HIGH PERFORMANCE LUBRICANT FOR WARM DIE COMPACTION

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ABSTRACT

The powder metal (PM) industry is constantly striving to increase the density in components in order to improve the mechanical performance. High density can be achieved with a variety of different manufacturing methods; however, warm die compaction has become popular due to the simplicity of the process. Using specially designed lubricants and heated tooling, high density can be achieved in a single compaction step. A new lubricant system has been developed which provides improved density and ejection performance. The optimal operating conditions and achievable properties of the lubricant system will be discussed.

INTRODUCTION

A fundamental way to achieve improved performance of PM components is to increase the overall density. Porosity lowers physical properties compared to wrought steels, therefore densification is an important parameter directly related to a components overall strength. Figure 1 shows the relationship of density compared to selected mechanical properties. Tensile and fatigue strength properties increase linearly as density increases, while elongation and impact energy increase exponentially [1].

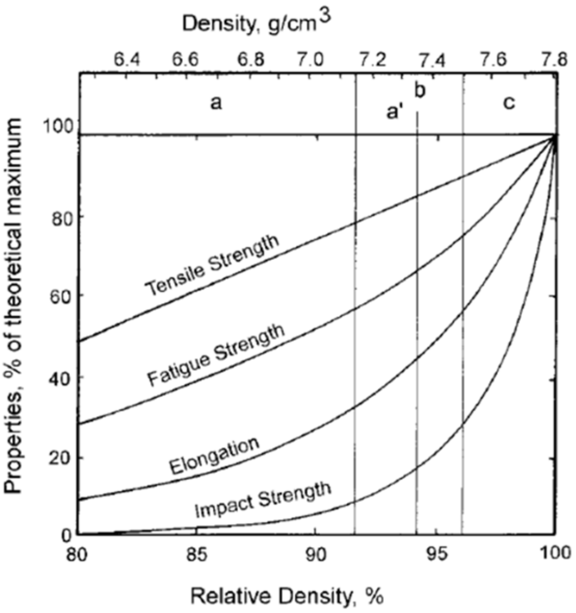

Figure 1: Density vs Physical properties [1]

As applications become increasingly more demanding, achieving high density is critical in order to meet performance requirements. High fracture resistance and good fatigue characteristics have become key limitations in many structural and automotive components [2]. Components such as transmission gears, sprockets, and pulleys are examples of highly stressed mechanisms that require superior strength properties. Reducing porosity, while maintaining low production costs, is crucial when competing with alternate fabrication methods such as casting, forging or machining [2].

The densification of iron powder mixes relies on a combination of three key factors for optimal compaction: compaction pressure, lubricant content, and tooling temperature [3]. Lubrication is necessary for compaction of iron powder mixes to reduce interparticle friction as well as the friction between the iron particles and the die wall. The reduction in friction provided by the lubricant allows for improved densification, lower part ejection forces and increased tool life. However, the addition of lubricant in mixes also adversely affects the densification process. The lubricant particles reside in the porosity and reduce the achievable pore free density, resulting in lower green and sintered component densities. Typically for every 0.1% of lubricant added to a mix, the achievable green density is reduced by 0.05g/cm^3 [4].

There are a number of methods to achieve high density PM components. Powder forging, double press/double sintering, high temperature sintering, and copper infiltration are all techniques that are currently being used in the PM industry. While these methods are effective at achieving high density, they are also costly and involve secondary processing steps that hinder productivity. Warm compaction and warm die compaction are two additional techniques used in the PM industry that utilize a single press / single sinter process to improve density. This enables them to remain cost efficient by achieving high density in a single compaction step while eliminating the need for double pressing or copper infiltration to reach density.

Warm compaction consists of heating the die, feed shoe and powder, and is typically used for components weighing over 454 g (1 lb). Typical temperatures of the die assembly and power range from 100 ºC to 150 ºC (212 ºF-302 ºF) [5]. Proper temperature control of the powder is crucial during warm compaction, yet is the most challenging aspect of the process. Improper heating of the powder can result in temperature variations of the powder resulting in the degradation of powder properties [2]. The challenge of maintaining a uniform temperature during warm compaction led to the development of an alternate method called warm die compaction.

Warm die compaction consists of heating only the tooling and is sufficient for components weighing less than 454 g (1 lb). Unlike warm compaction, warm die compaction utilizes lower temperatures ranging from approximately 60 ºC to 90 ºC (140 ºF– 194 ºF) [6]. During warm die compaction, the tool heat is used to soften the lubricant in the mix. This softening allows the lubricant to travel to the die surface faster than conventional compaction, and provides an increase in the amount of lubrication to the die wall surfaces [6]. The increase of lubricant to the die wall surfaces allows for a reduction in the necessary lubricant content, thus increasing potential density. Warm die compaction is widely used in industry due to its cost efficiency as well as simplicity.

As previously discussed, lowering the lubricant content allows for higher potential density. However, the lower lubricant content results in higher ejection forces and decreased tool life. Development of an efficient lubricant system that will provide sufficient lubrication at low content levels and elevated temperatures is an important aspect of high density compaction. A lubricant with too high or too low of a melting temperature will adversely affect compressibility, ejection, mechanical properties, surface appearance, and overall quality of components.

