DEVELOPMENT OF ENHANCED GREEN STRENGTH LUBRICATING SYSTEMS FOR GREEN MACHINING

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ABSTRACT

P/M parts are often machined after sintering to meet tight dimensional tolerances or accommodate design features that cannot be formed during compaction. However, with the advent of high performance materials that exhibit high apparent hardness and strength after sintering, green machining becomes a very attractive process to reduce machining costs and promote competitiveness. Machining parts prior to sintering is now possible by using new lubricating systems containing polymeric lubricants that significantly enhance the strength of green parts as compared to conventional lubricants. The higher green strength reduces the risk of initiating green cracks and/or edge chipping during machining.

This study compares green and ejection characteristics of FLC-4608 sinter hardening materials pressed with either a new polymeric lubricating system or a conventional EBS wax lubricant. This comparison was carried out on TR specimens and oil pump gears pressed from 6.7 to 7.1 g/cm$^3$ on laboratory and production scale presses. Sintered properties of the oil pump gears and part-to-part consistency are also reported.

INTRODUCTION

The development of new techniques to enable machining of parts prior to sintering could be of great advantage to the P/M industry. Indeed, with the advent of high performance materials that exhibit high apparent hardness and strength, machining prior to sintering becomes a very attractive process to improve tool life, increase productivity and promote competitiveness [1]. Previous studies investigated the feasibility of green machining sinter hardening materials by either using warm compaction or double pressing-double sintering (DP/DS) processes. Although these technologies provide enough green strength to enable machining in the green state, they also require the use of sophisticated peripheral powder heating equipment or additional operations which increase production costs.

The development of new polymeric lubricating systems is a promising avenue to allow machining of parts in the green state without any change in the existing compacting technology [2-6]. The increase of green strength is mainly due to the higher intrinsic mechanical properties of the
polymeric lubricants as compared to standard lubricants such as synthetic wax and metallic stearates. Indeed, some of these polymeric lubricants may have the ability to form a strong network, more or less continuous, that strengthens the green specimens during compaction and/or by simply using a curing treatment in air at relatively low temperatures (175-200°C). Additionally, unlike conventional lubricants which tend to be distributed at the surface of metallic powders during the mixing step, polymeric lubricants most often have a lower deformability and remain as discrete particles. This can potentially favor the formation of interlocking or microwelding between the metal powder particles during the compaction step, and, therefore, increase the green strength [7].

However, previous studies have demonstrated that not all polymers exhibit adequate shear resistance as well as lubricating properties during compaction and ejection [2,3]. Indeed, when formulating a polymeric lubricating system, the selection of polymers have to take into account several characteristics such as the nature, structure, molecular weight, softening temperature and/or particle size to achieve a compromise between the compressibility and lubricating properties of the powder mixes, while maintaining a good surface finish of parts. For example, under specific conditions and for a given polymeric lubricant, an increase of the molecular weight may have a beneficial effect on the lubricating performance during ejection, but a too high molecular weight may also deteriorate the compressibility of mixes due to the lower deformability or the higher shear resistance of the polymer [2]. Additionally, the ability of some polymers to have adequate lubricating properties during either compaction or ejection may be attributed to the regular arrangement of macromolecular chains and their ability to slide over one another when submitted to a shear stress as well as their affinity with metallic substrates. Indeed, it has been observed that polymeric lubricants should possess adequate wetting, adsorbing and adhering properties with the metallic powders and die cavity to form a lubricating film and reduce the shear stress during compaction and ejection of parts [3].

The purpose of this work is to compare the green properties and lubrication behavior of a sinter hardening material containing a newly developed polymeric lubricating system to those of powder admixed with conventional EBS lubricant on laboratory and production presses. Sintered properties of production parts and part-to-part consistency are also presented in this study.

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials

The materials investigated were FLC-4608 sinter hardening mixes containing either a new binder-lubricant system (BM system) or a conventional EBS wax. The mixes were prepared from a pre-alloyed steel powder ATOMET 4601 admixed with 2.5wt% copper, 0.9wt% graphite as well as either 0.65 or 0.75wt% of the respective lubricating system. Details of these systems are given in Table 1.

