Advanced Mixes with Improved Lubrication for Compaction of High Density PM Components

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Abstract
One of the fundamental means to improve the mechanical strength of sintered components is to increase density. In order to meet the performance of high strength application, such as transmission gears, high density is of outmost importance. In this paper, recent development of mixes with high performance PM lubricants will be presented. By improving the efficiency of the lubricant a lower amount is required in the mix and thus higher density can be achieved. The potential increase of compacted density will be demonstrated. A case study where a helical transmission gear was compacted to high density is presented.

Introduction
Higher density is required to improve the strength of PM components, in particular for the fatigue strength. Besides the compressibility of the base powder, the type and content of lubricant plays an essential role for the compressibility. It has been demonstrated that efficient lubricants in combination with warm die compaction is a feasible process route for higher compressibility [1, 2, 3].

However, a holistic approach is required when optimizing the compaction process for high density, This is due to the interaction of factors such as compacting pressure, tool die temperature and lubricant, see Figure 1. Lubricants have a significant influence on the theoretical density of a mix due to their low density, generally about 1 g/cm^3. Thus the lubricant content is a limiting factor to the compressibility. By increasing the tool die temperature the efficiency of the lubrication can be improved under the circumstance that a lubricant with a suitable temperature response is used. By enhancing the lubrication using higher tool die temperature a lower amount of lubricant can be used, while maintaining acceptable lubrication. In turn the lower lubricant amount will enable compaction to higher density.

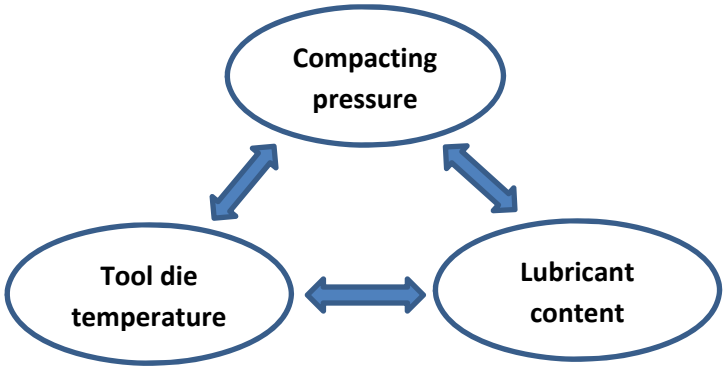


Figure 1: Factors influencing lubrication and compressibility

Intralube® E is a recently introduced press ready mix which is now used in substantial volumes for PM parts production. One important characteristic of Intralube E is a very favorable response to heated tool die. In this presentation the performance of a recently developed experimental mix with a high performance lubricant (X-Lube HD) is benchmarked with Intralube E mix and Premix with Amidewax as lubricant. Amidewax is the most commonly used lubricant in the PM industry.

Besides benchmarking the lubricants with specimens, results from an experimental mix with X-Lube HD are also presented. The experimental mix was used in compaction of a helical transmission gear with three upper, three lower punch levels and thirteen core rods. This demanding application showcases the performance of the mix in the compaction of a complex and demanding application.

Experimental
Lubricant benchmark
In Table 1 composition and analyses of mixes are presented. The mixes were analyzed with respect to flow (ISO 4490) and apparent density (ISO 3923). Organic content (lubricant/binder) and graphite content of the mixes were analyzed by solvent extraction and combustion analysis respectively.