Intralube® E is a common lubricant used for warm die compaction. This paper will compare a new lubricant system against Intralube® E for even better warm die compaction performance.

LABORATORY EVALUATION

Six compositions of both prealloyed and diffusion alloyed Fe-C steels were manufactured (Table 1). Varying amounts of lubricant were targeted in each mix.

Table 1: Material Systems Evaluated (wt%)

Base Iron	Graphite	Lubricant	MPIF Code
D.AB	0.30%	0.5% Intralube® HD	FD-0200
D.AB	0.30%	0.5% Intralube® E	
D.AB	0.30%	0.6% Intralube® E	
Astaloy 85Mo	0.30%	0.5% Intralube® HD	FL-4400
Astaloy 85Mo	0.30%	0.5% Intralube® E	
Astaloy 85Mo	0.30%	0.6% Intralube® E	

Each mix was compacted into 12.7 mm (0.5 in) TRS specimens. The mixes using Intralube E were compacted using a die heated to 60 ºC. The mixes using Intralube® HD were compacted using a die heated to 90 ºC. The lubricants were compacted at different temperatures due to the difference in designed operating temperatures of each lubricant. The bars were compacted at varying compaction pressures. Compressibility and ejection force were recorded at each pressure. Tensile specimens and impact energy specimens were compacted from each mix at a compaction pressure of 760 MPa (55 tsi).

Based on the laboratory testing, a maximum height compaction test was conducted to compare the surface appearance of Intralube® E vs Intralube® HD. One mix composition using each lubricant was chosen to observe the surface appearance at various heights. The following mix composition was evaluated:

D.AB + 0.3% Graphite + 0.5% Lubricant (FD-0200)

Cylindrical pucks with a 64 mm (2.5 in) diameter were compacted to difference heights using a die heated to 70 ºC. The heights were incrementally increased from 15 mm (0.59 in) to 50 mm (1.97 in) at 5 mm (0.20 in) intervals, while maintaining a density level of 7.30-7.35 g/cm^3 (Figure 2). Pucks over 50 mm (1.97 in) could not be compacted due to die fill limitations on the press. Thirty (30) specimens were compacted at each height. The surface appearance of the specimens was evaluated.

Figure 2: Incremented height specimens

Production Trial

Production trials were conducted at Symmco, Inc (Sykesville, PA). Intralube® HD verses Intralube® E were trialed in a mix consisting of the following composition:

Astaloy B + 1% Ni + 0.5% Graphite + 0.5% Lubricant (FLN-4205)

The mixes were used to compact a shift weight component shown in Figure 3. The mix with Intralube® E was compacted using a die heated to 60 ºC (140 ºF). The mix with Intralube® HD was compacted using a die heated to 90 ºC (194 ºF). The density and weight scatter were evaluated on every 10th component over 500 parts. After sintering, the components were sectioned and evaluated for sintered density in the hub and flange sections.

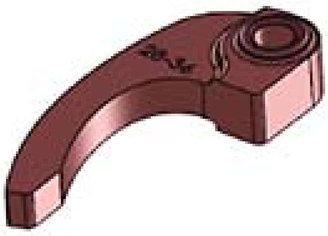

Figure 3: Part drawing of Symmco, Inc. shift weight component

Helical Gear Compaction Trial

Compaction trials were conducted of comparing the two lubricants on the 4th drive gear of a M32 GM gear box. The gears were compacted using a Dorst TPA800 HP/2 press. A helical drive manufactured by Alvier was used to control the rotational movement of the outer upper punch. The PM design of the gear consists of three upper levels and three lower levels with a helix angle of 32.25º. Twelve holes compacted into the gear body allow for weight reduction compared to the original wrought component (Figure 4). Gears were compacted from each of the following compositions:

D.AQ + 0.4% Graphite + 0.65% Intralube® E (FD-0105)
D.AQ + 0.3% Graphite + Intralube® HD (FD-0105)

The compressibility of the gears was evaluated. The mix with Intralube® E was compacted using a die heated to 60 ºC (140 ºF). The mix with Intralube® HD was compacted using a die heated to 90 ºC (194 ºF). For the production run of 400 gears, both mixes were compacted in a die heated to 70 ºC (158 ºF) to be cautious of tool clearances. The compacted gears were sampled during the run and evaluated for density consistency, temperature consistency, and gear tooth density distribution.

Figure 4: 4th drive gear for M32 GM gear box

RESULTS

LABORATORY TESTING
The apparent density of each mix is shown in Figure 5. The Intralube® HD mix has a slightly lower apparent density than the Intralube® E mix with the same lubricant content.

