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Tribology testing to friction determination in sheet metal forming processes

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Abstract

Reciprocating sliding tests were performed in order to find the effect of lubricant properties and other variables on the coefficient of friction of the steel sheets "Cold Rolled HSLA 380" in dry and lubricated conditions. For this material, tribology tests were performed with different lubricants. Test results showed that values of the coefficient of friction presented different patterns. The coefficient of friction varies over a wide range with different lubricating conditions and different sliding velocities. For some sliding velocities, the coefficient of friction is stable and lower, while for others it is unstable and higher.

Keywords: Friction; pressure; sliding velocity; sheet metal forming; lubricant; steel.

1. Introduction

Sheet metal forming processes were the main motivation for this study on tribology testing and friction determination. The desired shape is achieved through plastic deformation and sliding occurs between sheet metal and tools (punch, blank holder and die) [1].

It is known that oils and lubricants decrease the friction between sliding surfaces by filling the surface cavities and making the surfaces flatter. Therefore, tribology knowledge is essential to understand the importance of friction during the interaction of sheet and tool, and different contacts can be distinguished in each sheet metal forming process [2]. The different conditions for each contact may lead to different frictional behaviour, which in turn may lead to unacceptable variations in the process or even in rejection of the final product [4,5].

All sheet metal forming processes have in common that they are mostly performed with the aid of presses which drive the tools to deform the initially flat sheet material into a product. The sliding of a plastically deforming sheet against the tools makes both tribological and mechanical knowledge a fundamental need for optimum processing [6,7]. Friction between the sheet and the punch/die/blank holder is thus an important factor in the sheet metal forming.

2. Experimental Procedure

A pin-on-disc machine with reciprocating attachment has been used for the tests, using a sphere ball (tool material mounted on pin) and the rectangular sheet metal sample, as shown in Fig. 1. The initial roughness of the samples measured in the sliding direction was Ra = 1.45 ± 0.20 μm.

The stroke length used in all tests was 10 mm, and the frequency was defined from 30 min^{-1} to 78 min^{-1}.

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The contact pressure between blank and tool was settled in the range of 3 to 10 MPa.
The material of the ball used for the friction test is "AISI D2 Steel". D2 steel is an air hardening, high-carbon, high-chromium tool steel. Typical chemical composition of AISI D2 Steel is C = 1.50%, Si = 0.30%, Cr = 12.00%, Mo = 0.80% and V = 0.90% [6].

Fig.1. Test sample of HSLA 380 for friction test on pin-on-disc machine.

For the friction test with constant load, the following set up is used:

- Load = 24.5 N;
- Diameter of contact area = 0.6 to 0.7 mm;
- Area = 0.28 to 0.38 mm^2;
- Pressure = 6.5 to 9 MPa.

The contact area between the sphere ball (mounted on pin) and the sample is circular. During the experiments, this circular contact was kept constant by changing periodically those spheres and therefore the contact area for all the tests was considered the same. The coefficient of friction between the sphere ball and the surface of sheet metal is calculated according to Coulomb's friction law:

$$\mu = \frac{F}{N} \quad (1)$$

where F is the tangential force of friction and N the normal applied load [9,10]. The value of F is measured by load cell attached to the pin-on-disc machine.
The value of normal load used is N = 24.5 N.
For the friction sliding test, different sliding velocities were achieved by varying the cycles (rpm) of the pin-on-disc machine.
The equations used for the calculations of sliding velocity are as follows.

$$t = \frac{y}{x} \quad (2)$$

$$\text{Velocity} = \frac{\text{Distance}}{\text{time}} = \frac{2\,l}{t} \quad (3)$$

where t is the time required for one cycle in seconds, x the number of cycles per minute (rpm), y = 60 seconds, l the track length (l = 10 mm). The distance covered in one revolution is twice the track length as the tool is in reciprocating motion.
Table 1 shows the relation between velocity (rpm) and the corresponding average linear velocity, by using Eqs. (1) and (2). For the friction tests on pin-on-disc machine, the lowest velocity used was 30 rpm. Using lower velocity than 30 rpm is avoided as the machine would give non smooth motion.