Table 1: Composition and analyses of powder mixes

		Analyses of mixes			
Mix	Nominal composition	Flow (s/50 g)	AD (g/cm³)	Graphite (%)	Lubricant (%)
A08	Distaloy® AB + 0.3% C-UF4 + 0.8% Amidewax	32,7	3,04	0,27	0,76
A065	Distaloy AB + 0.3% C-UF4 + 0.65% Amidewax	28,5	3,08	0,28	0,60
E065	Distaloy AB + 0.3% C-UF4 + 0.65% Lube E	28,0	3,09	0,28	0,58
HD08	Distaloy AB + 0.3% C-UF4 + 0.8% X-Lube HD	29,1	3,01	0,29	0,74
HD065	Distaloy AB + 0.3% C-UF4 + 0.65% X-Lube HD	28,0	3,05	0,28	0,61
HD05	Distaloy AB + 0.3% C-UF4 + 0.5% X-Lube HD	27,2	3,09	0,29	0,48

Compaction trials were carried out in an instrumented hydraulic press, Result EHP125, with ring-shaped specimens. The outer diameter of the specimens was 40 mm, the inner diameter was 20 mm and the height was 15 mm. The core rod was fixed in relation to the tool die. Compaction trials were carried out with the tool die heated to 20, 45, 70 and 90°C. All mixes were compacted at 20°C and 45°C. A tool die temperature of 45°C is judged to be a typical temperature for a non-heated tool die under continuous operation. Specimens of E065 were also compacted at 70°C and specimens of HD08, HD065 and HD05 were compacted with a tool die temperature of 90°C. These temperatures were selected based on the optimum operating temperatures for the lubricants. Specimens were compacted at 700, 800 and 900 MPa. Forces and positions of tool members were logged during the compaction and ejection. From these data the maximum static ejection force and energy required for the ejection were calculated. The green density of the specimens was evaluated by the Archimedes principle.

Maximum height trial

To benchmark the lubrication of the Intralube® E mix and a mix with X-Lube HD, cylindrical specimens with ø64 mm were compacted to different heights, see Figure 2. The height was incrementally increased from 15 mm to 50 mm. The mix composition was Distaloy AB + 0.3% C-UF4 + 0.5% lubricant.



Figure 2: Cylindrical specimens of increasing height

The press used was a Dorst TPA800 HP/2 and the tool die had a carbide insert. Compacting pressure was 750 MPa corresponding to a density level of 7.3-7.35 g/cm³ depending on the height of the samples. The tool die was heated to a temperature of 70°C. 25-30 parts were compacted with each setting. The results were evaluated by inspecting the surface of the pressed parts.

Helical gear compaction trial

Compaction trials were made on the 4th drive gear for an M32 GM gear box, see Figure 3. This gear has a helix angle of 32.25° and features three upper and three lower levels. Twelve weight saving holes have been added to the original design of the wrought gear.



Figure 3: 4th drive gear for an M32 GM gearbox



Figure 4: Helical drive system

To control the rotational movement of the outer upper punch, a helical drive manufactured by Alvier AG (see Figure 4) has been used. The gearbox converts the linear movement into the required rotation of the upper punch with high accuracy. By high-precision top punch entry, the tool wear is minimized and rounding of the edges of the punch faces is avoided. The other punches and core rods of the tool must be able to rotate and are thus placed on bearings. Powder mixes with different compositions were used to compact the gears. These compositions as well as analyses of the powder mixes are presented in Table 2.

Table 2: Composition and analyses of powder mixes

		Analyses of mixes				
Mix	Nominal composition	Flow (s/50 g)	AD (g/cm³)	GD (g/cm³)	Graphite (%)	Lubricant (%)
E065AQ	Distaloy AQ + 0.4% C-F10 + 0.65% Lube E	31.5	3.02	7.14	0.40	0.66
HD055AQ	Distaloy AQ + 0.3% C-UF4 + 0.55% X-Lube HD	29.6	3.03	7.17	0.30	0.52

Results and discussion

Lubricant benchmark

Figures 3 a-c show the influences of the tool die temperature on mix HD065 compacted at 700 MPa. It is seen in Figure 3 that the ejection energy is decreased by one third as the tool die temperature is increased from room temperature to 90°C. Also the static peak ejection force is significantly reduced by increasing the temperature, see Figure 3 b. In Figure 3 c the effect of tool die temperature on compressibility is shown as the density is increased by 0.13 g/cm³ when raising the tool die temperature from 20°C to 90°C. The benefit of increasing the tool die temperature is obvious from the improved compressibility as well as the more efficient lubrication which enables the use of lower amounts of lubricant.

