Frictional Characteristics of Mineral Oils in Sheet Metal Drawing

(2nd Report, Effects of Additives and Metal)

By Nozomu Kawai**, Kazuyoshi Kondo***, Isao Shimizu****, and Tamotsu Nakamura*

In this report, effects of oiliness improvers and extreme pressure additives on frictional characteristics are examined. Moreover, effects of metal are examined also by changing the sheet metal from aluminium to mild steel.

The following has been concluded.

(1) Lubricity of oiliness improvers is better than that of extreme pressure additives under such conditions of low sliding velocity and low surface pressure as used in this test.

(2) Aromatic compound contained in base oils acts as a sort of inhibitor against effects of oiliness improvers and extreme pressure additives.

(3) Lubricity of oiliness improvers and extreme pressure additives is excellent when added to a light oil refined highly.

(4) Frictional characteristics of mineral oils and additives found in cases of using an aluminium sheet hold all good for cases of using a steel sheet.

1. Introduction

In the previous report(5), the lubricating properties of the paraffin base oils and the naphthene base oils have been examined on the blank-holder surface in aluminium sheet drawing. As the result, lubricity of aromatic compound and oxygen dissolved in rich amount in low viscous oils has been confirmed. In this report, effects of various additives are examined, based on an understanding of the lubricating properties of the base oils. Moreover, the results obtained using an aluminium sheet are compared with those obtained using a steel sheet.

2. Effects of additives

Additives used commercially to improve the boundary lubricating properties may be usually classified into two large groups of oiliness improvers and extreme pressure additives. Moreover, the former may be classified into kinds of fatty acid, ester and alcohol, and the latter into kinds of phosphor, sulfur and chlorine, as shown in Table 1.

In this experiment, the additives shown in Table 1 are tested by using an aluminium sheet first.

2.1 Case of addition to liquid paraffin

Effects of both the additives are examined by adding them to the liquid paraffin L2 which contains little aromatic compound and sulfur component as shown in Table 2 of the 1st report. Figures 1 (case of oiliness improvers) and Fig. 2 (case of extreme pressure additives) show the variation of the friction coefficients during the process. After addition of the additives, the friction coefficient of L2 drops remarkably and keeps approximately constant during the process. That is, the friction coefficient at the stage of maximum punching force is 0.3 in case of L2. But, it drops to 0.15 after addition of fatty acid or ester and to 0.13 after addition of alcohol. And, it drops to 0.18 after addition of phosphide, sulfide and chlorine. Moreover, it drops to 0.05~0.10 in cases of segregation (cases of adding stearic acid or dibenzyl disulfide by 5%) or gelation (case of adding cetyl alcohol by 5%) occurring.

Figure 3 shows a relation between the contact ratio $R$ and the friction resistance $F$, at the stage of maximum punching force. The solid lines entered
in this figure mean that \( \tau_f \) is constant along them. The value of \( \tau_f \) is about 0.25 kg/mm² in case of the oiliness improvers and 0.30 kg/mm² in case of the extreme pressure additives. The lubricity of the oiliness improvers is better than that of the extreme pressure additives.

The additives influence strongly on appearance of the friction surface of metal. Figure 4 shows surface appearances of metal in cases lubrication by (a) the liquid paraffin L2, (b) L2 to which butyl stearate has been added by 1 wt% and (c) L2 to which chlorinated paraffin has been added.

