TRIBOLOGICAL PROPERTIES OF LUBRICANTS USED IN PM PROCESS
Naghi Solimanjad, Mats Larsson
Höganäs AB
Research & Development
SE-263 83 Höganäs / Sweden
E-mail: naghi.solimanjad@hoganas.com
Tel:+46 42 33 87 44
Fax: +46 42 33 81 88

ABSTRACT
This study is a step towards developing a means for predicting the performance of solid powder lubricant used in P/M process. Lubricant is an indispensable part of the P/M process. Lubricants are often used admixed with metal powders in order to reduce adhesion and friction between powder particles and between powder and the die-wall during the filling, compaction and the ejection process. The lubricants are often solid organic substances such as metallic stearates and amide wax. During compaction and ejection of a component the lubricant is exposed to high pressure and high shear stress. Experiments have been performed to evaluate tribological properties of lubricants from different aspects under such conditions. A powder friction-measuring device (PFMD) has been used to evaluate the friction of the powder die-wall contact. Results obtained from friction measurements using PFMD are shown to correlate well with the results from real pressing process. This paper will describe the performance of lubricants including Amide wax, Kenolube and Zinc stearate regarding friction properties.
1. INTRODUCTION
1.1 The lubrication system
The behaviour of lubricants during powder metallurgy processing is not fully understood since, among other things, it is difficult to observe formation of the lubricant film during the tests. In P/M, the lubricants are exposed to a high local pressure, either between the particles or in the contact between the particles and the die wall.

The primary difficulty with solids as lubricant generally is their re-supply. Fluids flow into the contact area but solid must be placed there. Thus the first step in the solid lubricant process is the formation of a thin film on the contact surface preferably on both surfaces. In P/M process this step is the most critical. However when a film has been created between the contact surfaces the sliding then takes place either between the films or between the substrate and the film. Generally the formation of the film from powders appears to depend on the roughness of the surfaces, the adhesion of the film to the substrate, and the sintering capabilities of the lubricant powder. Sintering here means changes of the lubricant from loose powder to a solid cohesive material due to the pressure.

In P/M process lubricants are usually used as an additive in the mixtures in order to reduce the friction, both internally between powder particles and also between powder compacts and the die-wall.

Thomas et al.\(^1\) showed that the solid lubricants stop to function in powder compaction within temperature close to the melting point of the lubricant. Thus the solid film is effective as long as it remains solid or acts as a solid and it loses its functionality when it melts.

The formation of the film at the die-wall surface and/or the compact surface is a complicated process. The lubricant is sometimes assumes to migrate to the die-wall surface, due to the difference in pressure, and form a lubrication film. But this assumption that lubricant can pass through the barrier of the deformed particles, unless there is an open porosity, the whole way to the die-wall seems far-fetched.

However some particles of lubricants are trapped in between the surfaces, and probably form a lubricant film, which does not cover the whole contact surface. Therefore the lubrication is most probably due to lubricant particles, which are in direct contact with the wall or are located close to the die-wall. These particles are smearing on the die-wall surface and form a kind of lubricant film, which is not uniform or continuous. Thus, the nature of lubrication in powder die-wall contact is a kind of mixed lubrication, where the solid contacts between unprotected metal surfaces, could lead to a cycle of adhesion, wear particle formation and even seizure.

The experimental measurement of friction in powder mixes has received increasing interest during the last years\(^2\)-\(^8\). In contrary to this has solid powder lubricant used in P/M process not been thoroughly investigated. There is still a lack of knowledge on solid powder lubricant in operating conditions as P/M process. Theoretical and experimental studies of solid powder lubricant for other application areas have been investigated by others\(^9\)-\(^11\).

In order to characterise the tribological properties of the solid powder lubricants Mellander et al.\(^12\) have been used pin-on-disc apparatus. However the common tribological test methods are not totally convenient for these kinds of lubricants due to the difficulty of forming a well-defined lubricant film on the test surface. In this paper some experiments have been performed in order to characterise the powder lubricants used in PM process. This study clearly illustrates the significance of the lubricant type.
2 EXPERIMENTAL SET UP

2.1 The experimental facility
The Powder Friction Measuring Device (PFMD) has been used for direct measurement of the coefficient of friction. Principal function of the device is shown in Fig.1. The device was designed utilizing the principle of the common uniaxial press. The cavity is filled with the sample (powder) and a pressure is applied by a punch. The position of the punch is kept constant at the end of compaction and die rotation is started. The friction is then measured between a rotating surface (powder compact surface) and a fixed surface (the punch surface). The forces are measured using strain gauges mounted on the punch. In this way the frictional shear stress can be measured and the coefficient of friction can be determined. The surface roughness, $R_a$, of the punch surface (the surface in contact with the powder during the test, which simulate the die-wall in this case) is 0.04 $\mu$m. A more detailed description of this device is given in\textsuperscript{6-7}.

