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Warm Die Compaction of High Density PM Components

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Abstract

By increasing the density of sintered steels, the attractive combination of both higher strength and higher ductility of the material is gained. One process route to achieve high density PM components is to use high performing lubricants in combination with heated tool die. The synergies of lubricant content, efficiency of the lubricant and tool die temperature are presented in this paper. Using the right combination of mix composition and compaction parameters is one of the keys to obtain higher density of PM components.

Introduction

To have high density of PM components is of great importance to achieve high strength material. By increasing the density both the strength as well as the ductility is improved.
There are different routes available for making high density PM components such as powder forging, high temperature sintering, copper infiltration, double press-double sintering and warm compaction [1].
A processing route which gains in popularity is warm die compaction. This is a technology where mixes with highly efficient lubricants in relatively low content are compacted with heated tool die and at relatively high compaction pressure [2]. A benefit of this process route is the simplicity, there are no additional processing steps, and the only addition to the standard PM processing route is the addition of heating device for the tool die.
Intralube® E mixes are well established on the market and contains a lubricant system suitable for warm die compaction. A more recently introduced product is Intralube HD mixes which have further enhanced lubrication performance and can be used at tool die temperature up to 90°C.

Experimental

A. Materials

Results from three investigations are included in this paper. In the first study, mixes with the following nominal composition were evaluated: AstaloyTM 85 Mo + 0.5% C-UF4 + lubricant. Three types of lubricants were used in the mixes; Amidewax, Zn-st and Lube E.
In the second investigation mixes with the following nominal composition were evaluated: Distaloy® AB + 0.3% C-UF4 + lubricant. In this investigation a recently introduced mix concept, Intralube HD mix, was also included. Intralube HD mix was developed to have optimum performance for compaction with heated tool die.

Finally results from compaction of a helical transmission gear with two different mixes will be presented:
Distaloy AQ + 0.4% C-F10 + 0.65% Lube E
Distaloy AQ + 0.3% C-UF4 + 0.55% Lube HD

B. Compaction trials

Result EHP120 is a hydraulic laboratory press instrumented for accurately logging forces and positions. The objective of these press trials was to study influence from lubricants and mixes on compressibility and lubrication.
The sample geometry used in the first evaluation was cylindrical according to ISO 3927 with ø25 mm and height of 20 mm. Specimens were compacted at 500, 600, 700, 800 and 900 MPa. Compaction of Intralube E mixes was carried out at room temperature and with the tool die heated to 80°C.
For the second study ring shaped specimens with ø40/20 mm and a height of 15 mm were compacted at 700, 800 and 900 MPa. A tool die temperature of 45°C was used for the mix with Amidewax as lubricant. The temperature 45°C is judged to be a typical temperature for a non-heated tool die under continuous operation. Intralube E mixes were compacted at tool die temperature of 70°C and Intralube HD mixes were compacted with a tool die temperature of 90°C. These temperatures were selected based on the optimum operating temperatures for the different lubricants.
Ejection curves of the parts were logged and the static ejection force and ejection energy were calculated by integrating the area under the force displacement curves from the ejection. The ejection

energy was divided by the envelope surface of the parts and expressed as J/cm². Since different geometries of specimens were compacted in the two studies the magnitude of the ejection energy was different and not directly comparable between the two studies. Compaction trials with a transmission gear, 4th drive gear for a M32 GM gear box, were carried out in a Dorst TPA800/HP2 press equipped with a helical drive system from Alvier AG [3]. See Figure 1 for part geometry. The tool die temperature was limited to 70°C to avoid problems with clearance between tool members due to thermal expansion of the tool. The density of gears compacted at different compacting pressures was measured.



Fig. 1. 4th drive gear for an M32 GM gearbox

Results and discussion

A. Astaloy 85 Mo mixes

In Figure 2 compressibility curves are presented for mixes with three different lubricants, Lube E (Intralube E mix), Amidewax and Zn-st. As can be seen the difference in compressibility between the mixes was small. The highest compressibility was achieved with Zn-st as lubricant, due to the fine particle size of the lubricant which is beneficial for the compressibility.