<table>
<thead>
<tr>
<th>Type of Mix</th>
<th>Lubricating System</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM system</td>
<td>0.65 wt% lubricants + binder</td>
</tr>
<tr>
<td>EBS reference</td>
<td>0.75 wt% EBS wax lubricant (atomized)</td>
</tr>
</tbody>
</table>
**Laboratory Scale Evaluation**

Green properties and lubrication behavior of the two materials were first compared using a laboratory hydraulic press at different compacting temperatures and green densities. These properties were evaluated by compacting 0.64 cm (¼ in) and 1.27 cm (½ in) thick standard transverse rupture (TR) specimens respectively. The die set was heated to reach either 45, 50 or 55°C during the experiments to simulate the frictional heat generated during typical compacting conditions on production presses. The mixes were pressed to reach green densities of 6.7, 7.0 and 7.1 g/cm³. Several specimens pressed with the new BM system to 7.0 g/cm³ (45°C) were also cured in air at 175°C for 1 hour. Details of the compacting conditions are listed in Table 2.

The ejection properties were evaluated using an automatic data acquisition system. The force required to eject the TR specimens was measured throughout the ejection step. By dividing the ejection load by the area of the compact in contact with die walls, it was possible to determine the stripping and sliding pressures needed to eject the specimens. The stripping pressure corresponds to the shearing stress required to initiate the ejection, while the sliding pressure represents the mean stress needed to move parts to the die entrance. Green strength was evaluated according to the MPIF standard test procedure N°15.

**Production Scale Evaluation**

A total of 500 oil pump gears (∼165 g) were produced on a 200 ton Yoshizuka mechanical press from each material at a green density of either 6.8 or 7.0 g/cm³ to compare green and sintered properties on a production scale.

The oil pump gears had an outer diameter of 3.8 cm (1.5 in) as well as an overall height (OAH) of 4.1 cm (1.6 in) with a bore of 1.3 cm (0.5 in). An illustration of this part is shown in Figure 1. The mechanical press was set to produce either 7 or 11 oil pump gears per minute. The temperature of the die set when starting the production run was at ~60-65°C. Details of the compacting conditions are given in Table 2. The temperature of parts was measured with a contact probe immediately at the exit of the die cavity at a frequency of once every 50 parts. The applied tonnage was also recorded during the production run. The press was not adjusted during the production runs of both materials.

Figure 1. Illustration of the oil pump gear
The green density and the load required to rupture the as-compacted gears (crush load) containing the new BM system were compared to those of gears made from the EBS containing mix. This comparison was done by sampling even numbered parts at a frequency of 5 every 25 parts. Several gears pressed to either 6.8 or 7.0 g/cm\(^3\) with the new BM system were also submitted to a curing treatment in air at either 175°C or 200°C for 1 hour and compared to as-compacted gears produced from the same mix. The as-compacted and cured gears were crushed with the device shown in Figure 2.

All odd numbered parts pressed to 6.8 g/cm\(^3\) (7 strokes/min) and 7.0 g/cm\(^3\) (11 strokes/min) were sintered for 30 min at 1120°C (2050°F) with a cooling rate of 1.4°C/s (2.5°F) in a production mesh belt furnace kept under a rich endogas atmosphere. The sintered properties, relative lubricant weight loss (\(WL_{\text{lub}} / \%\)lubricant) and part-to-part variations (sintered density, dimensional change, apparent hardness) after sintering were evaluated for both systems at a frequency of 10 every 50 parts. The D.C. was evaluated by measuring the bore of the oil pump gears using a coordinate measuring machine (CMM; Brown&Shape MicroVal). The part-to-part variation was determined by considering both the standard variation (\(\bar{X} \pm 3\sigma\)) and the variation on the maximum range (max-min). Statistical analysis was done on parts produced under constant compacting conditions, i.e. by sampling parts No.150 to 500.