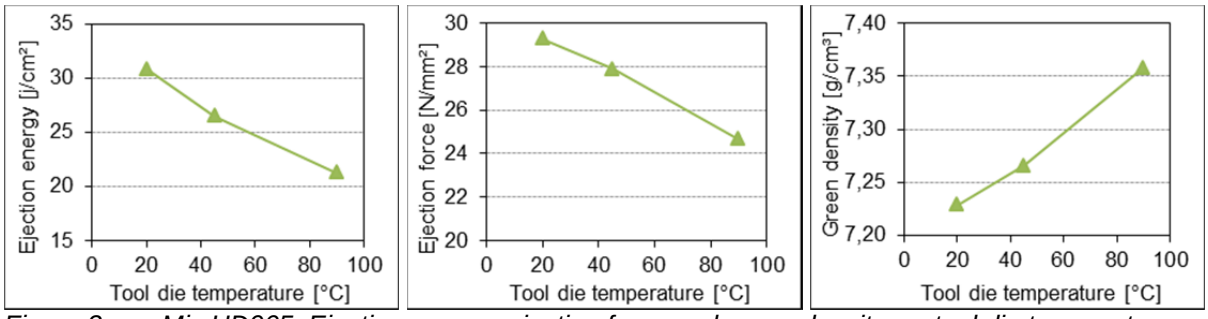


Figure 3 a-c: Mix HD065, Ejection energy, ejection force and green density vs. tool die temperature compacted at 700 MPa

Figures 4 a-c present the compaction performance of the three mixes with different types of lubricants but with the same lubricant content. A tool die temperature of 45°C used for mix A065 is relevant for a non-heated die. For mixes E065 and HD065, optimum tool die temperatures for the lubricant were used. It is obvious that the ejection energy and force were lower for E065 than A065 and that the numbers were even lower for HD065. What should also be noticed is that the response of increased compaction pressure on the ejection energy of A065 was very limited. However, for HD065, higher compacting pressure resulted in decreased ejection energy. Finally, Figure 4 c illustrates how density is increased by combining the more efficient lubricant used in mix HD065 with a heated tool die.

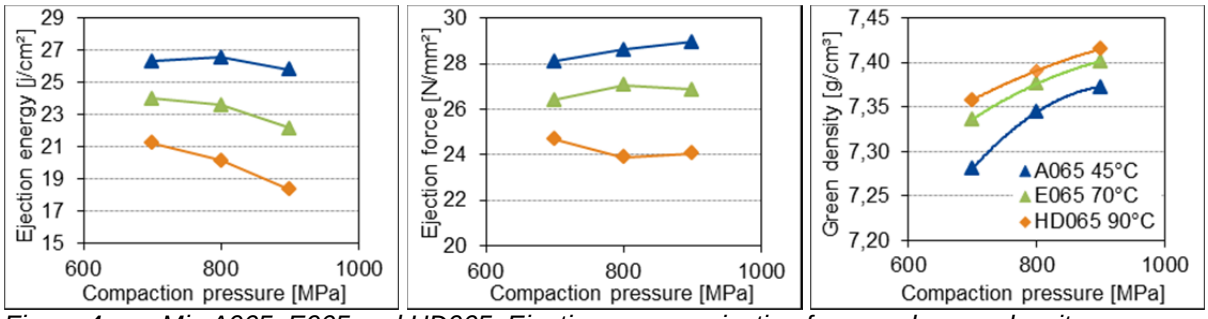


Figure 4 a-c: Mix A065, E065 and HD065, Ejection energy, ejection force and green density vs. compacting pressure