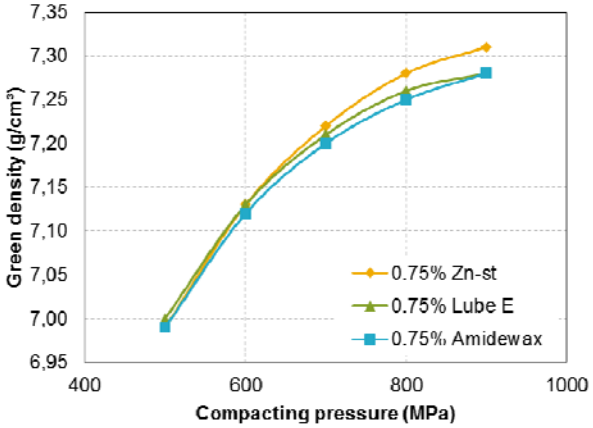


Fig. 2. Compressibility of mixes with three different lubricants.

Next factor to consider is the lubrication with different lubricants, ejection curves logged in a Dorst TPA45 mechanical press for the same three mixes are presented in Figure 3. As can be seen in the figure both the peak ejection force and the dynamic ejection force were highest for the Zn-st mix and lowest for the Lube E mix.

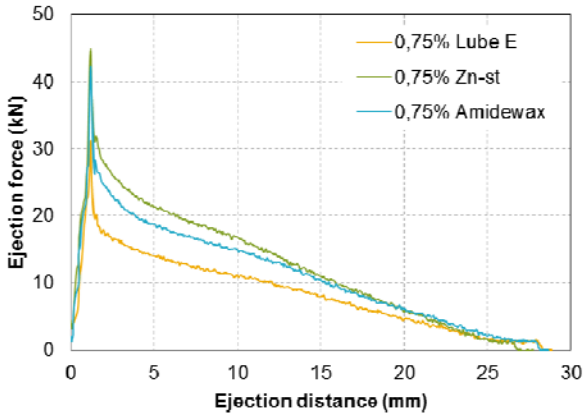


Fig. 3. Ejection curves of mixes with three different lubricants.

To further investigate the influence of the tool die temperature and lubricant content, three Intralube E mixes with varying lubricant content were compacted at room temperature and at a tool die temperature of 80°C. The results are presented in Figure 4. Obviously, the lubrication was better and ejection energy was lower with a higher lubricant content. With the two highest lubricant contents the ejection energy was decreasing slightly with increasing compacting pressure when compacted at room temperature. By increasing the tool die temperature the ejection energies were lower at all compacting pressures, the decrease in ejection energy was more significant at higher compacting pressures.

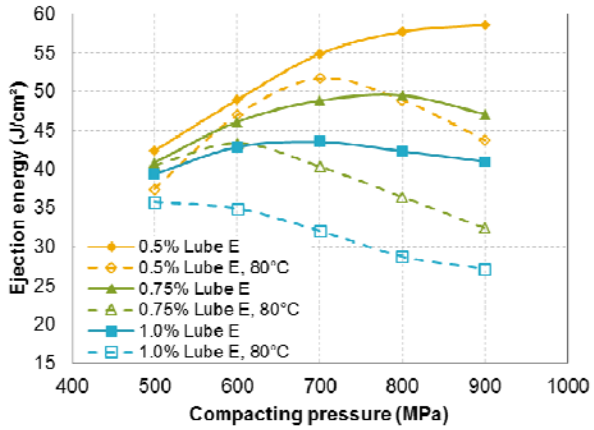


Fig. 4. Ejection energy versus compacting pressure

By plotting the ejection energy versus the green density the picture is even clearer, see Figure 5. With warm die compaction there was a considerable improvement in lubrication over a threshold density level. By decreasing the lubricant content the threshold density was increased.

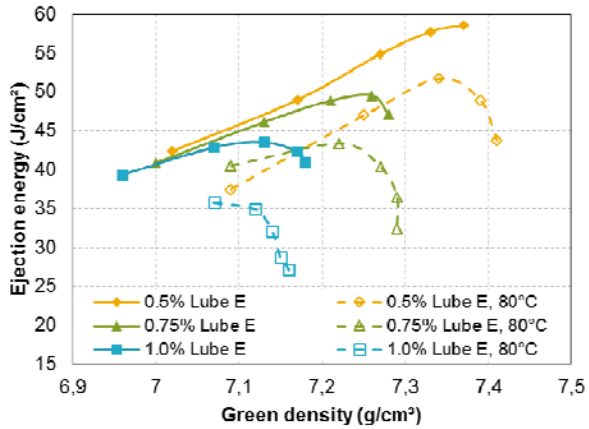


Fig. 5. Ejection energy versus green density

By plotting the ejection energy vs. the relative density of the powder mix it was found that the drop in ejection energy takes place when 98% relative density of the mix was reached, see Figure 6.