**TABLE 2**

<table>
<thead>
<tr>
<th>Type of Part</th>
<th>Type of Mix</th>
<th>Green Density, g/cm(^3)</th>
<th>Die Set Temp., °C</th>
<th>Strokes per min</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR bar</td>
<td>BM</td>
<td>6.7</td>
<td>45-50-55</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.1</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EBS</td>
<td>6.7</td>
<td>45-50-55</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil Pump Gear</td>
<td>BM</td>
<td>6.8</td>
<td>60*</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0</td>
<td>60-65*</td>
<td>7-11</td>
</tr>
<tr>
<td></td>
<td>EBS</td>
<td>6.8</td>
<td>60*</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0</td>
<td>65*</td>
<td>11</td>
</tr>
</tbody>
</table>

* temperature when starting the production run
RESULTS AND DISCUSSION

The BM system is a new high green strength (HGS) material with no zinc content that was developed to enhance the green strength and enable the machining of parts in the green condition. The performance of this system was evaluated against a conventional EBS lubricant on laboratory and production scales in conditions that simulated most production applications in terms of compacting temperature, green density and sintering conditions.

Laboratory Scale Evaluation

Compaction and Lubrication Behavior

Figure 3 presents the compressibility of mixes containing either the new BM system or the EBS wax measured on TR specimens compacted on a laboratory press at 55°C. The effect of the compacting temperature on the applied pressure to reach 6.7 and 7.1 g/cm³ is also given in Figure 4.

It is seen that the compressibility of mixes with the BM lubricating system is noticeably better compared to that of the EBS containing mix. For example, the compacting pressure required to reach 6.7 g/cm³ is about 21 MPa (1.5 tsi) lower with the BM system and this difference tends to significantly enlarge as the green density increases to 7.0 and 7.1 g/cm³ at a compacting temperature of 55°C. Indeed, the compacting pressure required to reach these green densities is respectively 40 MPa (2.9 tsi) and 90 MPa (6.5 tsi) MPa lower when using the new BM system. It is worth mentioning that similar differences in compressibility were also noticed at lower compacting temperatures, as shown Figure 4. Indeed, the differences in compressibility between BM and EBS systems at 45 and 50°C remain relatively the same as when using a compacting temperature of 55°C for specimens pressed to green densities of 6.7 and 7.0 g/cm³.

Figure 3. Compressibility of FLC-4608 mixes containing the BM system or EBS wax at 55°C.
With regards to the ejection performance, it is seen in Figures 5a and 5b that the new BM system exhibits excellent lubricating properties even if the amount of organic compounds in this system is reduced from 0.75 to 0.65 wt% as compared to the EBS containing mix. Indeed, the stripping pressure (shearing stress to start the ejection) is significantly reduced when using the BM system (Figure 5a) and this is even more pronounced as the compacting temperature increases from 45 to 55°C. For example, the stripping pressure of 1.27 cm (½ in) thick TRS bars made from the new BM system is about 7 to 10% lower than with the EBS mix at any green density between 6.7 and 7.1 g/cm³ at 45°C and 19 to 24% lower at 55°C. The sliding pressure is equivalent for both the BM and EBS lubricating systems regardless of the green density and compacting temperature, as shown in Figure 5b.

The good compressibility and excellent lubricating performance achieved with the new BM system can be related to the low shear resistance during compaction along with superior lubricating properties of the polymers used in this system compared to the conventional EBS wax. Indeed, the polymers included in the BM system have

Figure 4. Compacting pressure required to press TR specimens with the BM system or EBS wax to 6.7 and 7.0 g/cm³ as a function of the compacting temperature.

Figure 5. Stripping and sliding pressures required to eject 1.27 cm (½ in) thick TR specimens made with the BM system or EBS wax and pressed at various temperatures.
the ability to form an adhering discontinuous lubricating film at the surface of powder particles and die walls, which consequently lower the friction between these metallic substrates and facilitates compaction and ejection of parts.

Green Strength

Figure 6 compares the green strength of specimens made from mixes with BM and EBS lubricating systems as a function of green density and compacting temperature. It is obvious that, whatever the green density, the strength values of TR bars compacted from the BM system containing mix are significantly higher than those obtained with the EBS containing mix. This is even more pronounced as the compacting temperature increases from 45 to 55°C. The green strength of BM specimens is 16 to 24% higher than that of EBS specimens at 45°C, while this difference noticeably increases as the compacting temperature rises from 45 to 55°C. For example, the green strength of BM specimens reaches 19, 27 and 30 MPa (2800, 3985 and 4305 psi) at 6.7, 7.0 and 7.1 g/cm$^3$ respectively when using a compacting temperature of 55°C. These values are 75 to 78% higher than those of specimens compacted with the EBS wax at the same compacting temperature. It is noteworthy that a temperature of 55°C is usually attained in most production applications due to the frictional heat generated during compaction and ejection of parts.