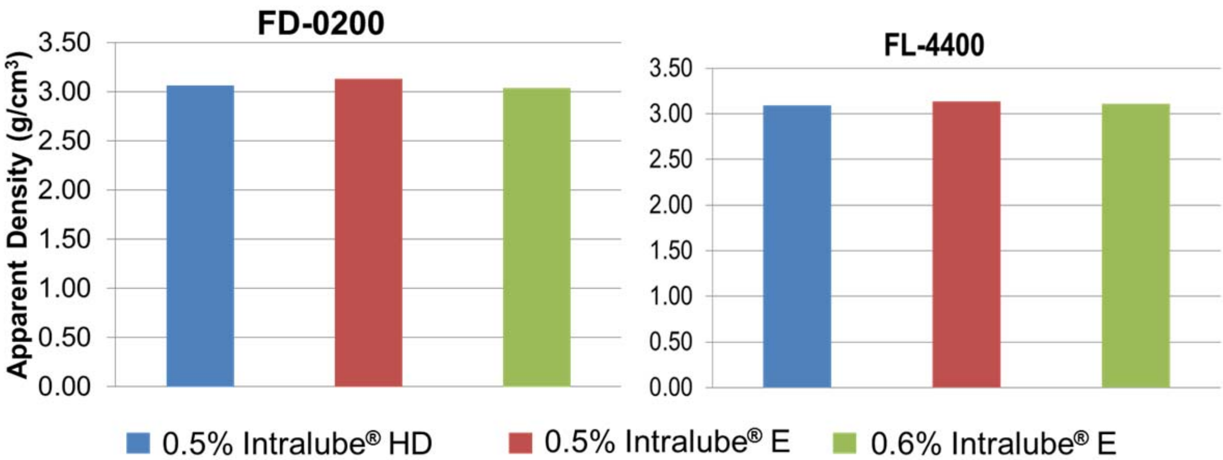

Figure 5: Apparent density of Intralube® HD mix verse Intralube® E mix

The flow of the mixes is shown in Figure 6. Powder flow was similar for all mixes.

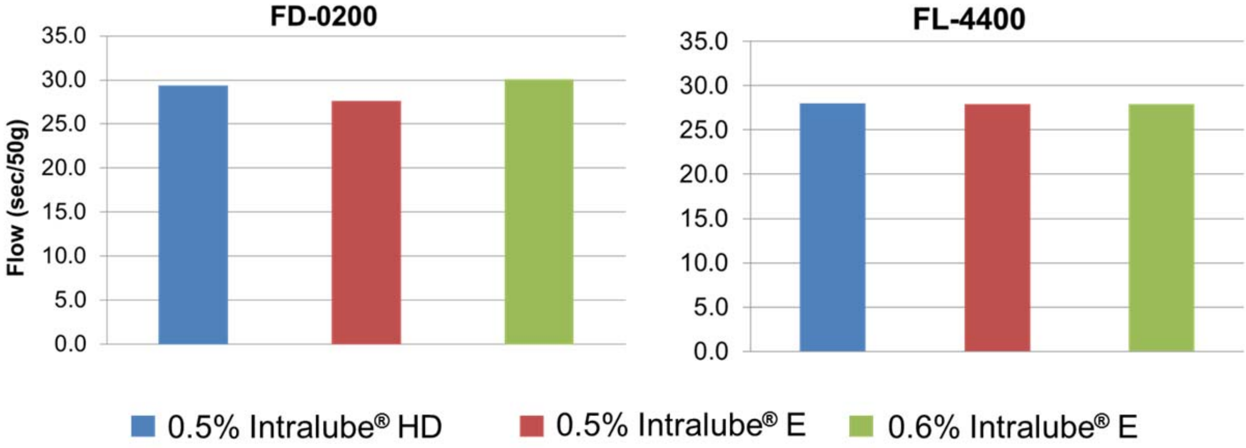

Figure 6: Flow of Intralube® HD mix verse Intralube® E mix

Figure 7 shows the compressibility of Intralube® HD compared to two different lubricant contents of Intralube® E. The Intralube® HD mix was compacted at 90 ºC (194 ºF) and the Intralube® E mixes were compacted at 60 ºC (140 ºF). The Intralube® HD mix shows that higher densities are achievable using the same lubricant content as the Intralube® E mix.