Fig. 1 Effect of oiliness improvers

Fig. 2 Effect of extreme pressure additives

Fig. 3 Effect of additives on friction shear stress

Table 1 Classification and constitutional formula of additives

<table>
<thead>
<tr>
<th>Additives</th>
<th>Constitutional formula</th>
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<tbody>
<tr>
<td>Rapeseed oil</td>
<td>( \text{CH}_2\text{OOCR} )</td>
</tr>
<tr>
<td>Butyl stearate</td>
<td>( \text{CH}_3\text{OOCR} )</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>( \text{CH}_3\text{COOH} )</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>( \text{CH}_3(\text{CH}_2)\text{CH}==\text{CH}(\text{CH}_2)\text{COOH} )</td>
</tr>
<tr>
<td>Cetyl alcohol</td>
<td>( \text{CH}_3(\text{CH}_2)\text{CH}_2\text{OH} )</td>
</tr>
<tr>
<td>Oleyl alcohol</td>
<td>( \text{CH}_3(\text{CH}_2)\text{CH}==\text{CH}(\text{CH}_2)\text{CH}_2\text{OH} )</td>
</tr>
<tr>
<td>Sulfurized fatty oil</td>
<td>Sulfide of fatty oil</td>
</tr>
<tr>
<td>Tricresyl phosphate</td>
<td>( \text{CH}_3)</td>
</tr>
<tr>
<td>Tributyl phosphate</td>
<td>( \text{CH}_3)</td>
</tr>
<tr>
<td>Dibenzyl disulfide</td>
<td>( \text{CH}_2\text{S} \text{S} \text{CH}_2 )</td>
</tr>
<tr>
<td>Zinc-diaryl dithio phsphate</td>
<td>( \text{RO} = \text{S} \text{P} = \text{S} = \text{P} \text{OR} )</td>
</tr>
<tr>
<td>Chlorinated paraffin</td>
<td>( \text{Cl}\text{O},\text{Cl}\text{H}_3\text{COOCH} ) (5 Cl per 1 mol)</td>
</tr>
<tr>
<td>Pentachloro methylstearate</td>
<td></td>
</tr>
</tbody>
</table>
by 1 wt%. The streaks observed in case of the liquid paraffin L2 disappear almost after addition of the additives. This lowers the values of $\tau_f$, of course.

2-2 Effects of components contained in base oils

In order to examine the effects of components contained in base oils on action of the additives, the liquid paraffin L2, the paraffin base oil P2 and the naphthenic base oil N2, to which the various additives have been added by 1 wt% respectively, are tested. Figure 5 shows a relation between the friction coefficients of the base oils and the added oils.

The following are found from this figure.

(1) The additives are scarcely effective when added to N2, effective when added to P2 and very effective when added to L2.

(2) The oiliness improvers and the extreme pressure additives do not make difference in the lubricity when added to N2, but the oiliness improvers are more excellent than the extreme pressure additives in the lubricity when added to P2 or L2.

These results may be explained as follows, although they are too difficult to fully understand.

The surface streaks produced when lubricated by L2 are eliminated remarkably by adding the additives to it as shown in Fig. 4, and those in case of P2 are eliminated also by adding the additives to it although the improvement is less. But, the surface appearance in case of N2 does not almost change when the additives are added to it, because the surface streaks does not appear when lubricated by N2 as shown in Fig. 11 of the 1st report. Such elimination of the streaks lowers the friction shear stress of course, and this in turn lowers the friction coefficient also.

Thus, the lubricity of base oil itself has remarkable influences on action of the additives. The difference observed among the lubricities of the base oils used must be due to the contents of aromatic compounds, as confirmed in the 1st report. Then, the effect of aromatic compound on action of the additives is examined. Figure 6 shows that the effect of chlorinated paraffin on the friction coefficient does not arise and that of butyl stearate is reduced by half by existence of aromatic compound. It is thinkable that the effect of the oiliness improvers is disturbed by competitive adhesion with aromatic compound. Meanwhile, the effect of the extreme pressure additives seems to be hindered by the fact that aromatic compound eliminates local temperature rise due to adhesion necessary for reaction of extreme pressure additives.

Consequently, the aromatic compound contained in base oils acts as a sort of inhibitor against the action of oiliness improvers and extreme pressure additives. This fact is confirmed also in case of thrust bearing where lubricity of additives is more excellent when those are added to light oils refined highly.

