Binder Treated Products for Higher Densities and Better Precision

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ABSTRACT

Continuing research in the chemistry of binders and lubricants yielded novel materials that combine traditional binder properties with improved lubricity and better dimensional control. New binder-lubricant systems were developed with lower organic content that made it possible to reach higher green and sintered densities and exceptional mechanical properties. Better powder flow and higher apparent density result in more uniform die fill, giving better weight and dimensional control and increased part precision. A comparison of the newly developed binder/lubricant system is made with traditional lubricants, such as EBS and zinc stearate.

INTRODUCTION

The quest for steady growth in the P/M industry requires the continuous development of new materials and new technologies that make it possible to create products with higher performance and better quality. Methods that can reach higher densities in a single compaction step are in the focus of attention. One such recent development is a proprietary binder/lubricant system, AncorMax D, that yields higher densities at 140°F to 160°F (60°C to 71°C) die temperatures without the need to preheat the iron powder. This paper discusses the physical and mechanical properties of this system in comparison to powder mixes with traditional P/M lubricants.

In order to achieve better physical and mechanical properties in P/M parts, higher green and sintered densities must be reached. Higher green densities can be reached by using higher compaction pressures and/or by using lubricant systems with better lubricity. Better internal lubricity results in denser compaction under the same compaction pressure.
while better lubricity between the die wall and the iron particles allows reduced friction during ejection.

In most applications only 98-99% of the pore free density can be reached even under the highest possible compaction pressures. Decreasing the amount of lighter additives, for example lubricant, in the iron mix increases the pore free density and makes it possible to reach higher densities.

Premixes that contain various ingredients in a broad range of particle sizes have a natural tendency to segregate during transportation and during the compaction process. This segregation can result in non-uniform material and density distribution in the pressed part. Application of a binder glues the smaller and larger particles together, preventing segregation and yielding better packing and homogeneity in the part and thus it provides higher density.\textsuperscript{1,2,3}

All organic additives that are present in a compressed part will burn off at the beginning of the sintering process, in the first segment of the sintering furnace. The completeness of this burn-off is an important factor in determining the final properties of the finished part.

Some P/M lubricants burn off incompletely, leaving behind soot, and in the case of zinc stearate or lithium stearate, some inorganic residues. These residues can weaken the sintered part by hindering more complete and uniform sintering of the iron particles and also may result in less favorable pore structure. The amount of residue depends on the type and amount of organic material present.

The recently developed binder/lubricant system exhibits better burn-off properties than some traditional P/M lubricants in that it decomposes faster and more completely. The organic content of this system is also lower than the level at which traditional lubricants are typically used, thus leaving behind less undesirable residue.

The new binder/lubricant system was evaluated on a production press for a part consisting of a segmented, fine tooth gear form on 1/3 of the profile with two core rods forming thin wall internal diameters.\textsuperscript{4} The nominal weight of the part was 48.72 grams and the nominal thickness was 0.666 in (16.9 mm). The production rate was the same as standard compaction rate and the green density target was 7.25 g/cm\textsuperscript{3} to 7.30 g/cm\textsuperscript{3}. The part weight was recorded 100\% sequentially after process stability was established. Part temperature reached a steady state shortly into the run and variation in temperature was less than 5°F (2.8°C). Capability analysis showed that both the weight (+/- 0.5\%) and the thickness (+/-0.6\%) exhibited a process capability (C\textsubscript{p} and C\textsubscript{pk}) greater than 2.0 indicating that the process was viable for production parts.
EXPERIMENTAL PROCEDURES

Materials

The testing was carried out on premixes made with Ancorsteel 85HP, a molybdenum prealloyed iron powder as the base material. This alloy was selected because of its good mechanical properties after sintering. Graphite (Asbury 3203) and nickel (INCO 123) were admixed together with ethylenebisstearamide (Acrawax C from Lonza) or zinc stearate (from Baerlocher USA) in the control mixes. The test mix contained the AncorMax D proprietary binder/lubricant system. The premixes were made as bottle mixes in the laboratory with compositions in Table I.

