Solutions for High Density PM Components

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Abstract
Higher density is a key route for higher performance of PM components. With higher density strength and ductility of the sintered materials are improved. There are a number of possible routes for higher density such as high temperature sintering, copper infiltration, liquid phase sintering and double pressing. It is however attractive if high density can be achieved by single press and single sintering process and thus avoiding large shrinkage during sintering in order to keep close tolerances. Recent developments with more efficient lubricants and powder mixing concepts open up new possibilities to compact components to high density. The possibilities by combining high performance lubricants with warm compaction or warm die compaction will be presented in this paper.

Introduction

High density is the one of the fundamental approaches to increase the strength of components manufactured by the PM route. With higher density not only the strength but also ductility can be improved. The influence of density on fatigue strength is even more pronounced than for the static mechanical properties. High density can be achieved by different process routes such as double pressing/double sintering, high temperature sintering and copper infiltration. These approaches are however less attractive than a single press/ single sintering process from a cost point of view.

In 1994 first generation of Densmix™ for warm compaction of PM components was introduced [1]. By heating the powder mix and the press tool to 150°C an increase in density in the range 0.15 – 0.20 g/cm³ over conventional compaction was reported. An increase in tensile and yield strength of 10-15% was achieved as a result of the higher density. Also the green strength was significantly improved with an increase of 50-100% compared to conventional compaction.

Warm compaction has been successfully implemented in the production of helical gears and bevel gears for hand power tool, pinion gears and synchronizing rings [2]. In 2002 an improved Densmix™ for warm compaction was introduced [3]. This second generation of Densmix™ was based on an improved lubricant system for which the optimum working temperatures were 120°C both for powder and tooling. The same density was achieved as for the first generation of Densmix™ even though the working temperature was lower. It was also reported that the lubrication, both in terms of static ejection force and ejection energy, was lower for the second generation of Densmix™. The surface appearance of warm compacted parts after sintering was also substantially improved for the second generation of Densmix™.

An alternative route to increase the compressibility is to only heat the tool die and not the powder mix. With heated tool die in combination with high efficient lubricant, in lower amount than customary, increased densities can also be achieved. In [4, 5] a new lubricant system, Intralube® E mix, was used in combination with tool die heated to 60-80°C, resulting in increased density and very efficient lubrication.

In this paper the performance of warm compaction and warm die compaction are compared to conventional compaction. The lubricant of Intralube® E mix has also been evaluated in bonded mixes. Finally a new lubricant under development with even higher efficiency has been included in the benchmark.

Experimental
All mixes in the investigation were based on Distaloy AB with addition of 0.3% graphite UF4 and different types and amounts of lubricants. Distaloy AB is a pure iron powder to which 1.75% Ni, 1.5% Cu and 0.5% Mo is diffusion bonded.

Designation	Mix type	Lubricant	Lubricant amount (%)
P-08	Premix	Amidewax PM	0.8%
S-08	Starmix	Lube E	0.8%
S-065	Starmix	Lube E	0.65%
S-05	Starmix	Lube E	0.5%
SX-05	Starmix	New experimental lubricant	0.5%
D-06	Densmix 600	DM120	0.6%

Table 1: Mixes included in the investigation

The following analyses of the mixes were carried out:

- Graphite content (Combustion analysis)
- Lubricant content ISO 13944 (Soxhlet)
- Hall Flow ISO 4490
- Apparent density ISO 3923
- Bonding degree of graphite

The bonding degree of graphite was calculated at the percent of graphite maintained after one minutes of separation on an air jet sieve (20 µm cloth) where the non-bonded graphite pass through.

Compaction trials were carried out in two different presses, Result EHP120 and Dorst TPA 45. Result EHP120 is an instrumented hydraulic press and Dorst TPA45 is an instrumented mechanical press. Both presses were equipped to log the positions and the forces on the tool parts. From the force-displacement curves the static peak ejection force and ejection energy were calculated. The ejection energy was calculated by integrating the force-displacement curves. Both values were divided by the envelope surface of the parts.

