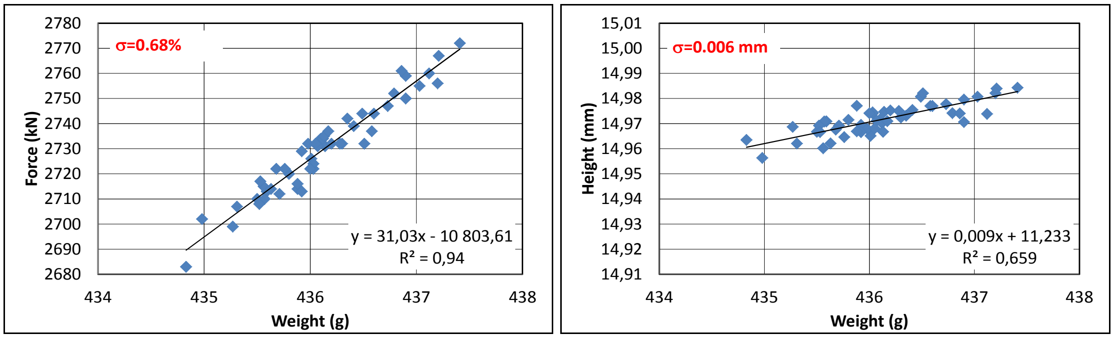
*Figs. 2 – 3: Trial C (Mix 1, Control mode: Standard), force (left) and height (right) plotted versus weight*

By utilising the improved measurement system for height control, the correlation between the weight and press force is strengthened (see *Figs. 4 – 5*). With the improved quality of the measured data, a better control of the press cycle is possible. As a result, the $R^2$ of the regression analysis of force versus weight is significantly improved. The $R^2$ of the height versus weight regression line is maintained.



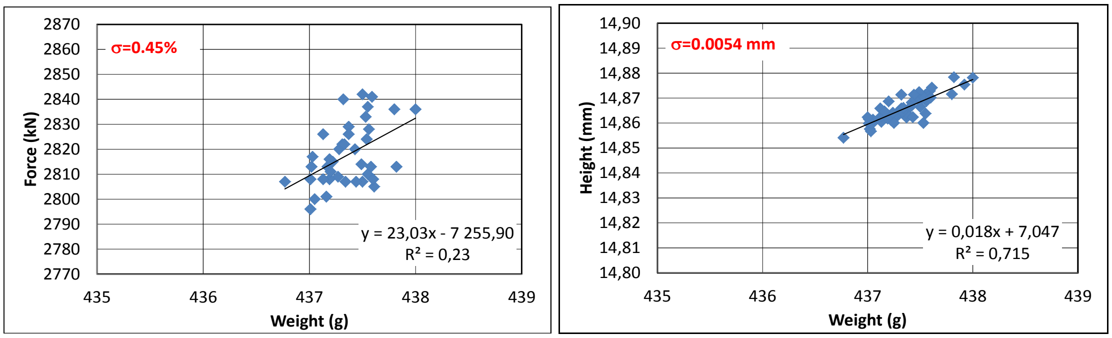
*Figs. 4 – 5: Trial D (Mix 1, Control mode: Connected), force (left) and height (right) plotted versus weight*

By adjusting the amplification factor in the control algorithm, the extent to which weight scatter translates into height scatter can be influenced. The best result with Mix 1 was achieved in Trial F, where the amplification factor was set to 1.5 (see *Figs. 6 – 7*). Comparing the slope coefficients of trials D and F, it can be seen that the slope coefficient of force versus weight was increased, and that the coefficient of height versus weight was decreased from 0.015 to 0.009. This means that the height was less influenced by variation in fill weight, while the force was allowed to vary more.



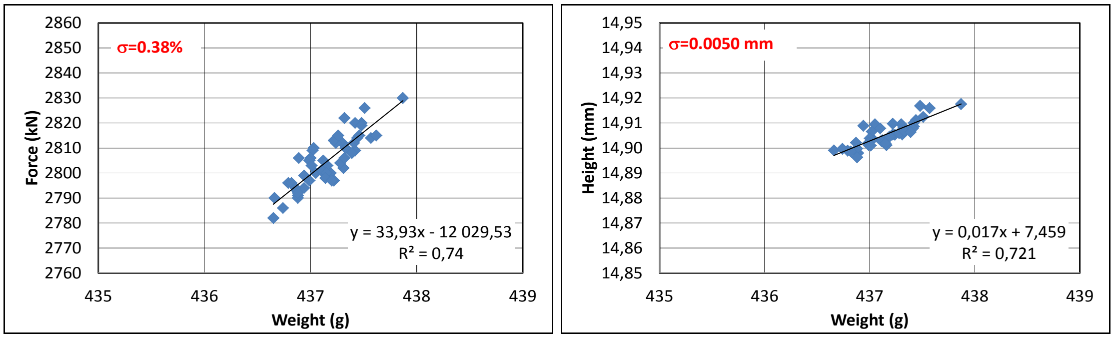
*Figs. 6 – 7: Trial F (Mix 1, Control mode: Controlling AF=1), force (left) and height (right) plotted versus weight*

The next parameter to investigate is the influence of the type of powder mix and how the consistency of the fill weight influences the results. In *Figs. 8 –9*, the results obtained with Mix 2 and Standard control mode are presented. With Mix 2, the weight scatter was reduced to less than half compared to Mix 1. In all trials with Mix 2 of this investigation, one sigma of the weight scatter was around 0.06% compared to 0.12 – 0.17% for Mix 1. Analogous to Trial C, $R^2$ of the linear regression was significantly lower for force versus weight than for height versus weight.