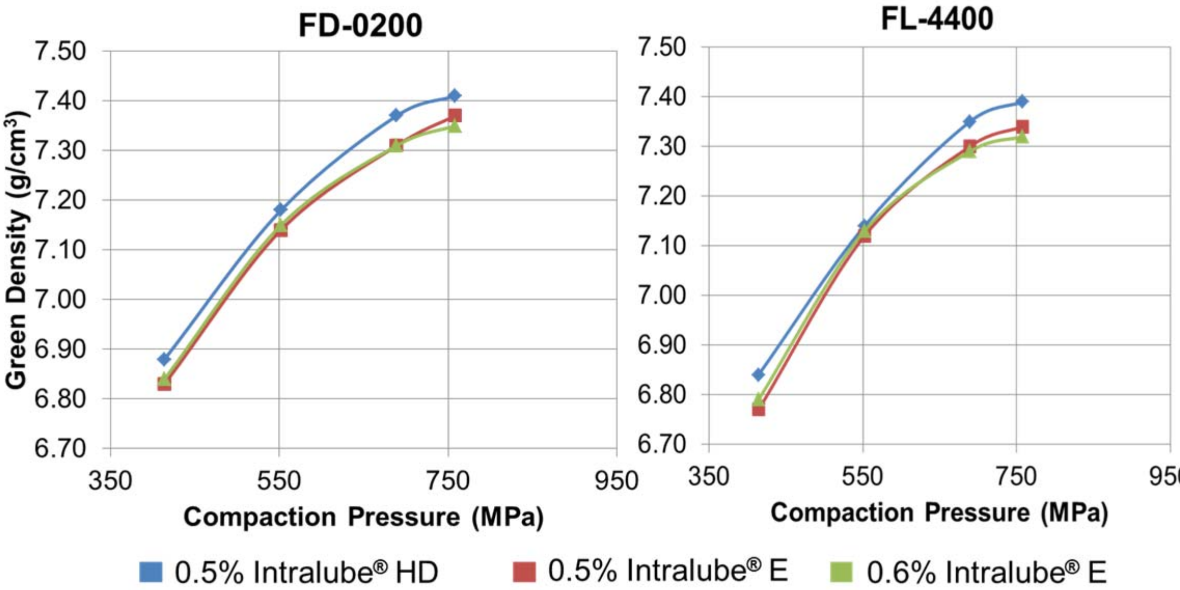

Figure 7: Compressibility curves of Intralube® E vs. Intralube® HD

Figure 8 shows the ejection properties at varying compaction pressures of Intralube® HD compared to two different lubricant contents of Intralube® E. The peak ejection forces of mixes containing a diffusion alloyed base iron as well as a prealloyed base iron were compared. The results show the Intralube® HD mix provides lower ejection forces compared to the Intralube® E mix with the same lubricant content. The Intralube® HD mix provides similar ejection forces to the mix that uses the higher 0.6% Intralube® E content.

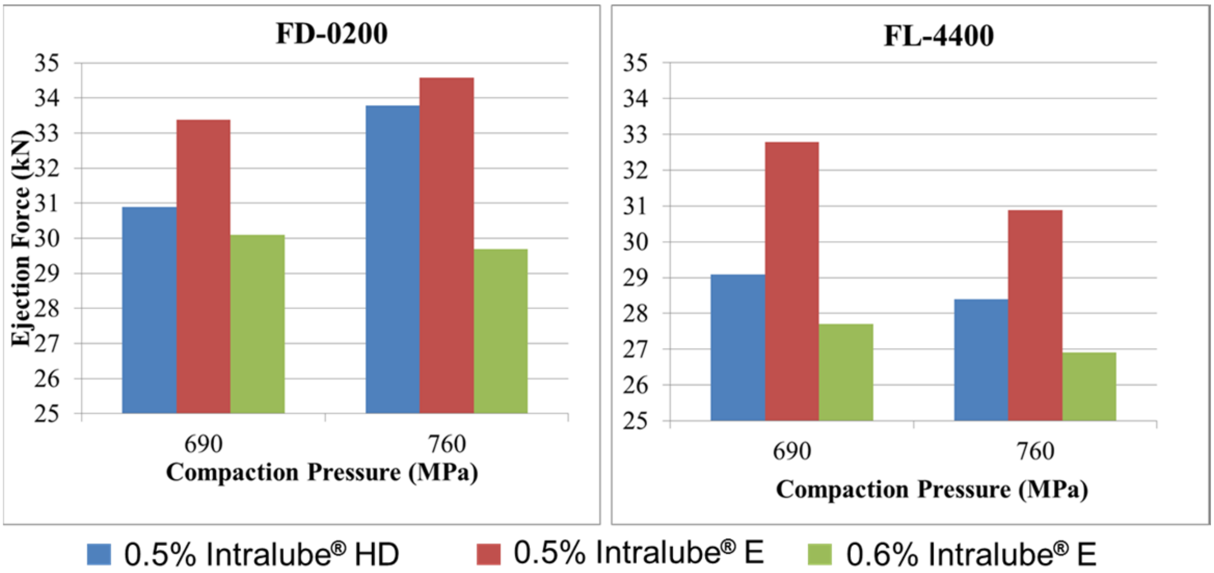

Figure 8: Ejection force properties of Intralube® E vs. Intralube® HD

The tensile strength of the mixes using both a diffusion alloyed base iron and a prealloyed base iron is shown in Figure 9, comparing Intralube® HD to two different levels of Intralube® E. The mixes containing Intralube® HD yield slightly higher tensile strength properties than the mixes using Intralube® E at both content levels at the same compaction pressure. The higher tensile properties of the Intralube® HD mixes are a result of achieving higher density at the same compaction pressure. The Intralube® HD mixes achieved green densities of 7.41 g/cm^3 and 7.39 g/cm^3 respectively, while the Intralube® E mixes with the same lubricant content reached densities of 7.37 g/cm^3 and 7.34 g/cm^3 respectively.