The increase in green strength as compared to the EBS lubricant may be explained by different phenomena, as shown in Figure 7. In particular, the higher green strength can be related to the formation of interlocking or microwelding between the steel particles due to the lower distribution of the polymeric lubricant at the surface of metallic powders during mixing. Indeed, contrary to EBS lubricant, polymers comprised in the BM system do not tend to form a continuous film at the surface of metal particles during mixing. Besides, it is also believed that there is formation of strong and adhering polymeric bridges between the steel particles when
compacting specimens with the BM system, which certainly further strengthen the green specimens. An illustration of these polymeric bridges is given in Figure 8. Indeed, the polymers included in the new BM system are very strong and also have the ability to interact strongly with the steel powder particles as compared to the conventional wax lubricant. It is noteworthy that the level of interaction between the polymer and metallic surfaces would be even more pronounced as the compacting temperature increases, particularly when the polymers sufficiently deform and/or partially soften, as strongly suggests the large improvement in green strength from 45 and 55°C when using the BM system (Figure 7).

Figure 7. Green strength of FLC-4806 TR specimens pressed from mixes with the BM system and the EBS wax as a function of the compacting temperature.

Figure 8. Illustration of polymeric bridges between the steel powder particles pressed with the BM system.
Should an application require a green strength significantly higher than those reported previously, it is possible to further increase the strength of green parts made from powder mixes containing the BM system by a simple curing treatment. For instance, green strength values of 48 MPa (7000 psi) are reached with specimens pressed to 7.0 g/cm$^3$ by simply using a curing treatment in air at 175$^\circ$C for 1 hour. This is more than twice as high as that obtained with the EBS mix, as seen in Figure 9. This high green strength is mainly explained by the ability of the polymeric lubricant comprised in the BM system to flow through the porosity during the curing treatment and to create a strong continuous polymeric network that strengthens the green specimens, as illustrated in Figure 10.

Figure 9. Effect of the curing treatment on green strength of FLC-4608 TR specimens pressed from mixes with the BM system and comparison with the EBS reference at 7.0 g/cm$^3$ (55$^\circ$C).

Figure 10. Illustration of the thin network of lubricant throughout cured TR specimens pressed from mixes with the BM system.
It appears that the green strength achieved in the as-pressed condition (55°C) with the BM system will be adequate for most green machining operations. Indeed, it was already demonstrated that parts with green strength approaching 21 MPa (3000 psi) can be successfully green machined when using suitable machining parameters and tool geometry [8]. However, for very demanding machining operation, the BM system also offers the possibility of further increasing the green strength of parts by simply using a curing treatment in air at a relatively low temperature (175°C).

Production Scale Evaluation

Several oil pump gears were also produced to compare the BM system with the conventional EBS wax during compaction and sintering on a production scale. These parts were pressed to green densities of 6.8 and 7.0 g/cm³ at either 7 or 11 strokes/min with compacting temperatures in the range of 70 to 80°C, due to the frictional heat generated during the production trials.

Compaction Behavior and Green Strength of As-Compacted and Cured Gears

The production scale evaluation confirmed the capability of the new BM system of producing parts on a production press and also enhancing the green strength in a relatively wide range of compacting conditions.

In particular, it appears in Figure 11 that the BM system exhibits a similar compressibility to that with the EBS containing mix, regardless of the green density and number of parts produced per minute. The compressibility of the BM mix was not affected by increasing the rate of production from 7 to 11 strokes/min.

