# A new test method for ranking sheet metal forming lubricants

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## Introduction

Environmental issues enhance the need to replace chlorine in forming lubricants by less disputable additives. To evaluate the tribological performance of newly formulated lubricants for stainless steel, a test method is developed. This test method is based on comparative testing at the TNO slider-on-sheet tribometer.

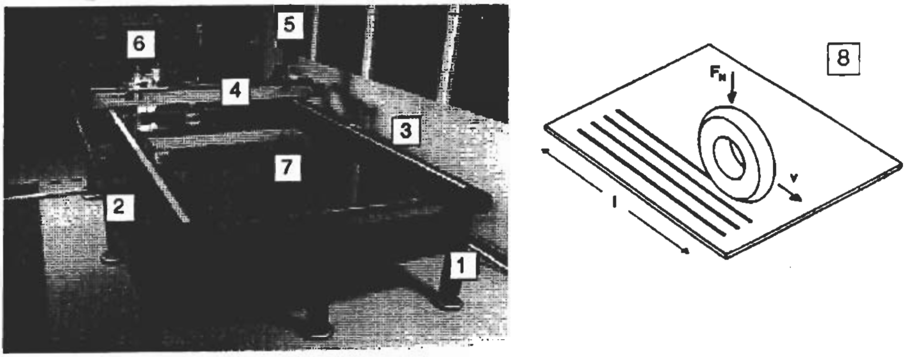


**Figure 1.** The TNO slider-on-sheet tribometer. Elements of the test equipment: (1) Frame; (2) Table; (3) Linear modules for translation in the x-direction; (4) Linear modules for translation in the y-direction; (5) Digital servo-motor; (6) Actual measuring device, including a pneumatic loading system and strain gauges for measuring friction and normal force; (7) Sheet material to be tested. (8) Principle of the TNO slider-on-sheet tribometer

A slider, representing the forming tool, is pushed against the sheet with a normal force $F_n$. Then the slider moves in the x-direction from $x=x_0$ to $x = l$, with a sliding speed v. During the track the normal force and the resulting friction force are measured by strain gauges. At the end of the track (l) the slider is lifted from the sheet and moved over a distance of 1 mm in the y-direction. The slider returns to the starting-point $x=x_0$, after which the next track is made assuring virgin sheet material in the tribo-contact. In this way 1 km sliding distance is realised on one square meter sheet material. The sliding speed (0.001 -1 m/s), normal force (1-1000 N) and track length (< 2.5 m) can be adjusted within their range.

During the sliding contact the friction force and normal force are measured at a sample frequency of 1 kHz and the coefficient of friction (f) is calculated each ms. To avoid a huge amount of friction data, average values are calculated per track. After the test the wear scar on a slider is inspected visually or by SEM. The depth and width of the deformation tracks give an impression of wear of the sheet material or the tool material. Therefore profile measurements are taken perpendicular to the sliding speed. The technical lifetime, $L_{f>0.2}$ , of the tribo system is set to the value for the sliding distance at which f becomes larger then 0.2 [-]. $L_{f>0.2}$ and the average coefficient of friction from 0 - 2 m, sliding distance ( $f_{start}$) are used as ranking criteria.

### Test-specimens

The sheet material used in the experiments is 1 mm thick, cold rolled austenitic stainless steel AISI 304 with surface finish 2B. Experiments are conducted parallel to the rolling direction. The surface roughness of the sheet material is measured with a Mitutoyo Surftest 300 apparatus. The average of five measurements (randomly chosen at the sheet) is taken in order to characterize one sheet. These measurements are taken both parallel and perpendicular to the sliding direction. The used cutoff length is 0.8 mm. Resulting average $R_a$-values vary from 0.29-1.09 µm (⊥) and 0.31-1.36 µm (//). This variation in surface roughness determine to a large extend the experimental scatter in the results. The hardness of the sheet material is 180 kg/mm$^2$ $HV_{10}$.

All sliders are made out of 12% Cr steel (WN 1.2379), a common tool steel. The steel was tempered at 200°C and has a hardness of 60-61 HRC. The slider's dimensions are Ø44x8 mm with a radius of 6 mm. The surface roughness of the sliders is measured with a Mitutoyo Surftest 500 apparatus (cutoff length 0.2_ mm). Measurements were taken parallel and perpendicular to the sliding direction. Resulting average $R_a$-values vary from 0.05-0.06 µm (⊥) and 0.02-0.03 µm (//)

The lubricants used in the experiments, are marked A, B, C, D and E. The only technical information available is the kinematic viscosity at room temperature (22 °C) combined with a qualitative description of the additives (table 1). Lubricant E is a widely used forming lubricant, based on chlorinated paraffin. This lubricant serves as reference.

**Table 1** Lubricant properties

| lubricant | ν [cSt] 22 °C | additives | | | remarks |
|---|---|---|---|---|---|
| | | Cl | S | Ca | |
| A | 215 | - | + | + | light duty forming oil |
| B | 336 | - | ++ | ++ | light-medium duty forming oil |
| C | 621 | - | + | + | medium-heavy duty forming oil |
| D | 338 | - | ++ | ++ | as B, but easier to clean |
| E | 237 | ++ | + | - | chlorinated reference |

## RESULTS

### Reference lubricant

The quality of a ranking test method is highly determined by the accuracy of the reference experiment, in this case the performance of lubricant E. Representative results for the coefficient of friction and for the maximum depth of the deformation tracks in the sheet both as a function of the sliding distance, are shown in figure 2.

