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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