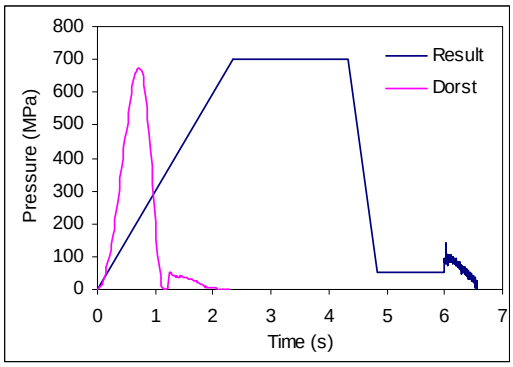


Figure 1: Example of press cycles as force - time charts

The same tool, a ring shape part with Ø25/19 mm, was used in the two presses. This enables to compare the influence of the press and press conditions used on the compaction and ejection performance. In Figure 1 examples of the press cycles of the two presses are shown as force – time charts. The compaction cycle of the Result press is based on the programmed cycle while the ejection part is actual logged data. The complete cycle of the Dorst press is based on logged data. From Figure 1 the difference in the kinematics of the press movements is clear.

It is seen that the compaction and cycle was much faster for the Dorst press compared to the Result press whereas the ejection velocities of the two presses were reasonably similar. The parameters used in the compaction trials are presented in Table 2.

Parameter	Result press	Dorst press
Filling	Suction	Gravity
Counter pressure during ejection	50 MPa	Not used
Compacting pressure	700 and 800 MPa	700 MPa
Part height	10 mm	10 and 18 mm
Number of parts per trial	10 parts	300 parts
Tool die and powder temperatures	45°C/R.T. (P) 60°C/R.T. (S, SX) 120/120°C (D)	45°C/R.T. (P) 60°C/R.T. (S, SX) 120/120°C (D)
Core rod	Floating (with constant pressure)	Floating (only with pressure after ejection)

Table 2: Parameters used in the compaction trials

Besides registering the ejection parameters the green density of the specimens were measured by weighing in air and water.

Results and discussion

Analyses of mixes are presented in Table 2. Graphite and lubricant contents of all mixes were close to the nominal content according to the plan. The bonding of graphite was improved by the Starmix process over the Premix while Densmix was on a much higher level. In a similar way, flow of the Starmix samples was faster compared to the Premix while Densmix was the fastest. Apparent density of Starmix was somewhat lower or similar to the Premix while the apparent density of Densmix was significantly higher than both Premix and Starmix. Higher AD have a positive effect on the ejection energy since the distance of ejection will be shorter since the part is compacted in a position higher up in the tool die.

	Graphite (%)	Lubricant (%)	Bonding degree of graphite (%)	Flow (s/50g)	AD (g/cm^3)
P-08	0.27	0.81	48	30.9	3.07
S-08	0.31	0.83	55	28.5	2.98
S-065	0.29	0.64	59	28.4	2.99
S-05	0.30	0.51	67	27.8	3.05
SX-05	0.34	0.50	62	28.0	3.11
D-06	0.26	0.60	100	24.4	3.53

Table 3: Analyses of the mixes

In Tables 4 and 5 the ejection properties and green density of the ring samples are presented.

	Compacting pressure 700 MPa			Compacting pressure 800 MPa		
Mix	Ejection force (N/mm^2)	Ejection Energy (J/cm^2)	Green density (g/cm^3)	Ejection force (N/mm^2)	Ejection Energy (J/cm^2)	Green density (g/cm^3)
P-08	38,2	26,4	7,22	39,9	26,9	7,27
S-08	35,6	23,3	7,23	37,2	23,6	7,27
S-065	37,5	24,7	7,26	39,6	25,7	7,33
S-05	38,9	27,0	7,29	41,2	27,1	7,36
SX-05	40,2	26,4	7,28	40,7	25,8	7,36
D-06	37,3	21,3	7,37	36,0	20,3	7,39

Table 4: Ejection performance and green density of rings compacted in the Result press

Mix	Part height 10 mm			Part height 18 mm		
	Ejection force (N/mm^2)	Ejection Energy (J/cm^2)	Green density (g/cm^3)	Ejection force (N/mm^2)	Ejection Energy (J/cm^2)	Green density (g/cm^3)
P-08	22,7	14,9	7,20	21,3	26,6	7,18
S-08	19,6	10,5	7,22	16,2	18,5	7,20
S-065	24,0	13,1	7,27	19,8	22,6	7,25
S-05	25,1	14,1	7,27	22,2	26,7	7,26
SX-05	25,1	13,1	7,28	20,8	23,2	7,25
D-06	26,9	13,6	7,37	26,0	27,2	7,33