A further potential to increase the compressibility is to, when possible, reduce the lubricant content with respect to the efficiency of the lubrication. If the ejection energy of HD05 in Figure 5 a is compared to A065 and E065 in Figure 4 a, HD05 showed better results than A065 and almost as good as E065, even though the lubricant content was 0.15% lower. As a result of the lower lubricant content the compressibility was further improved, see Figure 5 b. In Figure 5 c the density is plotted relative to the theoretical full density of the mixes. It can be seen that the relative density of mix HD08 does not exceed 99.1%. Thus there was no benefit of increasing the compacting pressure beyond 700 MPa with that mix. By decreasing the lubricant content the theoretical full density of the mix increases. However, to reach the same relative density with lower lubricant content, high compacting pressure is required.

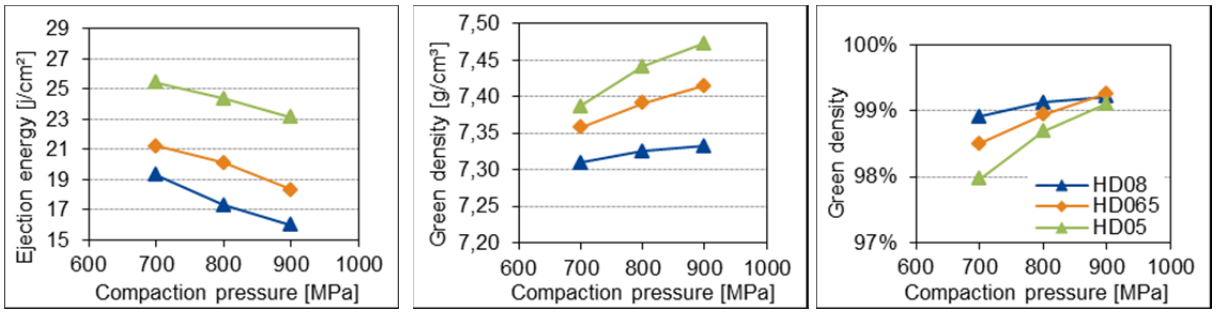


Figure 5 a-c: Mix HD05, HD065 and HD08, Ejection energy, green density and relative green density vs. compacting pressure compacted at a tool die temperature of 90°C

Maximum height trial

The result from the maximum height trials can be seen in Figure 6. The surface finish of three cylinders demonstrates the difference in performance between Intralube® E mix and X-Lube HD. With Intralube E mix it was possible to compact cylinders up to a height of 40 mm with a shiny surface without scoring. As the height was further increased to 50 mm, scoring appeared on the surface in the lower end of the cylinders. With X-Lube HD cylinders 50 mm high could be compacted with a shiny surface without scoring. Scoring on the surface generally becomes more severe if compaction is continued and may eventually lead to damage of the press tool. Higher parts than 50 mm could not be tested due to limitations of the fill height of the press tool. The results show that the more efficient lubricity of X-Lube HD enables compaction of higher parts with good surface condition after ejection.

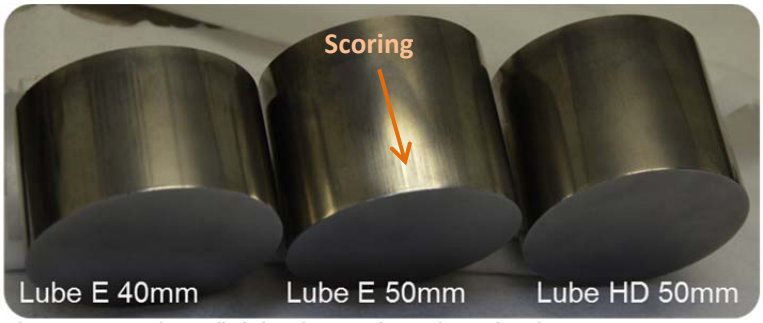


Figure 6: Surface finish of samples after ejection

Helical gear compaction trial

In Figure 7 compressibility of gears compacted of the two mixes is presented. When comparing HD055AQ with E065AQ it can be seen that higher density was achieved by combining the better lubrication performance of HD065AQ with lower lubricant content and higher tool die temperature. The density improvement increases with increased compacting pressure. Also presented in this figure is the compressibility of mix HD065AQ measured on cylindrical specimens according to ISO 3927.