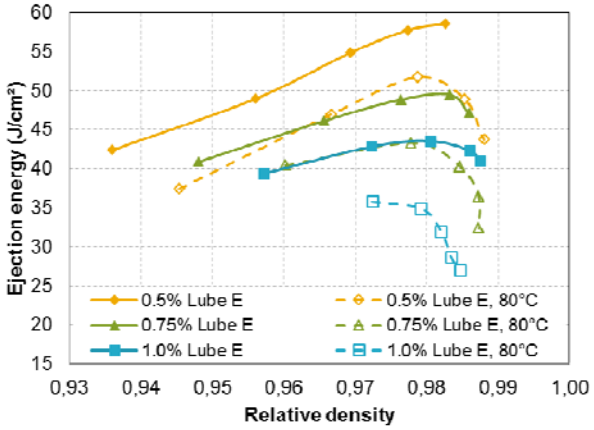


Fig. 6. Ejection energy versus relative density

What is then the potential increase in density? In Figure 7 compressibility curves for the three mixes with tool die at room temperature and 80°C are presented. As can be seen there was a density improvement by increasing the tool temperature. The exception was the combination of 1% lubricant, 80°C tool die temperature and high pressure which resulted in excessive springback and thus a drop density.

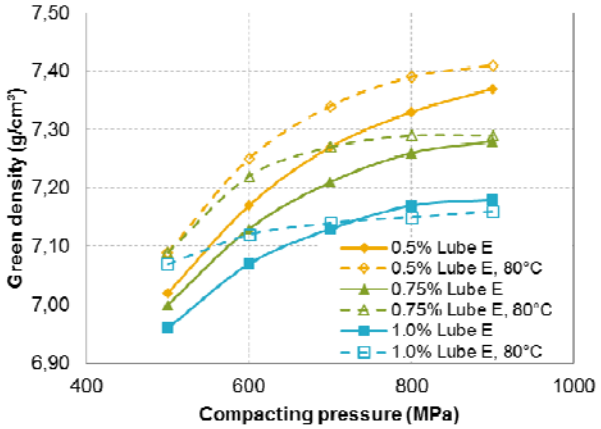


Fig. 7. Compressibility of mixes at room temperature and 80°C tool die temperature

In Figure 8 the ejection energy is plotted versus the green density for Intralube E mixes and also mixes with Amidewax and Zn-st as lubricants. With a lubricant content of 0.75% and heated tool die a significant improvement in lubrication was achieved. However the green density was limited by the theoretical density of the mix. With lower Lube E content in combination with heated tool die significant improvement in density can be achieved with lower ejection energy than for mixes with 0.75% of Amidewax or Zn-st as lubricant.

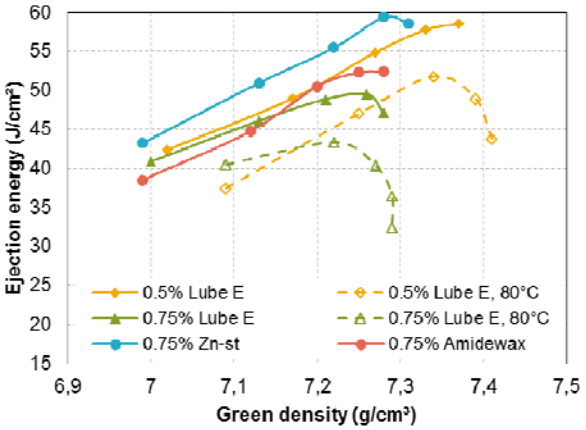


Fig. 8. Ejection energy versus green density

B. Distaloy AB mixes

In Figure 9 the ejection energy of three mixes is presented. With 0.65% lubricant added significantly lower ejection force was obtained with Intralube HD mix compared to Intralube E mix. Both these mixes were lower in ejection energy than the mix with 0.8% Amidewax. The Intralube HD mix with 0.5% lubricant was slightly higher in ejection energy compared to the Intralube E mix with 0.65% lubricant but lower than the mix with 0.8% Amidewax.