<table>
<thead>
<tr>
<th>TABLE I.: Composition of the Powders Evaluated</th>
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<tr>
<td><strong>Material</strong></td>
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<tr>
<td>Zinc stearate</td>
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<td>EBS</td>
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<td>MaxD</td>
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Processing

A Tinius-Olsen hydraulic press was used for pressing the parts with a heated die that maintained temperature at +/- 5°F (+/- 2.8°C). The tooling components were allowed to reach steady state temperature before compaction. Compaction of test samples was performed between 30 tsi and 60 tsi (414 MPa and 828 MPa) and between 75°F and 180°F (24°C and 82°C). After compaction the test specimens were sintered in a belt furnace at 2050°F (1121°C) for 30 minutes in a 75/25 v/o hydrogen/nitrogen atmosphere.

Testing

Green properties and ejection pressures were determined on test bars measuring 1.25 in (32 mm) x 0.5 in (13 mm) x 0.5 in (13 mm). Sintered properties were determined on test bars measuring 1.25 in (32 mm) x 0.5 in (13 mm) x 0.25 in (6 mm). The test specimens were evaluated according to industry standard test procedures.5
RESULTS AND DISCUSSION

Green Properties

Effect of Compaction Pressure

Green density and ejection pressure data as a function of compaction pressure exhibited differences between the three materials comprising either zinc stearate, EBS or MaxD. Figure 1 shows the green densities of the two premixes with 0.55% traditional P/M lubricants as well as the green density of the new binder/lubricant system with the same organic content. (It is worth noticing that traditional P/M lubricants are rarely used at this concentration level because of insufficient lubricity). The green density graph of 0.75% EBS premix is also shown for comparison. All specimens were pressed at 145°F (63°C) die temperature.

The density difference between the premixes with 0.55% traditional lubricant and the new binder/lubricant system is 0.03-0.05 g/cm³ at lower tonnages, but with increasing compaction pressure, the new binder/lubricant system yields 0.06-0.07 g/cm³ density improvement. The density gain becomes 0.10-0.12 g/cm³ when compared to the 0.75% EBS premix at or above 50 tsi (690 MPa). The green density of the 0.75% EBS premix is equal to or higher than that of the 0.55% lubricant premixes at 40 tsi (552 MPa) or lower compaction pressures. This is most likely the result of the effect of better lubricity provided by the higher lubricant concentration, that offsets the decrease in pore free density. This effect diminishes at higher compaction pressures and higher densities.

Figure 1: Effect of Compaction Pressure on Green Density
The slopes of the curves are similar at higher tonnages, indicating a limit to compressibility. Compressing at higher pressures may lead to lamination. In order to reach higher green densities we have to increase the pore free density of the system by further decreasing the concentrations of the lighter ingredients in the mixes, namely the lubricant and maybe the graphite content. This requires the development of more efficient lubricants.

Ejection properties of the three mixes with 0.55% lubricant were compared by measuring the sliding pressures during ejection. Sliding pressure is the force required to overcome dynamic friction during the ejection process, divided by the area of the test piece in contact with the die wall. Sliding pressures are shown in Figure 2.

![Figure 2: Effect of Compaction Pressure on Sliding Pressure](image)

At compaction pressures of 40 tsi (552 MPa) and above zinc stearate yielded 50-60% higher sliding pressures and EBS yielded 20-25% higher sliding pressures than the new binder/lubricant system, with the same total organic concentration. The importance of good lubricity and lower ejection pressure increases with the height and complexity of the part.

**Effect of Die Temperature**

The effect of changing the die temperature between 75°F (24°C) and 180°F (82°C) was studied on all three mixes at 50 tsi (690 MPa) compaction pressure. Green density and ejection pressure data as a function of die temperature exhibited differences between the
three materials. The green densities of the mixes increased gradually with increasing temperature, as shown in Figure 3. The new binder/lubricant system exhibited consistently higher green density than the traditional premixes.