Table 1. Friction test sliding velocities.

Frequency (rpm)	Time for one cycle (sec)	Average linear velocity (mm/s)
30	2	10
42	1.43	14
54	1.11	18
66	0.90	22
78	0.77	26

The material used for the friction test is cold rolled HSLA 380, which is defined by EN 10268 standard, having also designation of HC380LA. The number 380 refers to the minimum yield strength in transverse direction, in MPa. Its chemical composition and mechanical properties in the transverse direction are shown in Tables 2 and 3, respectively [9].

Table 2. Chemical composition of the steel.

C max (%)	0.12
Si max (%)	0.5
Mn max (%)	1.8
P max (%)	0.030
S max (%)	0.025
Al max (%)	0.015
Ti max (%)	0.15
Nb max (%)	0.09

Table 3. Mechanical properties of transverse test pieces.

$Rp_{0.2}$ (MPa)	380-480
Tensile strength (MPa)	440-580
Elongation A80 min (%)	19

Lubricants were applied with different combinations. First the sample is cleaned with ether alcohol. Then the lubricant is applied with the brush in the same way as applied during the deep drawing process in the industry. Lubricants Prelube A and Prelube B were combined with other four different lubricants. Prelube is a lubricant that comes with the sheet metal from producers to prevent oxidation.

3. Experimental Results

In this work it is found that the initial lubrication condition is enough to reduce the friction from 0.40-0.78 in dry conditions, as seen in Fig. 2, to values under 0.12 (Fig. 3).

Fig. 2 shows the dry coefficient of friction obtained with varying sliding velocity in reciprocating motion. Each test corresponds only to 40 s. Between 40 and 80 s, the test stopped and therefore, during this period, the friction line must be ignored. The same is valid for the periods 120-160, 200-240 and 280-320 s.

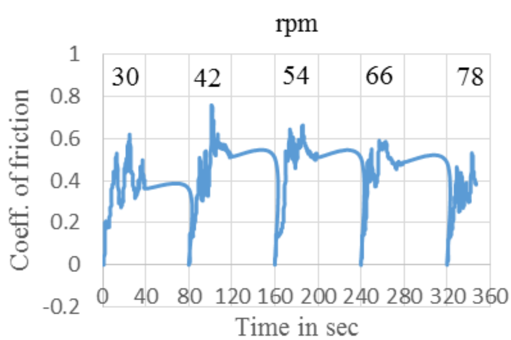


Fig. 2. Dry test – coefficient of friction with varying sliding velocity for "Cold Rolled HSLA 380".

Similar tests were carried out using different lubricated condition and the results with Prelube A and Prelube B lubricant are presented in Figs. 3 a) and b), respectively. The sliding velocity corresponding to the lowest friction is 54 rpm (18 mm/s) for both Prelube A and B.

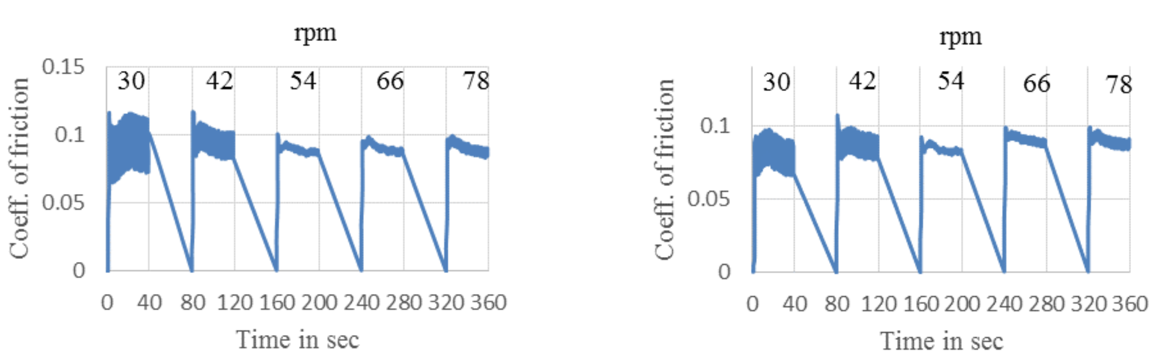
At the sliding velocity corresponding to 54 rpm, the smallest values coefficient of friction were obtained and the values are more stable, but at the beginning the coefficient of friction was higher but reducing with time. To summarize, all specified graphs show that the stable values of coefficient of friction are obtained with the sliding velocities 18 mm/s, 22 mm/s and 26 mm/s. The higher values for the coefficient of friction were obtained for sliding velocities 10 mm/s and 14 mm/s. These higher velocities also give higher instability coefficient of friction.