Additionally, it is seen in Figure 12 that the BM oil pump gears display a better green strength than those pressed with the conventional EBS wax, independently of the green density and the rate of compaction. For example, the crush load to rupture the BM parts reaches 2033 and 2220 N (457 and 499 lbf) at 6.8 and 7.0 g/cm³ (7 strokes/min) respectively, with only slight impact of the compaction rate from 7 to 11 strokes/min, as seen in the diagrams.
Figure 12. Hence, the green strength obtained with the BM system is as mush as 58 to 70% higher than that of parts pressed with the EBS wax in the same compacting conditions. It should be noted that this improvement in green strength is only slightly lower than with TR bars pressed at the same green density, i.e. 70 vs. 77% at 7.0 g/cm$^3$. This small difference could be related to the different modes of rupture to break laboratory specimens and production parts. Indeed, the TR bars were broken using a 3-points bending fixture, while the gears were partially supported by the teeth during the crush load measurement, as shown in Figure 2.

The green strength of oil pump gears pressed to 6.8 and 7.0 g/cm$^3$ was significantly increased by a simple curing treatment in air at 175°C for 1 hour, as shown in Figure 13. Increasing the curing temperature to 200°C only slightly further enhances this property. For example, the crush load increased by about 50 and 60% at 6.8 and 7.0 g/cm$^3$ respectively when curing specimens at 175°C and only improved by less than 5% at 200°C. This large improvement in green strength is mainly due to the formation of a skeleton of polymer, as previously shown in Figure 10 for cured lab specimens.

![Figure 13. Effect of the curing treatment on the crush load required to rupture oil pump gears pressed with the BM system to different green densities.](image)

Sintered Properties and Part-to-Part Consistency

The sintered properties and part-to-part consistency are also very important properties to consider when developing a new lubricating system. Some lubricating systems can provide good green properties and ejection performance, but in some cases, their use can also strongly affect the performance of a powder mix during compaction and sintering on a production scale. In particular, most common problems that might appear are the part-to-part weight and density variations of green and sintered parts due to some flow problem occurring during compaction and/or due to incomplete decomposition of the lubricating system during sintering. Improper de-lubrication can also reduce the level of densification and sintered strength, affect the D.C. and deteriorate the surface finish of parts after sintering.
Sintered properties and part-to-part variations after sintering (sintered density, dimensional change, apparent hardness) of the oil pump gears pressed with the BM system are compared to those with EBS wax in Table 3. This comparison was performed on parts pressed to different conditions, i.e. 6.8 (7 strokes/min) and 7.0 g/cm$^3$ (11 strokes/min).

It is seen that the sintered density, dimensional change and apparent hardness of BM parts are either quite similar or slightly better than those obtained with the conventional EBS wax. For example, the sintered density is 0.01 to 0.02 g/cm$^3$ higher with the new BM system for the green parts pressed to 6.8 and 7.0 g/cm$^3$. The D.C.$\text{Bore}$ of the oil pump is also relatively the same for both materials pressed to 6.8 g/cm$^3$, while this part section shrink 0.07% more with the new BM system at 7.0 g/cm$^3$. The apparent hardness remains within 35-37 and 34-36 HRC for the BM and EBS parts respectively. Finally, it is worth mentioning that the relative lubricant weight loss during sintering was equivalent for both materials (Figure 14), which is a good indication, together with the higher level of densification and the good surface finish of the sintered parts, that the new BM system decomposed cleanly during sintering.

Regarding the part-to-part variations, it is quite clear, based on statistical data reported in Table 3, that the two lubricating systems performed similarly in the conditions tested in this study. Indeed, the standard deviation ($3\sigma$) and maximum range (max-min) related to the sintered density and apparent hardness are similar for both lubricating systems, regardless of the compacting conditions (i.e. $F_{0.95,49,49} = (\sigma_{BM})^2/(\sigma_{EBS})^2$ lower than 1.61). Additionally, it appears in Figure 15 that the $3\sigma$-standard deviation on the D.C.$\text{Bore}$ is equivalent and the variation tighter with the new BM system. Hence, these results clearly demonstrate the clean burn-off of the new BM system during sintering and also confirm the excellent stability of this system on a production press.