![Diagram of PFMD](image)

**Fig 1:** The figure above illustrates the rotating die and the normal force ($F_N$) applied on the powder compact by the punch.

2.2 Experiment procedure
Powder forming process includes two main steps, powder pressing and ejection of the component. The focus of this paper will be on parameters influencing the ejection process. The first experiment is performed using PFMD at the stage when the powder mixes are compacted to some desired density/pressure. At this stage the powder compact (the die) rotates with a defined velocity, 8 mm/s in this experiment, against the punch surface, a solid surface that here simulates the die-wall. The normal force is kept constant by the punch and the friction coefficient is measured in the same way as when two solid surfaces are sliding against each other.
The frictional behaviour of the lubricant in contact between the die-wall and the compact is studied in a second experiment. In this experiment a thin lubricant film is manually deposited onto a porous surface (surface of a pre-compacted ring, (Fig 2) inside the cavity). The thin lubricant film is then sheared at a constant shear rate and a constant normal pressure. Thus, the tribological performance of the lubricant is studied at condition similar to a real P/M contact surface.

Fig 2: Porous surface for experiments with thin lubricant film

Experiments have also been carried out using an instrumented 120-ton hydraulic press where the ejection force acting on the compact and ejection energy can be measured as a function of the displacement. Rings Ø 55/45 has been compacted. Materials used for the experiments include atomised powder ASC100.29 mixed with graphite C-UF4 and three different kind of commonly used lubricants. The compositions of the mixes are according to the table 1. In addition to the test of powder mixes pure lubricants (table 2) have also been subjected for tribological test.

### Table 1

<table>
<thead>
<tr>
<th>Powder mix</th>
<th>Apparent density [g/cc]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC100.29+0,5%C+0,8% Kenolube™</td>
<td>3,21</td>
</tr>
<tr>
<td>ASC100.29+0,5%C+0,8% Zinc stearate</td>
<td>3,26</td>
</tr>
<tr>
<td>ASC100.29+0,5%C+0,8% Amide wax</td>
<td>3,14</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Lubricants</th>
<th>Particle size [x50µm]</th>
<th>Melting point [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenolube™</td>
<td>21</td>
<td>70-135 (interval)</td>
</tr>
<tr>
<td>Zinc stearate</td>
<td>3-5</td>
<td>123</td>
</tr>
<tr>
<td>Amide wax</td>
<td>8-12</td>
<td>145</td>
</tr>
</tbody>
</table>
3. RESULTS AND DISCUSSION

3.1 Results from Powder Friction Measuring Device

Results from PFMD for powder mixes is shown in Fig 3. This experiment is performed at a constant normal pressure of 250 MPa, which corresponds to the radial pressure experienced during compaction of the P/M parts. The shear stress at constant shear rate and the normal pressure are measured. The coefficient of friction is determined by using $\mu = \tau / p$ where $\tau$ is the shear stress (shear strength) and $p$ is the normal stress. The results distinguish clearly the effect of different lubricant in the powder mixes. Kenolube™ reduces the friction more than the other lubricants used in this experiment and in that range of pressure.

![Graph showing friction coefficient vs. sliding distance](image)

**Fig 3:** Result of powder mixes (ASC 100.29, 0.5% C, 0.8% lubricant), at 250 MPa normal pressure and 8 mm/s sliding velocity

Experiments with the deposition of the powder lubricants on the pre-compacted surface are performed using also PFMD. The most important issue in this experiment is to ensure whether the sliding occurs at the interface between tool and the lubricant or inside the lubricant. Here the actual sliding is in the interface between the metal surface and the lubricant. This can be observed directly after the tests from the surface of the samples. Fig. 4 shows the results from the experiments with a thin lubricant film on a porous surface. These results correlate well with the result for powder mixes Fig 3. Kenolube™ lubricant shows lowest coefficient of friction compare to the others. The increase/decrease of the friction coefficient after some sliding distance is believed to be due to the temperature rise and other tribological phenomena.
3.2 Result from instrumented press

One of the significant aspects of a good lubrication in P/M is the dependency of ejection properties on the height of the parts, high/long and thin parts have frequently been observed to be difficult to produce without surface defects.