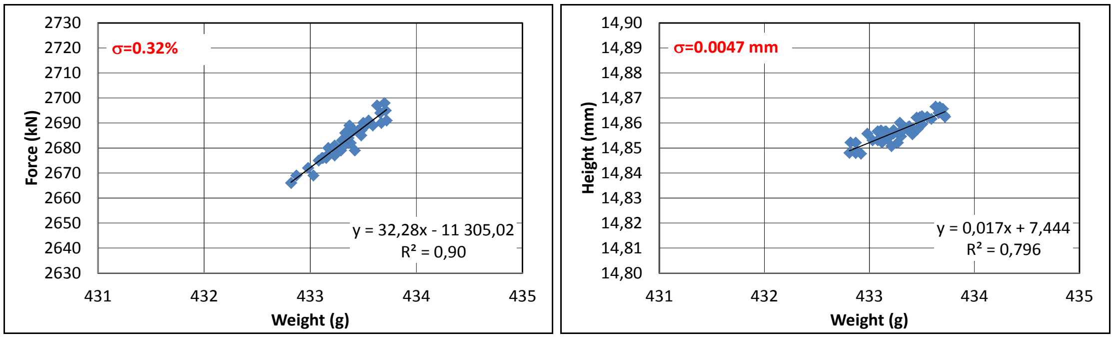
*Figs. 8 – 9: Trial N (Mix 2, Control mode: Standard), force (left) and height (right) plotted versus weight*

By using the 'Controlling' control mode, $R^2$ of force versus weight regression analysis, as well as the slope coefficient were increased. With the small fill weight variation, and thus a small height scatter from the start, only a small improvement of the height scatter was gained.



*Figs. 10 – 11: Trial I (Mix 2, Control mode: Controlling AF=1.5), force (left) and height (right) plotted versus weight*

Encouraged by the good results from Trial I, a final trial (Trial M) was carried out, in which the press rate was further increased to 11.3 strokes/minute. At the higher press rate, optimised for productivity, Mix 2 (in combination with the control mode 'Controlling') resulted in the best height consistency of the investigation.



*Figs. 12 – 13: Trial M, stroke rate 11,3 pcs/min (Mix 2, Control mode: Controlling AF=1.5), force (left) and height (right) plotted versus weight*

In *Fig. 14*, the height scatter is plotted versus the weight scatter for all trials. This graph summarises the influences of the improved press control system and improved powder mix. Trials running the control mode 'Standard' system are non-filled markers. By decreasing the scatter in fill weight, the height scatter was significantly improved, comparing Trial N to Trial C; the weight scatter of Trial N was 39% of the weight scatter of Trial C, and the height scatter was decreased to 40%. By using control modes 'Connected' or 'Controlling', only a small further improvement was gained.

However, the results of Mix 1 clearly showed that, with higher fill weight variations, control mode 'Controlling' was capable of reducing the height variation to less than 50%. It should also be noted that the fill weight variation of Mix 1 is by no means excessive, as weight variation in the range 0.012 – 0.017% is representative of what is achieved with plain elemental mixes.

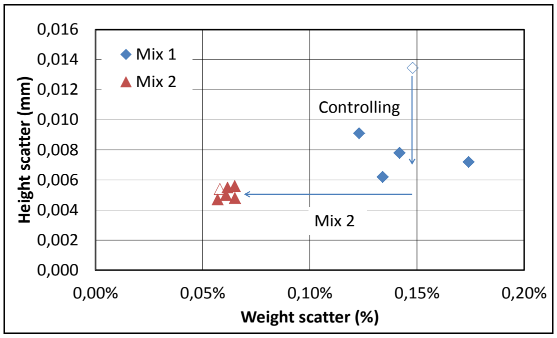


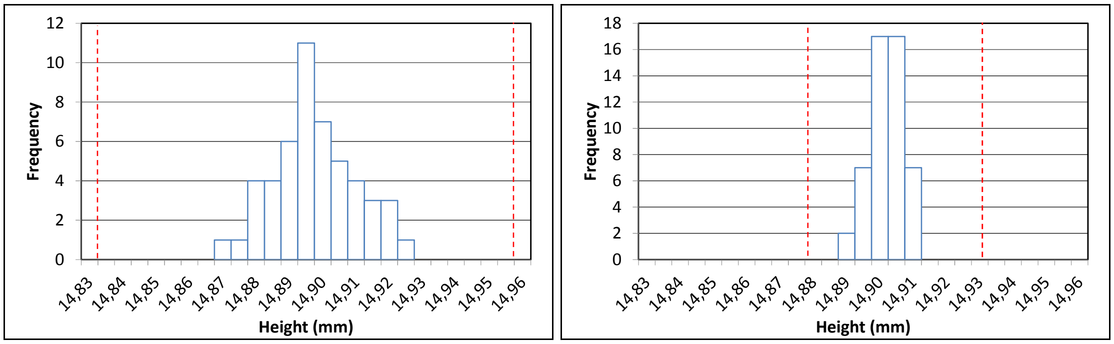
*Fig. 14: All trials, height scatter plotted versus weight scatter*