Figure 3: Effect of Die Temperature on Green Density

Figure 4: Effect of Die Temperature on Sliding Pressure
Figure 4 shows the ejection data of the three mixes. The sliding pressure of the new binder/lubricant system showed steady decline with increasing temperature. The sliding pressures of zinc stearate and EBS did not change significantly with increasing die temperature. They were respectively 40% and 15% higher at room temperature and 80% and 60% higher at 180°F (82°C) than the sliding pressure for the new binder/lubricant system.

Sintered Properties

Figure 5 shows the sintered densities of the two premixes with 0.55% traditional P/M lubricants as well as the sintered density of the new binder/lubricant system with the same organic content. All specimens were sintered at 2050°F (1121°C) in a dissociated ammonia atmosphere (75/25 v/o hydrogen/nitrogen). The sintered density of the 0.75% EBS premix is shown for comparison. The improvement in green density carried over to the sintered density. The difference in sintered density between the premixes containing 0.55% traditional lubricant and the new binder/lubricant system is 0.06-0.07 g/cm³ at 30 tsi and 40 tsi (414 MPa and 552 MPa), but with increasing compaction pressure the new binder/lubricant system yields 0.08-0.09 g/cm³ sintered density improvement. The density improvement becomes 0.12-0.15 g/cm³ when compared to the 0.75% EBS premix at or above 50 tsi (690 MPa).

Figure 5: Effect of Compaction Pressure on Sintered Density
**Burn-off Properties**

The burn-off properties of the three lubricants (zinc stearate, EBS and MaxD) were compared by Thermal Gravimetric Analysis (TGA). Figures 6, 7 and 8 show the weight loss vs. temperature curves for the pure traditional lubricants and the new binder/lubricant system.

**Figure 6: Weight loss vs. Temperature for zinc stearate**

**Figure 7: Weight loss vs. Temperature for EBS**
Burn-off was monitored by heating the samples from room temperature to 1652°F (900°C) in a nitrogen atmosphere. The new binder/lubricant system started burning off earlier and finished faster than either zinc stearate or EBS. It reached completion by 750°F (400°C). It also left behind minimal residue, comparable to EBS, while zinc stearate left about 15% residue. Figure 9 shows the weight loss for the new binder/lubricant system in an iron mix.
Pore Structure

Pore shape and pore size distributions of the three mixes are provided in Figures 10 and 11.

Figure 10: Pore Shape Distribution

Figure 11: Pore Size Distribution
The shape factor, or circularity, indicates a degree of irregularity. It is calculated by the expression $4\pi A/P^2$, where $A$ is the area of the pore and $P$ is the circumference of the pore. A shape factor of 1 represents a circular pore. As the shape factor decreases, the degree of irregularity increases.\textsuperscript{6,7}

Sinter bars of the same density from the zinc stearate, EBS and MaxD containing mixes were compared and there was no significant difference found between them either in pore shape or pore size distribution.

**CONCLUSIONS**

1. The new binder/lubricant system provides a means of reaching 0.06-0.08 $g/cm^3$ higher densities than with traditional P/M lubricants at the same total organic content, at or above 50 tsi (690 MPa) compaction pressure, with the die temperature between 140°F to 180°F (60°C to 82°C).
2. The density increase is 0.10-0.15 $g/cm^3$ when compared to premixes with 0.75% lubricant concentration.
3. Ejection forces were reduced with the new binder/lubricant system by 10% to 50% over a broad range of compaction pressures and temperatures, and they decreased with increasing die temperature, up to 180°F (82°C).
4. Burn-off properties of the new binder/lubricant system are equal to or better than the burn-off properties of traditional P/M lubricants.
5. Pore shape and pore size distribution for the new system was found to be no different from the other lubricants.
6. The new binder/lubricant system is viable for the single step compaction of production parts to high densities, without the need to heat the powder.

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**REFERENCES**