For the lubricated parts, the coefficient of friction is dependent on contact pressure and sliding velocity and lubricant properties. On the other hand, an adhesive friction state exists in most of the dry friction regions. Therefore, the coefficient of friction of dry surfaces is assumed to depend on the mechanical properties of the steel sheet, such as shear strength and plastic flow stress, and is defined as a constant value [10].

Based on these results, the sliding condition in an actual stamping process is estimated to be placed between the unlubricated condition and the lubricated condition in friction test.

Additional tribology tests were performed with lubrication conditions using the two Prelube lubricants, now mixed with other four lubricants. Corresponding results are presented in Figs. 4 to 7.

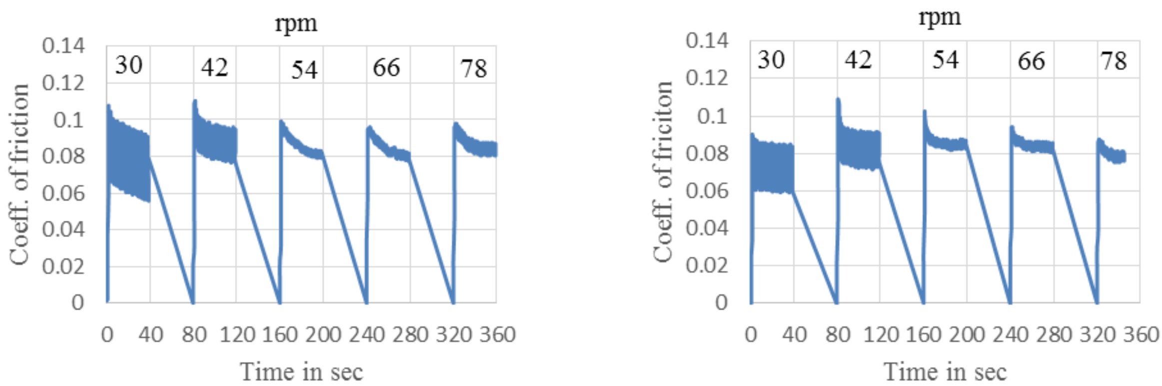
The lower values for the coefficient of friction are obtained for sliding velocities corresponding to 18 mm/s (Fig. 6 a)), 22 mm/s (Fig. 6 b)), 18 mm/s (Fig. 7 a)) and 18 mm/s, 22 mm/s, 26 mm/s (Fig. 7 b)). Figs 4 and 6 show that, at beginning, the coefficient of friction is higher and it gradually decreases with time.