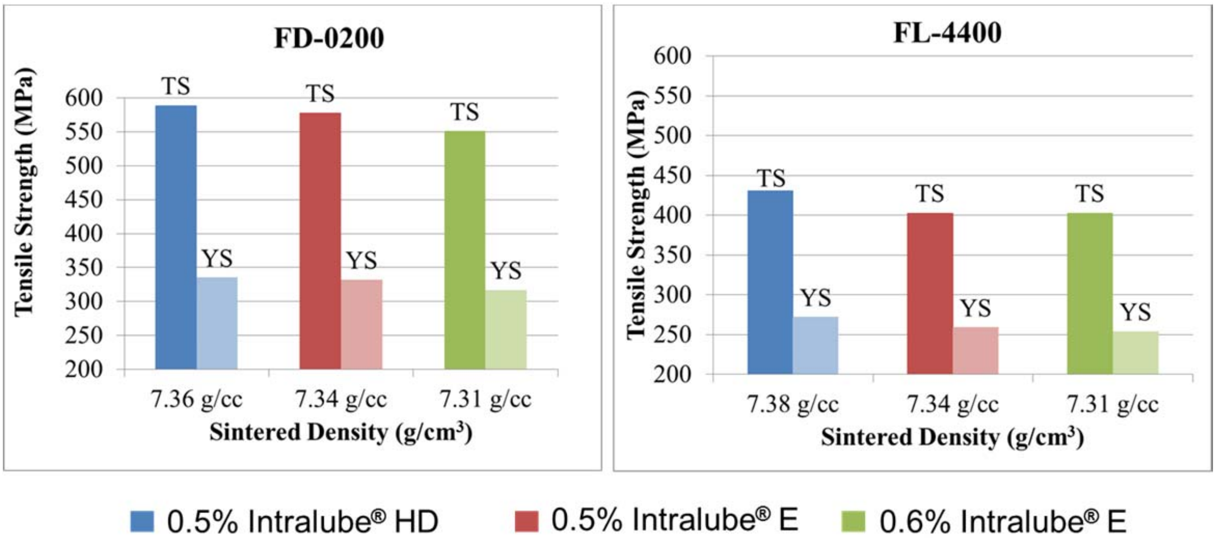

Figure 9: Tensile and yield strength properties of Intralube® E vs Intralube® HD at 750Mpa

The maximum height trials are depicted in Figure 10. The surface appearance of three cylinders manufactured from Intralube® E and Intralube® HD show the difference in performance of the two lubricants. For the Intralube® E mix, pucks could be compacted to a height of 40 mm and maintain a smooth and shiny surface without scoring. By increasing the height to 50 mm, scoring appeared on the bottom surface of the pucks. For the Intralube® HD mix, pucks could be compacted to a height of 50 mm and still maintain a smooth and shiny surface. The Intralube® HD mix proved to provide better lubrication at high compaction heights than the Intralube® E mix.

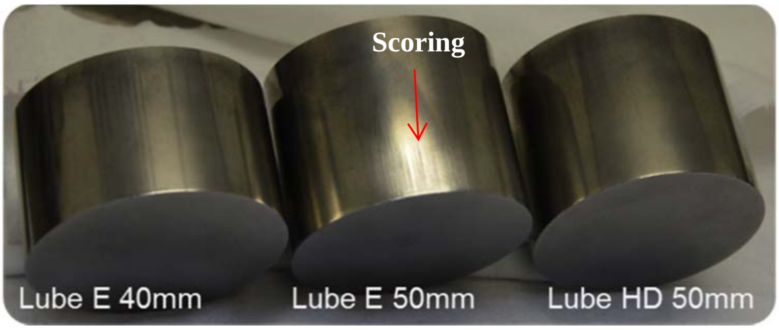

Figure 10: Maximum height test surface appearance of Intralube® E vs Intralube® HD

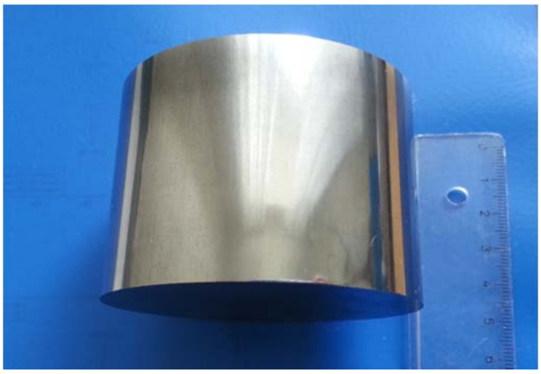

Figure 11: Compacted cylinder (64 mm diameter) of the mix D.AB + 0.5% Intralube® HD with a height of 50mm (part number 20).

Production Trial

The compressibility curve of the Intralube® E vs. Intralube® HD mixes is shown in Figure 12. The Intralube® HD mix compacted at 90 ºC (194 ºF) resulted in higher green densities at each compaction pressure than the Intralube® E mix compacted at 60 ºC (140 ºF).

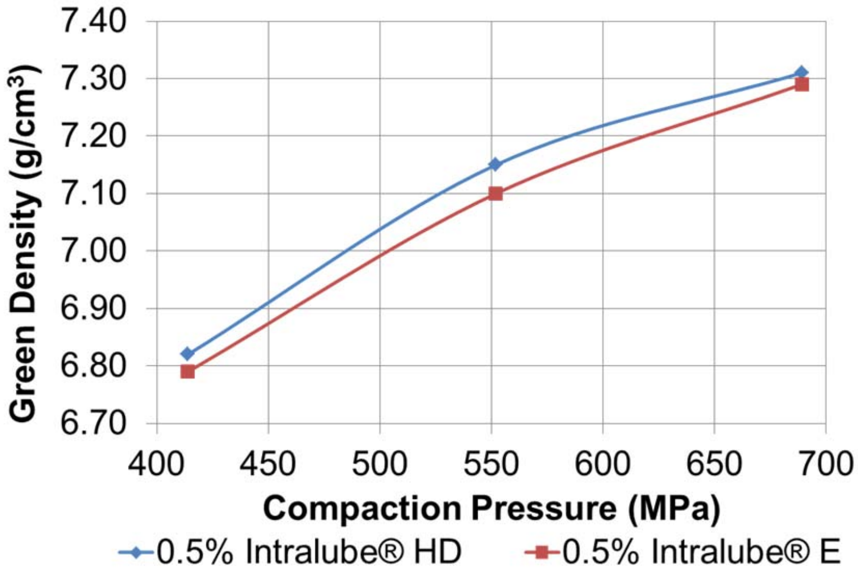

Figure 12: Compressibility Curve of FLN-4205 mixes with Intralube® HD and Intralube® E