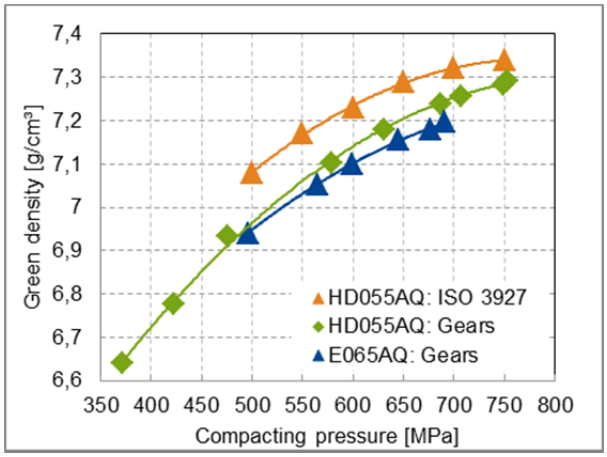


Figure 7: Compressibility of M32 gears versus specimens according ISO 3927

When comparing the difference in compressibility of the gear and the standardized specimen, it was found that the density was lower for the gear. However, the difference decreased with increasing compaction pressure. The main reason is of course the larger surface and complexity of the gear but there was also a difference in tool die temperature. For the standardized specimens the tool die temperature was set to 90°C which is the optimum temperature for this lubricant. In the case of the gears, the tool die temperature was limited to 70°C to avoid problems with clearance between tool members due to temperature differences.

Densities of concentric cut segments of a gear compacted at 750 MPa of HD055AQ are presented in Figure 8. There was a tendency to higher density in the upper half of the gear segment while the vertical density distribution in the hub was even. Measured density of the cut segments of the green components tends to be slightly lower than the overall density due to the rougher surfaces generated by the saw.

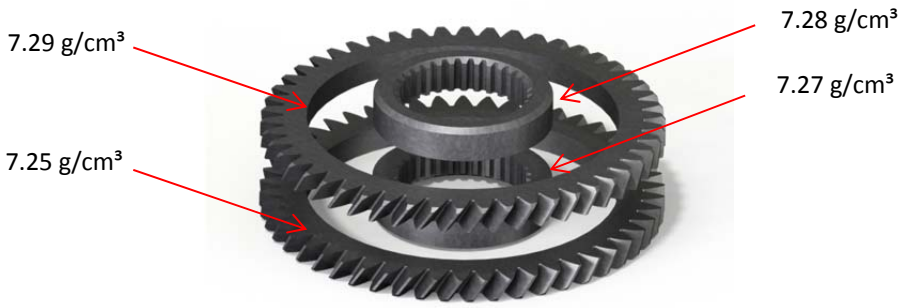


Figure 8: Green density measured on concentric segments

Figure 9 presents the results from a continuous production run of 400 gears with mix HD055AQat compacting pressure of 750 MPa. Green densities of gears sampled throughout this production run are presented in Figure 9 a. The density was stable around 7.3 g/cm³. The temperature stabilized around 67°C after 200 parts, see Figure 9 b. The low number of parts required to reach steady state temperature is a result of the controlled heating of the tool die. The peak force of the lower ram of the press was similar (800 kN) between E065AQ and HD055AQ even though the lubricant content of the latter mix was 0.1% lower and the compacting pressure was 50 MPa higher. This, in combination with the observation of the same shiny component surface conditions with both mixes, indicates that the lubrication of HD055AQ was very efficient and that a lubricant content of 0.55% X-Lube HD was sufficient also for this highly complex part.