a) Prelube A lubricant

b) Prelube B lubricant

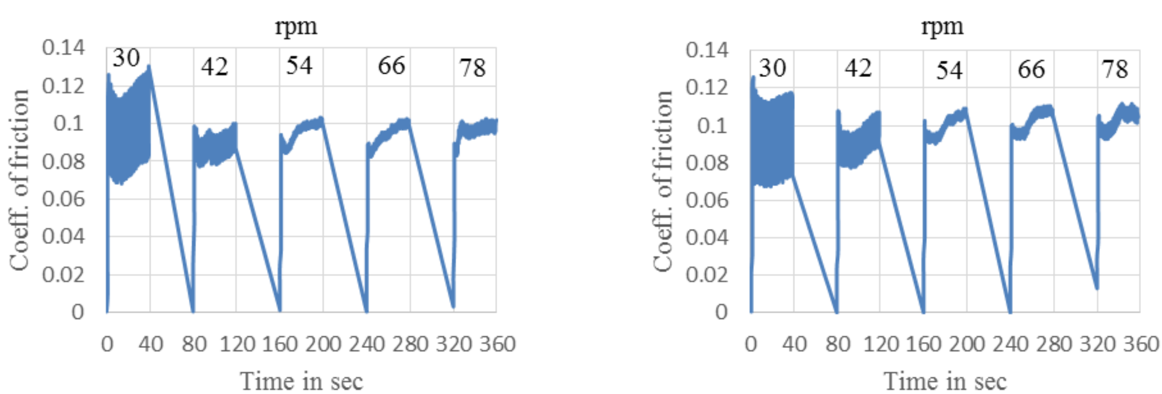
Fig. 3. Lubricated condition – coefficient of friction with varying sliding velocity for "Cold Rolled HSLA 380".



a) Prelube A + Lub 1

b) Prelube B + Lub 1

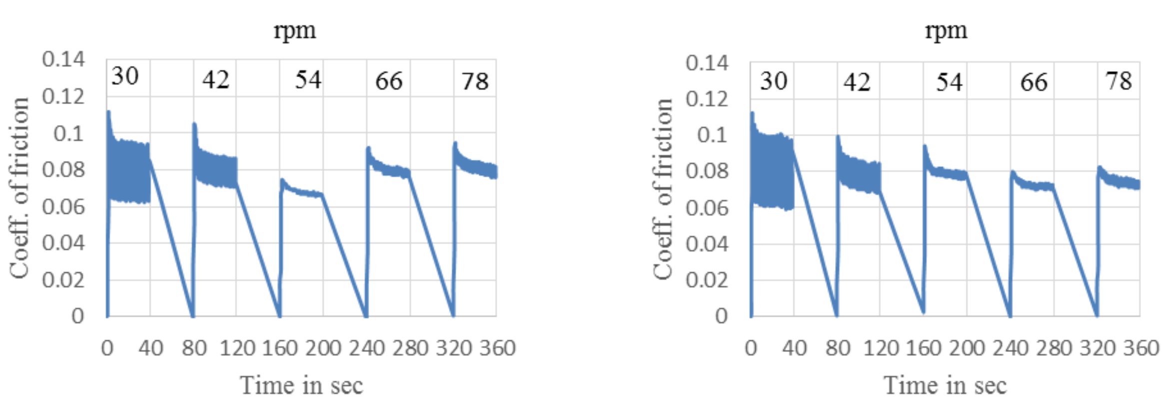
Fig. 4. Lubricated condition – coefficient of friction with varying sliding velocity for “Cold Rolled HSLA 380”.



a) Prelube A + Lub 2

b) Prelube B + Lub 2

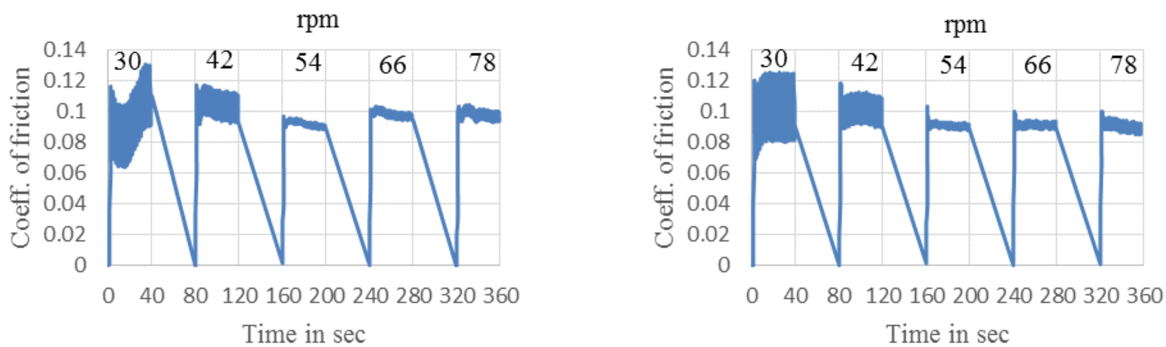
Fig. 5. Lubricated condition – coefficient of friction with varying sliding velocity for “Cold Rolled HSLA 380”.