![Figure 14. Relative lubricant weight loss (WL$\text{lub}$ / %lub) during sintering for BM and EBS oil pump gears pressed to different green densities.](image-url)
### TABLE 3
Sintered Properties of Oil Pump Gears Pressed with the BM System and EBS wax using Different Compacting Conditions

<table>
<thead>
<tr>
<th>SINTERED PROPERTY</th>
<th>STATISTICAL ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BM system</td>
</tr>
<tr>
<td></td>
<td>6.8 g/cm³</td>
</tr>
<tr>
<td></td>
<td>7 strokes/min</td>
</tr>
<tr>
<td>Sintered Density, g/cm³</td>
<td></td>
</tr>
<tr>
<td>Average (X̄)</td>
<td>6.765</td>
</tr>
<tr>
<td>Std Dev (3σ)</td>
<td>0.024</td>
</tr>
<tr>
<td>Relative Std Dev (3σ/X̄)</td>
<td>0.35%</td>
</tr>
<tr>
<td>Range (max-min)</td>
<td>0.039</td>
</tr>
<tr>
<td>Relative Range</td>
<td>0.58%</td>
</tr>
<tr>
<td>D.C.-bare, % from die size</td>
<td></td>
</tr>
<tr>
<td>Average (X̄)</td>
<td>-0.120</td>
</tr>
<tr>
<td>Std Dev (3σ)</td>
<td>0.087</td>
</tr>
<tr>
<td>Range (max-min)</td>
<td>0.109</td>
</tr>
<tr>
<td>Apparent Hardness, HRC</td>
<td></td>
</tr>
<tr>
<td>Average (X̄)</td>
<td>35</td>
</tr>
<tr>
<td>Std Dev (3σ)</td>
<td>5</td>
</tr>
<tr>
<td>Range (max-min)</td>
<td>5</td>
</tr>
</tbody>
</table>

* Δ between systems considered significant only if $F_{0.95,49,49} = (σ_{BM})^2/(σ_{EBS})^2$ higher than 1.61

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**Figure 15.** D.C.-bare variation of parts pressed with the BM system and the EBS reference to 7.0 g/cm³ at 11 stokes/min.
CONCLUSIONS

This study was undertaken to evaluate the feasibility of using a new polymeric lubricating system to increase green strength of a FLC-4608 sinter hardening material and enable machining operations in the green condition. This new system was compared to a conventional EBS lubricant during compaction and sintering on a laboratory and production basis. The most relevant conclusions that can be drawn are as follows:

- Mixes containing the new lubricating BM system exhibited better compressibility and lubrication behavior than those containing conventional EBS wax for TR bars pressed in various compacting conditions (6.7 to 7.1 g/cm$^3$ at 45°C to 55°C). The compressibility of the BM mix was also similar to that of the EBS wax when compacting oil pump gears on a production scale using different conditions, i.e. 6.8-7.0 g/cm$^3$ at 7 or 11 strokes/min.

- The green strength obtained with the newly developed polymeric lubricating system was significantly higher than that of a conventional EBS wax lubricant. Results obtained on a laboratory press demonstrated that the improvement was even more pronounced when the compacting temperature was raised from 45 to 55°C. The green strengths of BM specimens pressed to 6.7 to 7.1 g/cm$^3$ were 16 to 24% higher than EBS specimens at 45°C and 75 to 78% higher at 55°C. Green strengths reached 19, 27 and 30 MPa (2800, 3985 and 4305 psi) at 6.7, 7.0 and 7.1 g/cm$^3$ respectively when using a compacting temperature of 55°C. These results were also confirmed with oil pump gears produced on a production scale at 7.0 g/cm$^3$ and 11 strokes/min. The crush loads required to rupture these parts were about 70% higher with the BM system than with EBS wax.

- The green strength of BM parts also further improved with a simple curing treatment in air at 175°C for 1 h. This property enhanced by 75% and 60% for lab specimens pressed to a green density of 7.0 g/cm$^3$ (48 MPa /7000 psi) and oil pump gears pressed at 7.0 g/cm$^3$ and 11 strokes/min respectively.

- The sintered properties and part-to-part consistency (sintered density, dimensional change, apparent hardness) of the oil pump gears produced with the new BM system were similar to those obtained with the conventional EBS lubricant. The new BM system also cleanly decomposed during sintering.

REFERENCES


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