Table 5: Ejection performance and green density of rings compacted in the Dorst press

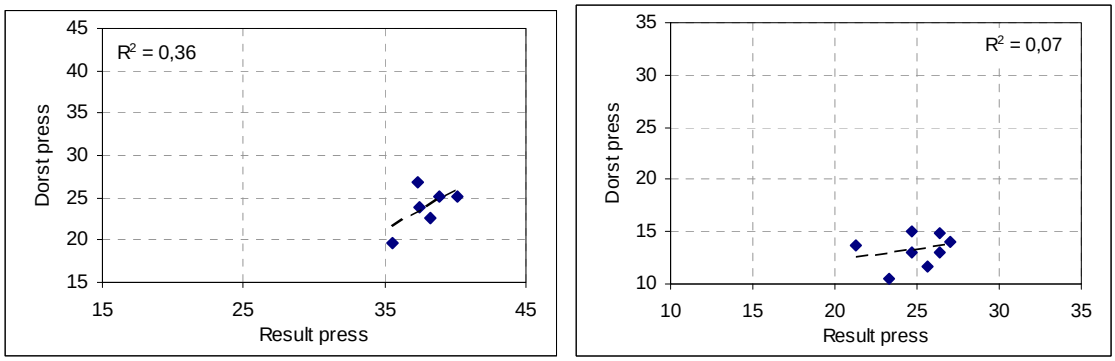
Influence of the type of presses, compacting pressure and part height

Comparing the performance of the compaction of the two presses the compressibility was similar, comparing the 10 mm high rings compacted at 700 MPa, see Tables 4 and 5, the difference was 0.02 g/cm^3 or less for all mixes. Density increased by 0.02 – 0.08 g/cm^3 with higher compacting pressure and decreased 0.01 – 0.03 g/cm^3 by increasing the part height.

In Figures 2 and 3 the ejection force and ejection energy of 10 mm high parts compacted at 700 MPa with the two presses are plotted. There were significant differences in the results; both the force and energy were significantly lower for the parts from the Dorst press compared to the Result press. The difference was surprisingly big considering that it was the same press tool, the same mixes, the same part height and density and that the tool was pre-heated to the same temperatures.

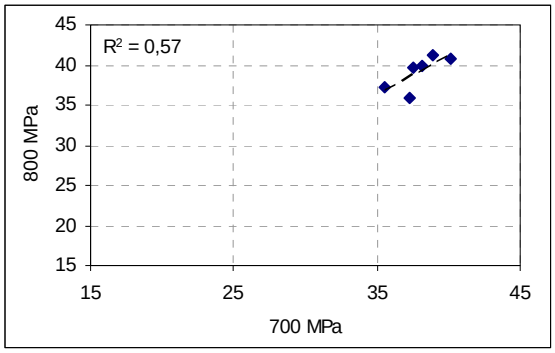
One of the main differences was the kinematics of the press movements where the cycle was much shorter in the Dorst press. The Dorst press was also run continuously to reach steady state conditions. Other factors which contributed to the higher ejection force and energy in the Result press were the use of counter pressure during ejection, constant pneumatic pressure on the core rod and use of suction filling. These factors are all known to influence the ejection force.

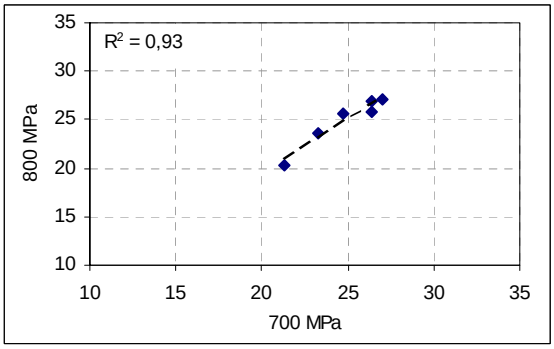
From the R^2 value of the linear regression lines in the diagrams in Figures 2 and 3 it can be seen that there was little correlation in the results from the two presses.