The aspect ratio H/D is an essential parameter in powder compaction. Where H is the height of the component after ejection and D is the thickness.

Besides the H/D ratio there are other parameters that should be investigated in order to study the lubrication performance of the powder components. Some of these observations that can provide useful information are ejection force and ejection energy, which can easily be measured. Kinetic ejection force development as an important parameter in evaluation of the lubricant has been suggested by Katsuhiko et al.\textsuperscript{13}.

An illustrative example of a typical diagram for ejection of components is shown below. Static and dynamic friction forces are shown as point (a) respective (b). Ejection energy is defined as the area under the ejection curve.

Fig. 5: Ejection force and definition of static (a) and dynamic (b) friction
In order to study and to quantify the differences between two lubricants one should use the output parameters as ejection force and energy in correlation with the aspect ration H/D. These parameters provide a good indication about how effective the lubricants are during the ejection.

Powder mixes according to table 1 have been used for this experiment. Fig 6a shows the ejection energy as a function of the applied pressure. The powder mix with Kenolube shows the lowest energy. The difference between lubricants is even higher at higher pressure.

Figure 6: Ejection energy (Ee) as a function of compaction pressure (a) and aspect ratio (b)

The ejection energy as a function of the aspect ratio at 600 MPa compaction pressure is shown in Fig 6b. By increasing the aspect ratio the difference between lubricants becomes more clear.

The static and dynamic friction as a function of the aspect ratio has also been studied. The static friction is a measure of the frictional force that resists ejection. It is dependent on the residual stress of the green compact and also influenced by the increase of the normal stress due to the applied ejection force. If the adhesion between the green compact and the die-wall
is larger than the cohesive forces between the powder particles some particles can be detached from the compact and become trapped between the surfaces and damage the component. The differences in static friction between the lubricants shown in Fig. 7a are not significant in this experiment. Zinc stearate has similar static friction as the others. However zinc stearate shows higher dynamic friction. One explanation for this behaviour of Zinc stearate could be the poor adhesion of this material to the surfaces. The dynamic friction as a function of aspect ratio for all three mixes is shown in Fig. 7b.

**Fig 7.** Static (a) and dynamic (b) frictional forces measurement during ejection of the components

The history of the compaction and the lubrication is of particular importance for a successful ejection. As has been mentioned the powder lubricant can be smeared against the die wall and partly cover the surfaces in contact. This occurs near the end of the compaction process, which means that at the top of the die there will be very little lubricant. However some of the lubricant can be transfer to the top of the die by the component during the ejection. Experience show that ejection of the parts is always more difficult in the beginning and become easier after ejection of few parts.
4. CONCLUDING REMARKS
The study was undertaken to evaluate the feasibility of using a new method to characterise the
tribological properties of powder mixes and also solid powder lubricants used in P/M process.
The method allows evaluation of the powder materials in condition similar to the P/M
process. The most relevant conclusion are summarised as follows:

- PFMD can be used to evaluate the tribological behaviour of solid powder lubricants.
The most important advantage compared to the conventional tribological methods is
that the powder lubricants are tested at similar condition as in the P/M process. Both
powder mixes and pure powder lubricants can be subjected for tests in the PFMD.
- Results obtained from friction measurements using PFMD correlate well with the
results from real pressing process.
- There is no significant difference between lubricants used in this experiment regarding
to the static friction. The main differences are due to the kinetic friction of the
lubricants that leads to lower ejection energy.
- At higher pressures/densities the differences between lubricants become clearer.

5. REFERENCES
[1] Y. Thomas, S. Pelletier and J.M. McCall, "Effect of Temperature on the Behaviour of
Lubricants during Powder Compaction" Powder Metallurgy, vol. 43, no 2, pp.139-142,
2000.


Shear Plate Technique” Powder Metallurgy, 45, pp.345-353, 2002.


