ABSTRACT

The recent introduction of a high-density lubricant system enables the processing of ferrous P/M components to up to 98% of pore-free density when using a heated compaction tool. This system, AncorMax D, uses proprietary lubricants that enable the total organic content of a P/M premix to be reduced while maintaining comparable ejection characteristics. This results in the ability to compact components to higher green densities (up to 7.40 g/cm$^3$) using higher compaction pressures. This paper outlines production experience using this advanced system.

INTRODUCTION

The creation of new products with better quality and higher performance through the development of new materials and technologies has made it possible for the P/M industry to achieve steady growth over the years. Especially important are processes and products that allow the manufacturer of P/M parts to reach higher green and sintered densities in a single press/single sinter operation.

A recent development in this area is a high density lubricant/binder system, AncorMax D, that can reach green densities up to 7.40 g/cm$^3$ at 140°F to 160°F (60°C to 71°C) die temperature and 50 tsi to 60 tsi (690 MPa to 830 MPa) compaction pressure [1, 2, 3]. Preheating the iron powder is not required with this technology. This technology allows for the reduction of organic material within the premix to increase the pore free density, but maintains a good level of lubrication. One limitation of the system is that it can be used on parts with overall lengths of about 0.75 in (19 mm). Improvements in the AncorMax D system have been developed that allows the processing of longer parts, up to 1 in to 1.25 in (25 mm to 32 mm) depending on the complexity of the part, with a lower total organic content (0.50 vs. 0.55 w/o). This paper discusses the physical and mechanical properties together with production experience using this advanced system.
EXPERIMENTAL PROCEDURES

Materials

The testing was carried out on FLN2-4405 premixes made with Ancorsteel 85HP*, a base iron prealloyed with 0.85 w/o Mo that was admixed with 0.6 w/o graphite (Asbury 3203) and 2.0 w/o nickel (INCO 123). Two test mixes were prepared, one with 0.5 w/o AncorMax D and one with 0.75 w/o EBS (Acrawax C). The mixes were made as 500 lbs (227 kg) mixes with compositions listed in Table I. Note that the AncorMax D mix is a fully bonded material, where the mix with EBS is a standard premix.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Base Material (w/o)</th>
<th>Elemental Additions (w/o)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe Mo</td>
<td>Ni Graphite Lube &amp; Binder</td>
</tr>
<tr>
<td>AncorMax D</td>
<td>Balance 0.85</td>
<td>2.00 0.60 0.50 w/o AncorMax D</td>
</tr>
<tr>
<td>EBS</td>
<td>Balance 0.85</td>
<td>2.00 0.60 0.75 w/o EBS</td>
</tr>
</tbody>
</table>

Testing

A Tinius-Olsen hydraulic press was used for pressing the compressibility samples with a heated die that maintained temperature at 145°F (63°C). Compaction of test samples was performed between 40 tsi and 60 tsi (550 MPa and 830 MPa). All testing was performed in accordance with MPIF standards [4].

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 carried out on standard transverse rupture samples (TRS) pressed as listed above. The samples were subsequently sintered at 2050°F (1120°C) in an atmosphere consisting of 90 v/o N₂ – 10 v/o H₂.

Production press trials were performed on a 220 ton Cincinnati mechanical compaction press. The die was preheated to 120°F (48°C). No powder heating was used. Bushings 1.5 in (38.1 mm) OD x 1.0 in (25.4 mm) ID were compacted to an overall length of 1.0 in (25.4 mm). Compaction was done at 55 tsi (760 MPa) and the press rate was 10 parts/min.

RESULTS AND DISCUSSION

Compressibility & Ejection Characteristics

Figure 1 shows a comparison of the compressibility of the two materials evaluated. Note that under the same pressing conditions the AncorMax D results in green densities that are 0.05-0.15 g/cm³ higher than the standard EBS premix. Also, note that the density

* Ancorsteel and AncorMax D are trademarks of Hoeganaes Corporation.
difference is more pronounced at higher compaction pressures. There is little benefit from the high-density lubricant binder system below 40 tsi (550 MPa).

![Graph showing compaction pressure vs. green density for AncorMax D and EBS](image)

Figure 1: Compressibility of FLN2-4405 with high-density lubricant/binder system and standard EBS premix. Compaction die preheated to 145°F (63°C).

In addition to the higher green density that is achieved, the high-density lubricant/binder system also has superior ejection characteristics. Table II show a comparison of green properties for both test materials compacted at over a range of densities. The data show that even with the higher density, the ejection pressures (Strip and Slide) are lower for the AncorMax D. One interesting feature of the high-density lubricant/binder system is that the sliding pressure decreases as compaction pressure goes up. This may explain the ability for density to keep rising without forming green cracks.