Figures 2 and 3: Ejection force [N/mm^2] and Ejection energy [J/cm^2], different presses

In Figures 4 and 5 the results achieved in the Result press with 800 MPa compaction pressure are plotted versus results achieved with 700 MPa compacting pressure. Both ejection force and energy correlated well between the two compacting pressures. This was a good indication of that the test methods for these properties are repeatable.

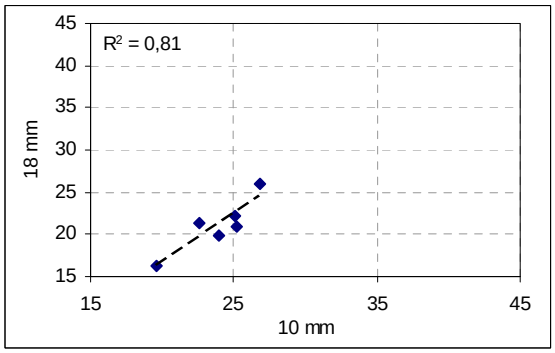


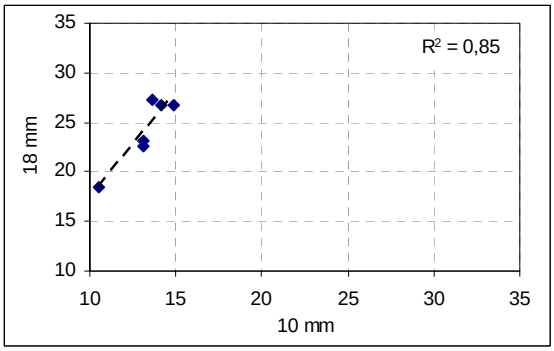


Figures 4 and 5: Ejection force [N/mm²] and Ejection energy [J/cm²], different compaction pressures

In Figures 6 and 7 the results achieved in the Dorst press with 18 mm part height are plotted versus 10 mm part height. For both ejection force and ejection energy there was good correlations in the results with the two part height. Comparing the two part heights, there was a much greater difference in the magnitude of the results for the ejection energy than for the ejection force, even though the energy was divided by the envelope surface area of the parts. The reason was that the ejection distance becomes longer for a higher part and the energy is calculated by integrating the force-displacement curve, the same ejection force per envelope surface area unit but with a longer distance will thus result in higher ejection energy.

An observation was that the difference in ejection energy between the mixes was greater for the higher parts. To evaluate the lubrication efficiency the higher part was more appropriate.





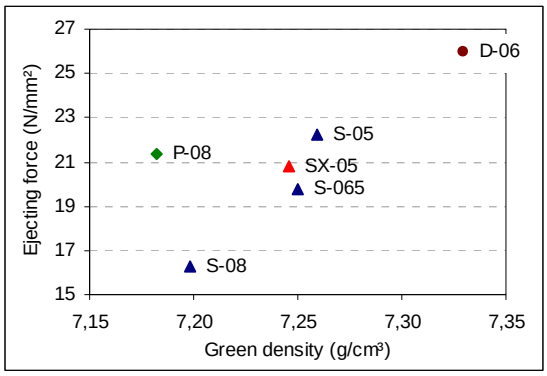
Figures 6 and 7: Ejection force [N/mm²] and Ejection energy [J/cm²], different part heights

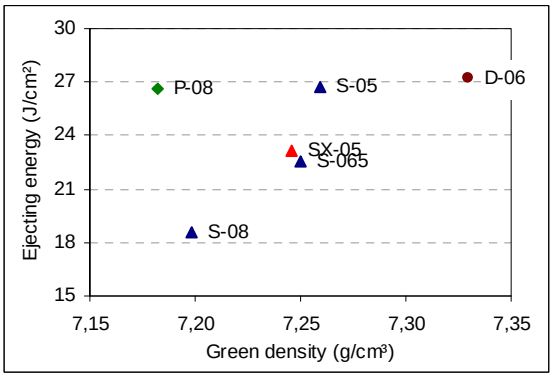
Influence of the type of mix and lubricant content

To compare the different mixes the results from the Dorst press with 18 mm high parts compacted to 700 MPa will be scrutinized. In Figures 8 and 9 ejection force and ejection energy are plotted versus green density.