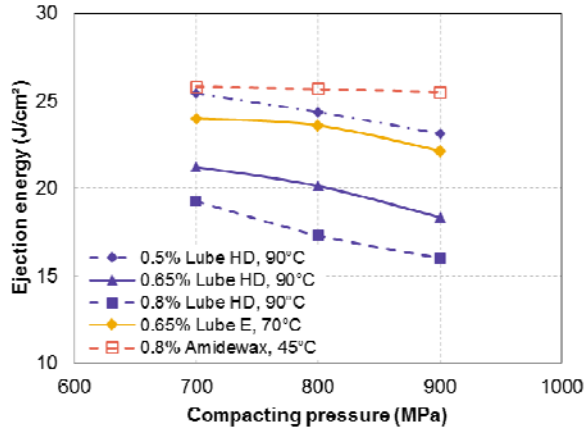


Fig. 9. Ejection energy versus compacting pressure

In Figure 10 the ejection energy is plotted versus the green density. Also in this investigation the ejection energy was decreasing by increasing density with warm die compaction. By lowering the amount of lubricant in the Intralube HD mix green density and ejection energy increased. But even with 0.5% Lube HD the ejection energy was similar or lower compared to the mix with 0.8% Amidewax while the green density was significantly higher. The ejection energy of Intralube E mix was in between the Intralube HD mixes with 0.65% and 0.5% lubricant. This shows a potential to decrease the lubricant content of Intralube HD mixes in comparison to Intralube E mixes, and thus enable an increase of green density.

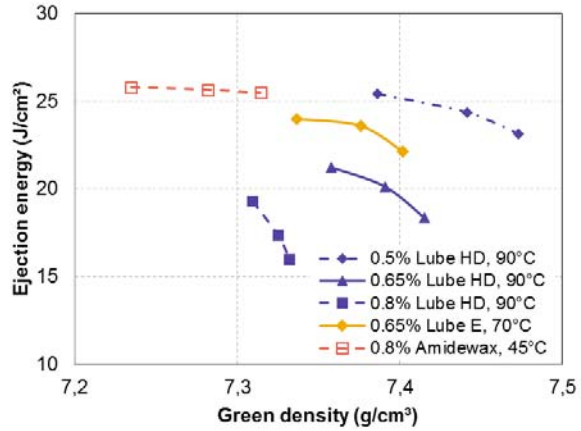


Fig. 10. Ejection energy versus green density

C. Helical gear compaction trial

In Figure 11 the green density of the pressed helical gears is plotted versus the compacting pressure. Even though the full potential of the Intralube HD mix have not been utilized since the tool die temperature was limited to 70°C, significant increase of the density was gained. The Intralube HD mix with 0.55% Lube HD had sufficient lubrication to press the helical gear to a density of 7.30 g/cm³ under steady state conditions.

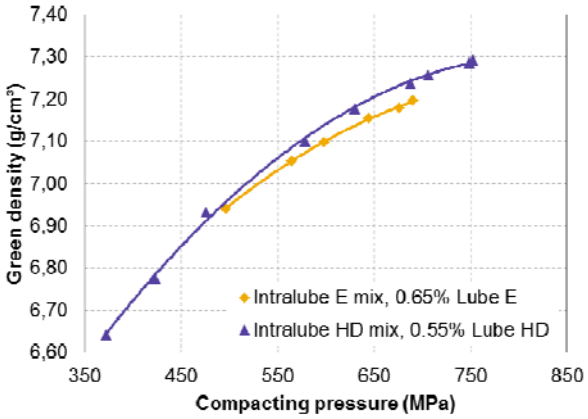


Fig. 11. Compressibility of M32 gears

Conclusion

Warm die compaction is a cost efficient process route for making high density PM parts. A prerequisite to reach high density is to keep the lubricant content at relatively low amounts. The combination of efficient lubricants and heated tool die will improve the efficiency of lubrication and allow lower lubricant amounts.

Intralube HD mix is a recently introduced mix concept in which the lubricant system is optimized for compaction with the tool die heated up to 90°C. The highly efficient lubricant and the ability to be used with higher tool die temperature is an excellent solution for compaction of high density PM components.

References

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