Based off the tonnage monitor on the press while compacting the shift weights, the average compaction pressure was approximately 3 tons lower using the Intralube® HD mix than the Intralube® E mix while still achieving the same density. Figure 13 shows the difference in average tonnage of the Intralube® HD mix verse the Intralube® E mix when compacted to similar green densities.

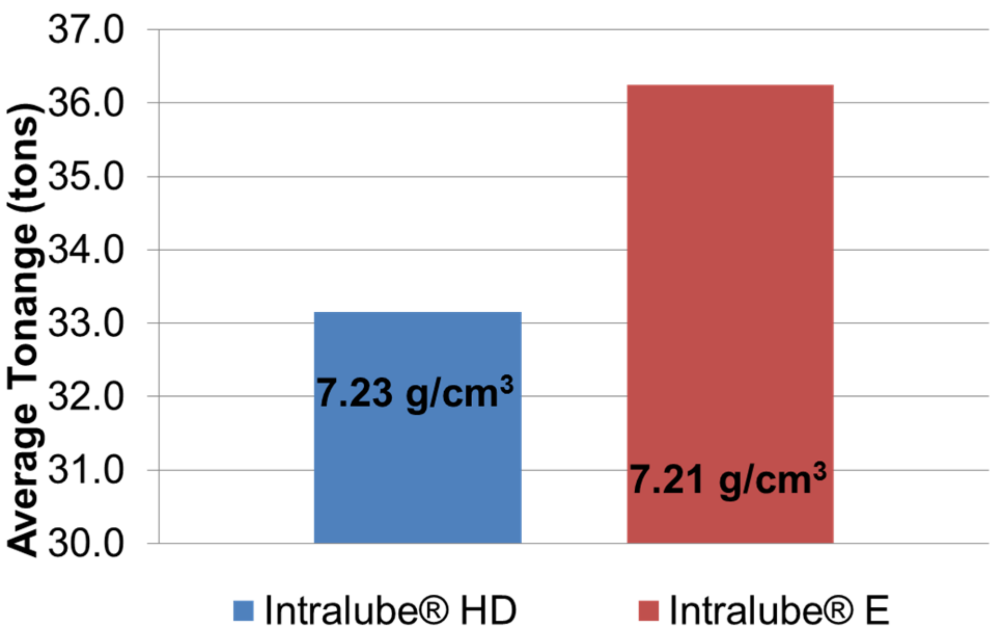

Figure 13: Average compaction tonnage at similar green densities

The components were weighed throughout the production run. The weight scatter was acceptable for both mixes. Ejection performance of the components was also acceptable for each mix. The microstructures of a component from each mix were evaluated and are shown in Figure 14. No differences in structure were seen between the Intralube® HD and Intralube® E mix.

Intralube® HD **Intralube® E**

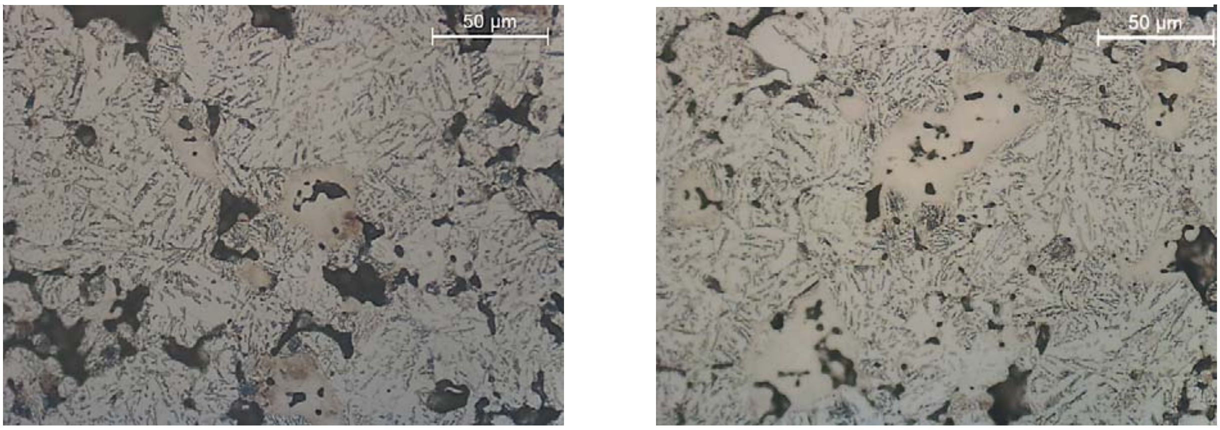

Figure 14: Microstructures of FLN-4205 shift weight components

Helical Gear Compaction Trial

Figure 15 shows the compressibility measured on the helical gears from each mix. The curve demonstrates that higher density is obtainable by using a lower content of the Intralube® HD lubricant system while utilizing a higher tool die temperature (90 ºC). The improvement in density achieved with the Intralube® HD mix verse the Intralube® E mix increases as the compaction pressure increases.