It is also important that improved height control is maintained after sintering. The results from the measurement of sintered parts from five of the trials are presented in *Table 6*. For all trials, the scatter in height of the sintered parts was the same or better compared to the green parts. It can thus be concluded that the improvement in height control of the green parts was maintained after sintering.

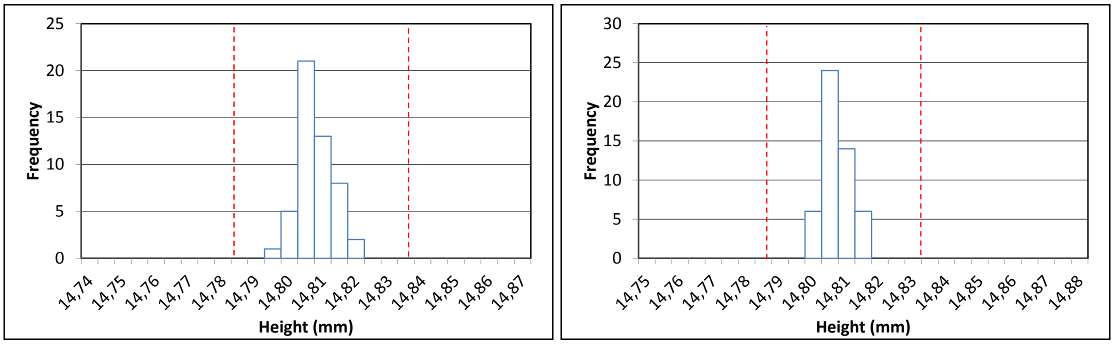
*Table 6: Summarised results of sintered parts*

| | | | | Green height scatter | | Sintered height scatter | |
|---|---|---|---|---|---|---|---|
| Powder | Trial | Control mode | Amp. Factor | 1 σ (μm) | ±5 σ range (μm) | 1 σ (μm) | ±5 σ range (μm) |
| Mix 1 | C | Standard | 0 | 13,5 | ±68 | 12,5 | ±63 |
| Mix 1 | F | Controlling | 1,5 | 6,2 | ±31 | 5,2 | ±26 |
| Mix 2 | N | Standard | 0 | 5,4 | ±27 | 5,3 | ±27 |
| Mix 2 | K | Controlling | 1,5 | 5,5 | ±27 | 5,2 | ±26 |
| Mix 2 | M | Controlling (High press rate) | 1 | 4,7 | ±24 | 4,6 | ±23 |

In figs. 15 – 18, the height scatter of sintered parts is plotted as histograms. Each of these graphs also includes red, dashed lines corresponding to ±5 σ. If the specification of the height of the parts is set according to these lines, parts can be produced with a process capability, Cp, of 1.67 for the height. With the combination of Mix 2 and control mode 'Controlling', a specification with of ±23 μm can be met with a process capability of 1.67.



*Figs. 15 – 16: Sintered height scatter of trials C (Mix 1, Control mode: Standard) and F (Mix 1, Control mode: Controlling A.F.=1.5) plotted as histograms*



*Figs. 17 – 18: Sintered height scatter of trials N (Mix 2, Control mode: Standard) and M (Mix 2, Control mode: Controlling A.F.=1, press rate 11.3 pcs/min) plotted as histograms*

## Conclusion

An improved measurement system for the position of the tool members enables better control of the press movements, which improves the height control of the pressed components.

The control algorithm of the Netshape® system further improves the height control of the pressed parts.

Weight scatter was significantly reduced by using Starmix® BOOST instead of Premix. As result, a very small height scatter was achieved. The smallest height scatter in the investigation (1 σ= 4.7 μm) was achieved with Starmix® BOOST in combination with the Netshape® system.

The improvement of the height control of green parts was maintained after sintering of the parts.

With the combination of Starmix® BOOST and the utilisation of the Netshape® system, height control of the sintered parts was improved by 65% compared to when using a Premix and a Standard control mode of the press.

With the combination of Starmix® BOOST and the utilisation of the Netshape® system, a specification of ±23 μm can be met with a process capability of 1.67 for the part used in this paper.

This improvement in height control suggests an interesting potential to reduce machining operation as practised today.

With Starmix BOOST parts with excellent height scatter (1 $\sigma$= 4.7 $\mu$m) was pressed at a rate of 11.3 psc/min.

**References**

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