Influence of the lubricity of different lubricants in the same amount can be seen by comparing P-08 and S-08, the more efficient lubrication of S-08 resulted in significant lower ejection energy and ejection force whereas the compressibility was only marginally improved. By lowering the lubricant content, see S-065 and S-05, compressibility increased while ejection force and energy increased. Even though the lubricant content of S-065 was 0.15% lower compared to P-08, the lubrication was better. Even the ejection energy of S-05, with only 0.5% lubricant, was similar to P-08. However, the decrease in lubricant content from 0.65% to 0.5% only marginally increased the compressibility under the conditions used in this compaction test.

It can also be seen that warm compaction, see mix D-06, resulted in higher density than any of the other mixes. The ejection force was higher while the ejection energy was similar to P-08 and S-05. Compared to P-08 the density achieved with D-06 was 0.15 g/cm³ higher.



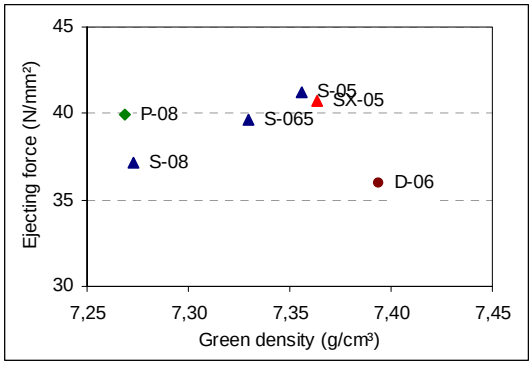


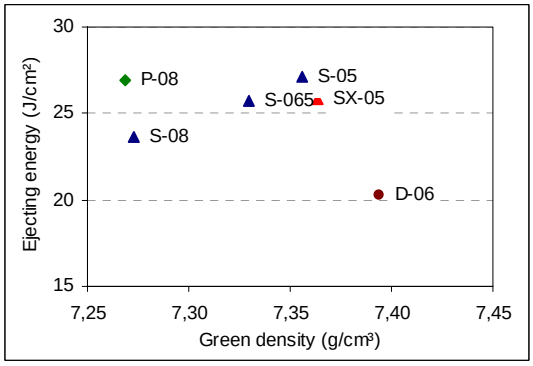
Figures 8 and 9: Compaction of 18 mm high parts at 700 MPa in the Dorst press, ejection force and ejection energy plotted versus green density

Comparing the performance of mix SX-05, the experimental mix with further improved lubricant, ejection force and energy were lower compared to S-05. However, no improvement in compressibility compared to S-05 was found under these test conditions. The compacting pressure was not high enough that lubricant content below 0.65% was required to increase the density.

Therefore it is of interest to make the same comparison from the trials in the Result press were a compacting pressure of 800 MPa was used, see Figures 10 and 11. To start with the relations between P-08, S-08, S-065 and S-05 were quite similar. One difference was that by decreasing the lubricant content to 0.5%, see S-05 and SX-05, an improvement in compressibility was obtained compared to S-065. The green density of S-05 and SX-05 was 0.1 g/cm³ higher than P-08 and was only marginally lower compared to the warm compacted mix D-06.

The lubrication performance of D-06 was under these test conditions the best of all mixes in this investigation.





Figures 10 and 11: Compaction of 10 mm high parts at 800 MPa in the Result press, ejection force and ejection energy plotted versus green density

Conclusions

In the compaction trials carried out in two presses the compressibility results were similar while there were significant differences in ejection force and ejection energy. The differences were explained by differences in press kinematics, use of counter pressure during withdrawal, force of core rods, and fill mode.

The use of more efficient lubricant in combination with warm die compaction significantly improved the lubrication performance, enabling the use of less amount of lubricant with maintained lubricity. With lower amount of lubricant the compressibility was improved, an effect which was more pronounced at higher compaction pressure.

Highest compressibility was achieved with warm compaction with both the powder and press tool heated. However, at a compacting pressure of 800 MPa, warm die compaction with efficient lubricants was only 0.03 g/cm³ lower in density compared to warm compaction.

References

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