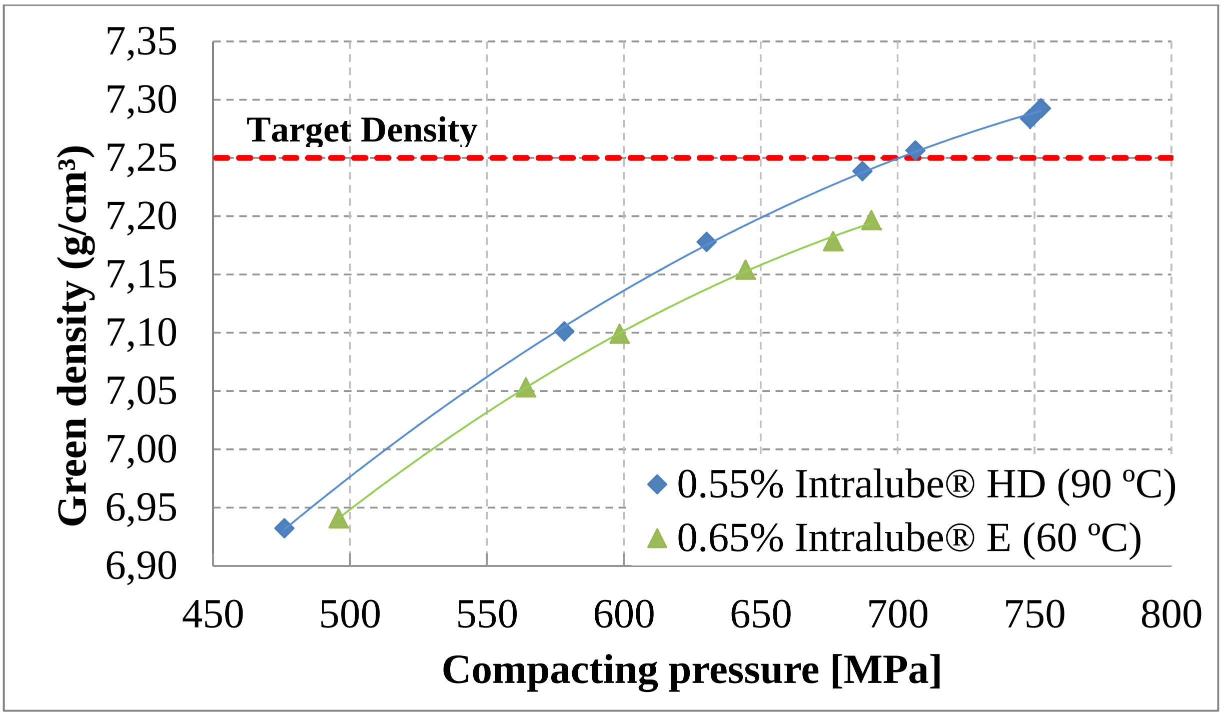

Figure 15: Helical gear compressibility curve

Green densities were evaluated on various sections of the gear. Slightly higher densities were observed in the upper half of the gear segments. Figure 16 depicts the approximate densities of each section.

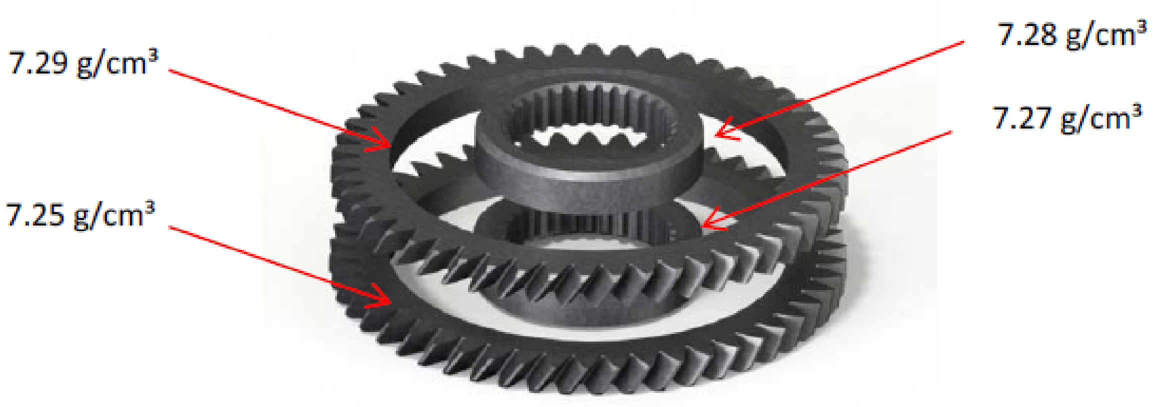

Figure 16: Sectioned density of helical gears

Figure 17 shows the results of a production run of 400 gears using the Intralube® HD mix. The gears were compacted at a constant compacting pressure of 750MPa. Gears were sampled throughout the run and evaluated for overall green density and part temperature. Figure 17-a shows the overall green density of the gears remained stable around 7.3 g/cm^3 throughout the run. Figure 17-b shows the temperature of the parts stabilized after 200 parts at 67 ºC. All gears exhibited a smooth and shiny surface condition.