2-3 Effects of viscosity of base oils

In order to examine effects of viscosity of base oils on action of the additives, some additives

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(a) Liquid paraffin L2  
Aluminium sheet  
Flange rim portion in rolling direction at the stage of maximum punching force  
Fig. 4 Effect of additives on surface appearance
were tested by adding them by 1 wt% to three kinds of the liquid paraffins (L1, L2 and L3 shown in Table 2 of the 1st report) which contain no aromatic compound and little sulfur component. Figure 7 shows the friction coefficient \( \mu \), the contact ratio \( R \) and the friction shear stress \( \tau_f \) of the added paraffins measured at the stage of maximum punching force according to the viscosity of the liquid paraffins. The value of \( \tau_f \) decreases with a lowering viscosity of the liquid paraffin. The friction shear stress \( \tau_f \) in case of adding the oiliness improvers is smaller than in case of the extreme pressure additives. When the additives are added to L1 and L2, the contact ratio \( R \) becomes larger than that of the liquid paraffins itself in spite of no variation in the viscosity due to adding the additives. This remains unexplained up to the present time.

Meanwhile, the contact ratio decreases when segregation (cases of adding stearic acid or dibenzyl disulfide by 5%) and gelation (case of adding cetyl alcohol by 5%) take place, as shown in Fig. 3. In such cases where the viscosity increases after addition of the additives, the contact ratio decreases naturally. In any case, Fig. 7 shows that the values of \( R \) are almost independent of kind of the additives and decrease with an increasing viscosity of the base oils. The friction coefficient becomes minimum in cases where the additives are added to L2, because it is proportional to the product of \( \tau_f \) and \( R \).

Consideration is next made of the fact that the additives present better lubricity when added to base oil of lower viscosity.

In case of the oiliness improvers, it may be explained by the fact that oxygen required for the reaction is dissolved in rich amount in low viscous oils. In order to confirm this, the values of \( \tau_f \),
of the liquid paraffins containing 1 wt % butyl stearate of oiliness improver are compared with those of the ones deaerated in Fig. 8. Figure 8 shows that the increase of $\tau_f$ due to the deaeration treatment is larger when added to low viscous oils and lower when added to L3. Figure 9 shows the effect of the deaeration treatment on the friction coefficient.

The cases of the extreme pressure additives will be explained next. Figure 10 shows appearances of the metal surface lubricated by three kinds of liquid paraffins. The streaks ought to appear severely when lubricated by low viscous oils, but in case of L1, they appear only a little by action of oxygen dissolved in rich amount in it. Therefore, the streaks are most severe when lubricated by L2. It is found from Fig. 7 that the value of $\tau_f$ in case of L2 drops most remarkably when adding the extreme pressure additives to it. This is due to the fact that the effect of the extreme pressure additive is displayed most remarkably in case where the streaks appear most severely.

Thus, the effects of the viscosity of base oil on the action of the additives are influenced notably by oxygen dissolved in rich amount in low viscous oil. Consequently, it is concluded that both the

![Figure 8: Effect of dissolved oxygen on action of oiliness improver](image1)

![Figure 9: Effect of dissolved oxygen on action of oiliness improver](image2)

![Figure 10: Surface appearance in case of applying liquid paraffins](image3)

(a) Liquid paraffin L1  
(b) Liquid paraffin L2  
(c) Liquid paraffin L3  
Aluminium sheet: Flange rim portion in rolling direction at $R_{max}$ stage
oiliness improvers and the extreme pressure additives exhibit better lubricity when added to low viscous oil.

3. Frictional characteristics in case of using steel sheet

The results stated so far have been obtained for a commercially pure aluminium sheet. In this chapter, the results for a steel sheet shown in Table 2 are compared with those for an aluminium sheet. The experimental conditions are almost the same as those in case of aluminium sheet, but the blankholder pressure is changed to two times that in case of aluminium sheet i.e. about 0.48 kg/mm² in the initial value and 1.1-1.2 kg/mm² at the stage of maximum punching force.