### TABLE II: Green Properties of Test Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Pressure (tsi)</th>
<th>Green Density (g/cm³)</th>
<th>Green Strength (psi)</th>
<th>Strip (psi)</th>
<th>Slide (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AncorMax D</td>
<td>40</td>
<td>650</td>
<td>7.13</td>
<td>1868</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>690</td>
<td>7.30</td>
<td>2300</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>760</td>
<td>7.34</td>
<td>2397</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>830</td>
<td>7.37</td>
<td>2397</td>
<td>16.5</td>
</tr>
<tr>
<td>EBS</td>
<td>40</td>
<td>550</td>
<td>7.08</td>
<td>2191</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>690</td>
<td>7.21</td>
<td>2349</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>760</td>
<td>7.24</td>
<td>2352</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>830</td>
<td>7.26</td>
<td>2347</td>
<td>16.2</td>
</tr>
</tbody>
</table>

**Sintered Properties**

The sintered density of FLN2-4405 with both lubricant systems is shown in figure 2. The presence of Ni in this alloy causes a net shrinkage during sintering and the density increases slightly. At the highest compaction pressure the sintered density reaches 7.40 g/cm³. The TRS increases with the higher density. Examination of figure 3 shows that TRS generally increases with density independent of lubricant system. It is also notable
that at 60 tsi (830 MPa) the strength of the 0.75 w/o EBS version drops. This is caused by laminations introduced from over compacting this material that has a higher organic content and a lower pore free density.

Figure 2: Sintered density of FLN2-4405 with high-density lubricant/binder system and standard EBS premix. Sintered at 2050°F (1120°C).

Figure 3: Transverse rupture strength (TRS) of FLN2-4405 with high-density lubricant/binder system and standard EBS premix. Sintered at 2050°F (1120°C).

Production Press Test Results

The mixes were evaluated on a Cincinnati 220 ton mechanical press by pressing 500 cylinders with 1.5 in OD and 1.0 in ID. The rings had an over all length (OAL) of 1 in. The die was preheated to 120°F (49°C) and the parts were pressed at 55 tsi (760 MPa) at 10 parts per minute rate. Weight was measured for every fifth part and surface temperature was measured for every fiftieth part. Figure 4 shows the weight variation for the modified AncorMax D mix and Figure 5 for the EBS mix.

The modified AncorMax D mix gave a slightly tighter weight control, with a standard deviation of 0.216 g versus 0.223 g for the Acrawax mix. Green densities were 7.24 g/cm³ versus 7.18 g/cm³ and sintered densities were 7.32 g/cm³ and 7.22 g/cm³ for the
two mixes respectively. The standard deviation between the measured density values was slightly lower for the high-density lubricant system.

![Figure 4](image1.png)

**Figure 4:** Weight variation of FLN2-4405 bushings using the AncorMax D system. Compaction die preheated to 120°F (49°C), compacted at 55 tsi (760 MPa).

![Figure 5](image2.png)

**Figure 5:** Weight variation of FLN2-4405 bushings using EBS. Compaction die preheated to 120°F (49°C), compacted at 55 tsi (760 MPa).

Ejection forces were virtually equal for both materials. Part surface temperatures varied between 148°F (64.4°C) and 156°F (68.9°C) for the AncorMax D and between 155°F (68.0°C) and 162°F (72.2°C) for the Acrawax mix. This difference in part surface temperature indicates lower ejection pressure and better lubricity for the test mix.
TABLE III: Green and Sintered Densities of FLN2-4405 Bushings
Compaction die preheated to 120°F (49°C), compacted at 55 tsi (760 MPa), Sintered at 2050°F (1120°C)

<table>
<thead>
<tr>
<th>Material</th>
<th>Green Density</th>
<th>Green Density Standard Deviation</th>
<th>Sintered Density</th>
<th>Sintered Density Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AncorMax D</td>
<td>7.24</td>
<td>0.006</td>
<td>7.32</td>
<td>0.005</td>
</tr>
<tr>
<td>EBS</td>
<td>7.18</td>
<td>0.008</td>
<td>7.22</td>
<td>0.007</td>
</tr>
</tbody>
</table>

The surface of bushings pressed using the high-density lubricant/binder system and 0.75 w/o EBS are shown in Figures 6 and 7, respectively. Comparison of the SEM micrographs show that the average pore size for the higher density compact is smaller than the EBS version, as expected. The number and severity of score marks present in the AncorMax D sample is less than in the EBS sample. The EBS part surface also has scale marks caused by a breakdown in lubricant. These defects are not present in the AncorMax D version. Overall, the surface quality is better for the high density lubricant/binder system.

Figure 6:
SEM photomicrograph of the surface finish of FLN2-4405 bushings using AncorMax D. Compaction die preheated to 120°F (49°C), compacted at 55 tsi (760 MPa), 10 parts/min.

Figure 7:
SEM photomicrograph of the surface finish of FLN2-4405 bushings using 0.75 w/o EBS. Compaction die preheated to 120°F (49°C), compacted at 55 tsi (760 MPa), 10 parts/min.
CONCLUSIONS

- When processed under the same compaction conditions, the AncorMax D produces a green density that is 0.05-0.15 g/cm$^3$ higher than a conventional EBS premix.
- The ejection pressures are lower for AncorMax D at 7.37 g/cm$^3$ than the EBS mix at 7.25 g/cm$^3$.
- The weight control and ejection characteristics of bushings prepared with both materials tested are similar, even with the significant difference in green density.
- The surface finish of samples pressed with the high-density lubricant/binder system contains less scoring and a lower degree of scale like defects than an EBS mix pressed under the same conditions.

REFERENCES