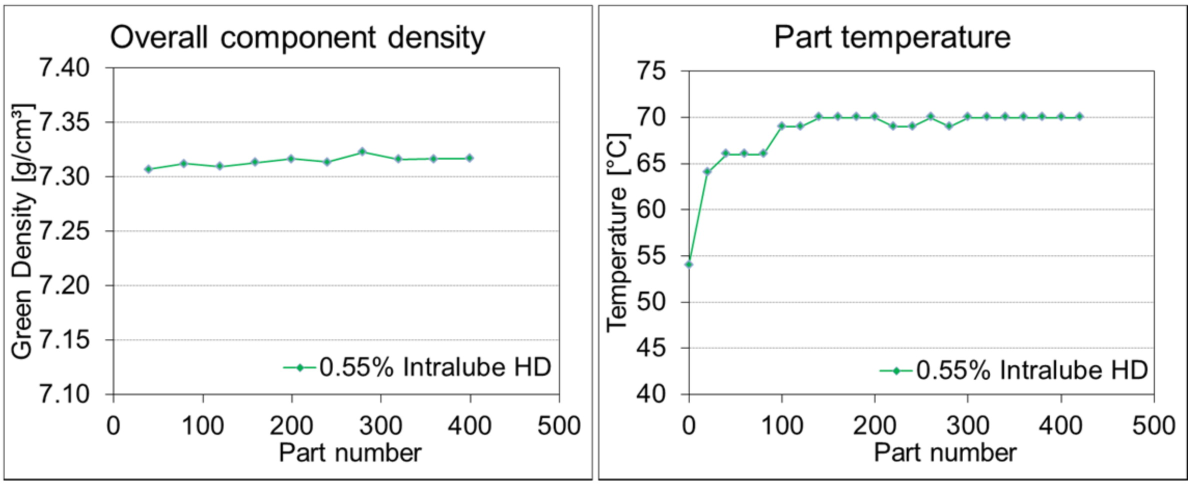

Figure 17: a.) Green density scatter of helical gears after ejection over 400 parts **b.)** Temperature scatter of helical gears after ejection over 400 parts

The gears were sectioned and the metallography of the teeth was evaluated. The pore structure of gear teeth compacted at three different heights is shown in Figure 18. A homogenous, high density pore structure is observed at all three heights. The density distribution was similar at each height.

Top Center Bottom

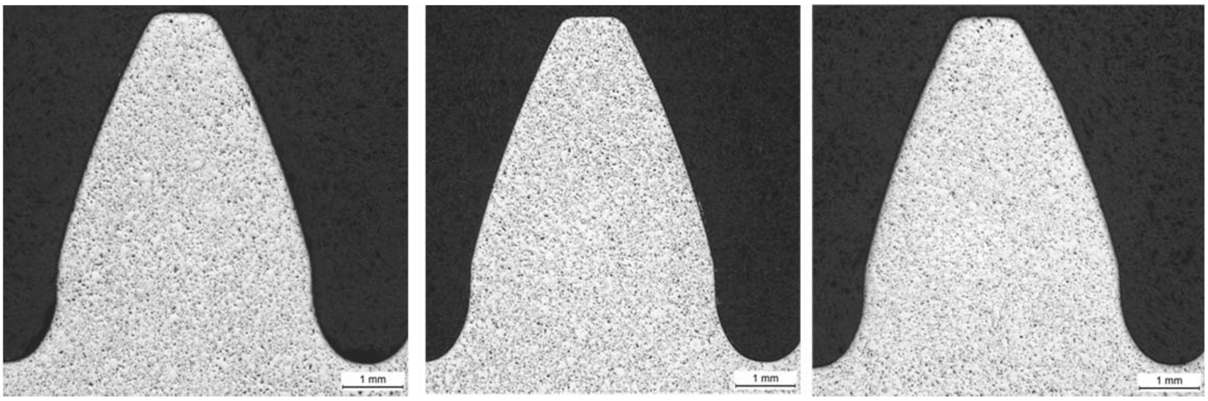

Figure 18: Horizontal cross section of helical gear tooth

CONCLUSION

- Powder properties of the Intralube® HD lubricant are similar to those of Intralube® E
- Mixes containing Intralube® HD have higher compressibility than mixes using Intralube® E Lower ejection forces were measured with the Intralube® HD mix. The Intralube® E mix showed scoring on pucks compacted to 50 mm. The Intralube® HD mix did not show scoring at 50 mm.
- The Intralube® HD mix allowed for a drop of 3 tons to achieve the same density of the Intralube® E mix when compacting shift weight components in a production environment
- Helical gears compacted using Intralube® HD consistently achieved a green density of 7.3 g/cm^3. Homogenous density distribution in the helical gear teeth was observed

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