a) Prelube A + Lub 3

b) Prelube B + Lub 3

Fig. 6. Lubricated condition – coefficient of friction with varying sliding velocity for “Cold Rolled HSLA 380”.



a) Prelube A + Lub 4

b) Prelube B + Lub 4

Fig. 7. Lubricated condition – coefficient of friction with varying sliding velocity for "Cold Rolled HSLA 380".

These results show that similar pattern instability is observed for the lower sliding velocities 10 mm/s and 14 mm/s. More stability in all graphs is observed for the higher sliding velocities 18 mm/s, 22 mm/s and 26 mm/s only when Prelube A + Lub 2 and Prelube B + Lub 2 are used. It is clear from the test results that the lubricant 2 is having a negative effect on friction behaviour. It increases the coefficient of friction with time as it can be clearly seen in Fig. 5. Lubricant 2 is a vanishing oil (designed to evaporate very quickly) and loses lubrication capacity within the test duration.

4. Conclusions

In this work tribological tests were carried out using pin-on-disc machine which were aimed to determine the coefficient of friction and behaviour between sheet metal and tools during forming. The research has considered the frictional characterization of reciprocating sliding tests in order to find the effect of lubricant and other variables on the coefficient of friction of the steel sheets cold rolled HSLA 380 with different lubrication conditions.

It was found that the Prelube A + Lub 3 lubricant gives the lowest values for the coefficient of friction and a constant behaviour with time. It is also found that the optimum sliding velocity is 54 rpm, i.e., 18 mm/s. For the combination Prelube B + Lub 3 lubricant the lowest values coefficient of friction correspond to 66 rpm, i.e., 22 mm/s.

When the Lubricant 2 is combined with Prelube A and with Prelube B an adverse effect is obtained on the coefficient of friction and friction behaviour. Lubrication 2 is a vanishing oil which is evaporates very quickly and leaves residuals on the surfaces. Hence, this combinations of the lubrication may not be very useful for the sheet metal drawing operations.

References

[1] B.H. Lee, Y.T. Keum, R.H. Wagoner, J. Mater. Process. Technol. 130–131 (2002) 60.

[2] E. Ceretti, A. Fiorentino, C. Giardini, Int. J. Mat. Form. 1 (2008) 1219.

[3] T. Mang, W. Dresel (Ed.), Lubricants and Lubrication, 2nd ed., Wiley-VCH Verlag GmbH & Co. KGaA, 2007.

[4] S. Aleksandrovich, M. Stefanovic, T. Vujinovic, Tribol. Ind. 25(3&4) (2003) 100.

[5] I. Buyanovskii, J. Frict. W. 31(1) (2010) 33.

[6] Steel Express, D2 Steel Properties, 2016 <http://www.steelexpress.co.uk/toolsteel/D2-Steel-properties.html> (accessed 29.06.2015).

[7] Bharat Bhushan (Ed.), Introduction to Tribology, 2nd ed., John Wiley & Sons, Ltd., 2013.

[8] T. Trzepieciński, A. Bazan, H.G. Lemu, Int. J. Automot. Technol. 16(5) (2015) 849.

[9] E. Ghassemieh, in M. Chiaberge (Ed.), New Trends and Developments in Automotive Industry, in Tech Europe, Rijeka, Croatia, 2011, pp. 365–394.

[10] A.K. Padap, G.P. Chaudhari, S.K. Nath, Dry Sliding Wear and Corrosion Behavior of Ultrafine-grained HSLA Steel Processed using Multi Axial Forging, in Supplemental Proceedings: Materials Fabrication, Properties, Characterization, and Modeling, vol. 2, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2011.