Figure 11 shows variation of the friction coefficients during the process in cases lubricated by the paraffin base mineral oils. The results are almost the same as the ones in case of aluminium sheet (Fig. 5 of the 1st report) both qualitatively and quantitatively.

Figure 12 shows the friction coefficient μ, the contact ratio R and the friction shear stress τf at the stage of maximum punching force according to the viscosity of the mineral oils. It is found from comparison between these cases and the cases of aluminium (Fig. 7 and Fig. 8 in the 1st report) that both the friction coefficient and the friction shear stress in case of steel present maximum similarly to the case of aluminium although at higher viscosity than in case of aluminium and that the friction coefficient and the friction shear stress of P1 and P2 increase remarkably by the deaeration treatment similarly to the case of aluminium. Also, it is the same as the case of aluminium that the contact ratio increases with a lowering viscosity of the oils and is influenced only by the viscosity independently of kind of oils.

Figure 13 shows an effect of additives on the friction shear stress when added to the liquid paraffin L2 by 1 wt %. The additives used are three kinds of the oiliness improvers (butyl stearate, stearic acid and oleyl alcohol) and three kinds of the extreme pressure additives (chlorinated paraffin, tricresyl phosphate and dibenzyl disulfide). It is found from the figure that the value of τf drops from 0.9 kg/mm² in case of the liquid paraffin L2 to 0.4-0.5 kg/mm² in cases of adding the oiliness improvers and about 0.7 kg/mm² in cases of adding the extreme pressure additives and that the oiliness improvers have better lubricity than the extreme pressure additives similarly to the cases of aluminium (Fig. 3).

Table 2 Dimensions of steel sheet used

<table>
<thead>
<tr>
<th>Metal</th>
<th>Dimensions</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC 3(JIS)</td>
<td>Outer diameter 54 mm</td>
<td>Tensile strength 33.6 kg/mm²</td>
</tr>
<tr>
<td>Soft</td>
<td>Drawing ratio 1.86</td>
<td>Strain hardening exponent n=0.21</td>
</tr>
<tr>
<td></td>
<td>Thickness 0.4 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface roughness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rmax=1.6μm</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 11 Friction coefficient of paraffin base oils](image1)

![Fig. 12 Effects of viscosity on frictional characteristics of mineral oils](image2)

![Fig. 13 Effect of additives on friction shear stress](image3)
Frictional Characteristics of Mineral Oils in Sheet Metal Drawing (2nd Report) 641

Figure 14 shows the effect of the aromatic compound on action of the additives when added to the liquid paraffin L2 by 1 wt%. The lubricity of the additives is made worse by existence of the aromatic compound, similarly to the cases of aluminium (Fig. 6).

Figure 15 shows the effect of the viscosity of the liquid paraffins used as base oil on action of the additives. The results shown in this figure are the same as in the case of aluminium (Fig. 7). Therefore, it is concluded that oxygen dissolved in the low viscous oils influences strongly the action of the additives.

Consequently, the frictional characteristics found in case of an aluminium sheet hold all good for a steel sheet.

4. Conclusions

Effects of various oiliness improvers and extreme pressure additives have been examined, based on the lubricating properties of the base oils.

The frictional characteristics of the base oils and the additives found in case of aluminium have been compared with those in case of steel.

The following has been concluded.

(1) Lubricity of oiliness improvers is better than that of extreme pressure additives under such conditions of low sliding velocity and low surface pressure as used in this experiment.

(2) Aromatic compound contained in base oil acts as a sort of inhibitor against the effect of oiliness improvers and extreme pressure additives.

(3) Lubricity of oiliness improvers and extreme pressure additives is good when added to low viscous oils.

(4) Friction characteristics of various mineral oils and additives found in cases of using an aluminium sheet hold all good for cases of using a steel sheet.

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References