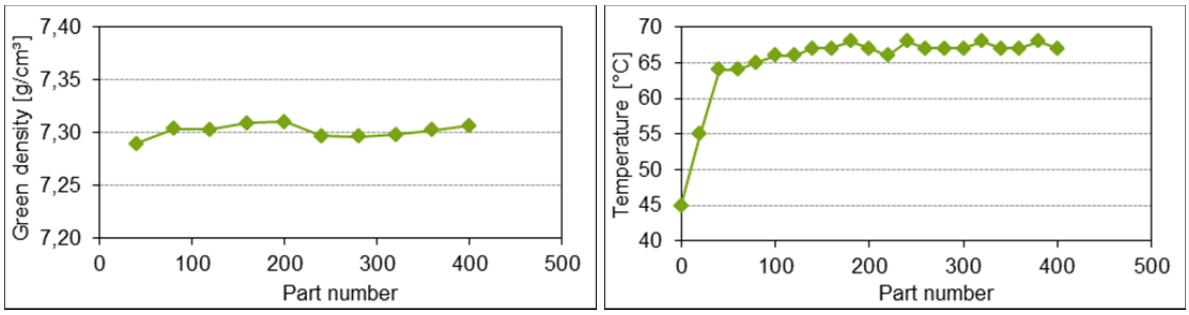


Figure 9 a – b: Green density (left) and part temperature after ejection (right) from production run of 400 gears of FD-0105 (HD)

Density distribution in a gear tooth is presented in Figure 10 a-c as horizontal cross section through top, centre and bottom. In the cross sections, high and uniform density was found at the three levels.

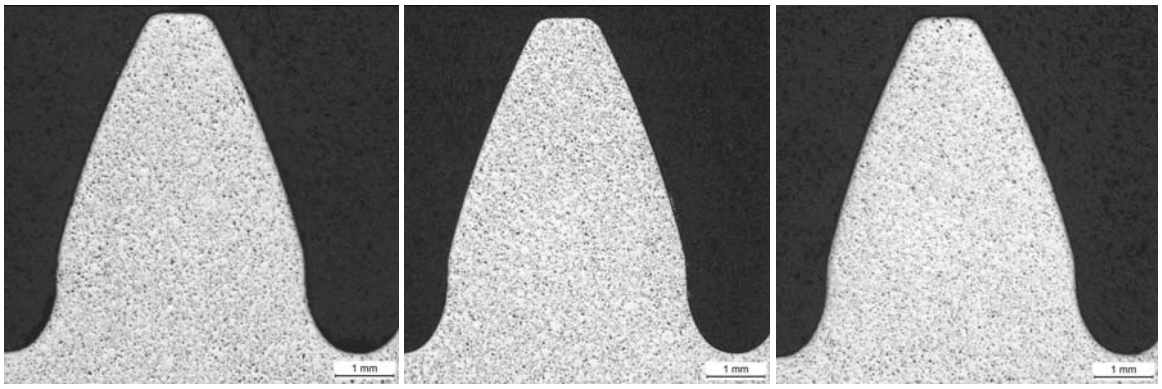


Figure 10 a-c: Unetched metallographic horizontal cross section through top, centre and bottom of a tooth

Conclusions

A new lubricant system under development, X-Lube HD, is optimized to be used with tool die heated to 90°C. When combined with heated tool die, the lubrication is highly efficient and enables compaction to high green density by decreasing the amount of lubricant added and increasing the compaction pressure.

In trials with compaction of large specimens with incrementally increasing height it was shown that higher parts could be compacted with X-Lube HD compared to Intralube E mix before scoring appeared on the surface of the compacts.

Highly complex helical gears were compacted with a mix containing 0.55% X-Lube HD. With a compacting pressure of 750 MPa and with heated tool die the overall green density was 7.3 g/cm³. Compaction process was running stable and 400 gears were compacted without any deterioration of the surface finish of the parts.

References

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