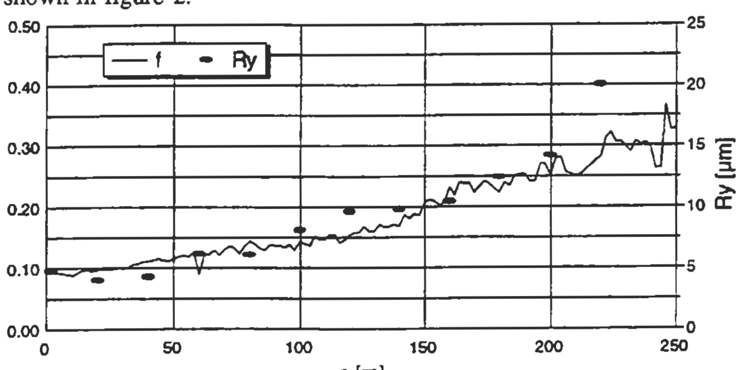


**Figure 2** f (drawn line) and Ry (dot) versus s for the reference lubricant.

The coefficient of friction increases with s from initially 0.1, to larger then 0.3 at s = 250 m. This increase in friction corresponds remarkably well with the increase in Ry [JIS]. The first deformation track is hardly visible on the sheet but at 250 m severe scuffing occurs, resulting into an increase of Ry of almost 15 μm. SEM analysis shows transferred stainless steel at the contact surface of the slider. Therefore it can be concluded that adhesive wear or pick-up is the main wear mechanism.

Initially, the velocity difference is accommodated by shearing of the lubricant film (low friction, virtually no wear) but with increasing sliding distance this changes to shearing of the sheet material (high friction, severe wear of the sheet).

**Ranking of five lubricants**
It was decided to perform comparative tests at v = 0.01 m/s and at v = 0.5 m/s. The normal force is set to Fn = 100 N and the track length to l = 2000 mm. Figure 3.a shows the technical lifetime and figure 3.b shows the $f_{start}$ value, for the tested lubricants.

Experimental conditions
- v = 0.01 m/s and v = 0.5 m/s
- Fn = 100 N

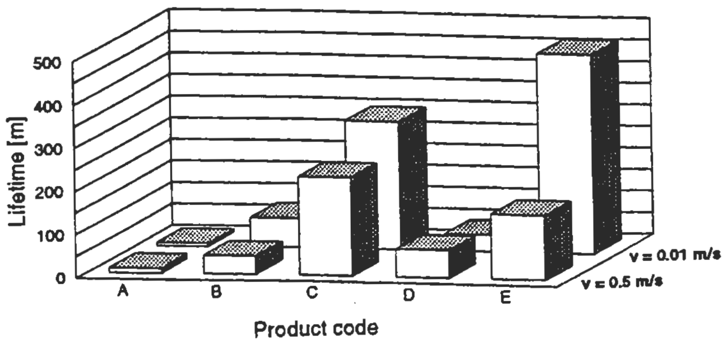


**Figure 3.a** Technical lifetimes $L_{f>0.2}$ at two different sliding velocities.

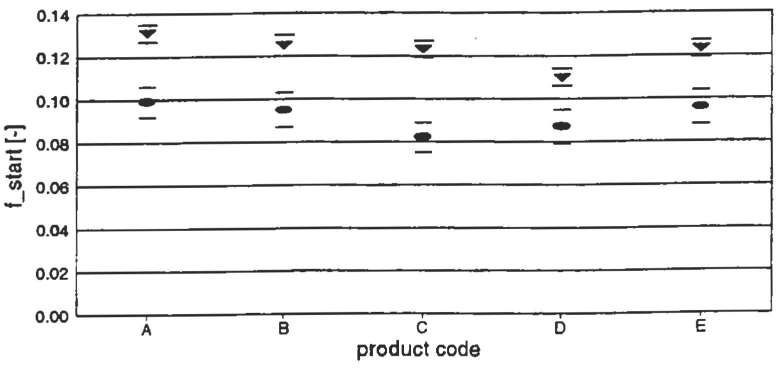


**Figure 3.b** Average coefficient of friction from 0 - 2 m sliding distance (standard deviation indicated) at two sliding velocities (0.01 m/s = dot, 0.5 m/s = triangle).

The lubricants can be divided into three groups based on the $f_{start}$ or $L_{f>0.2}$ criterion (table 2)

**Table 2** Comparison of ranking criteria with industrial experience.

| performance | industrial experience | $f_{start}$ criterion | | lifetime criterion | |
|---|---|---|---|---|---|
| | | v = 0.01 m/s | v = 0.5 m/s | v = 0.01 m/s | v = 0.5 m/s |
| - | A | A | A, B, E | A | A |
| + | B and D | B, C, E | D | B, D | B, D |
| ++ | C and E | D | C | C, E | C, E |

Ranking based upon minimising $f_{start}$ can result into a non realistic ranking. See for example the results for lubricant D. From table 2 it can also be seen that the ranking order strongly depends on the sliding speed. However, ranking based upon the lifetime criterion matches the industrial experience and the ranking order is independent of the sliding speed.

## CONCLUSIONS

From the presented results it can be concluded that :

1. Ranking based on long-term behaviour differs from ranking based on short-term behaviour
2. Ranking based on $L_{f>0.2}$ matches the industrial experience.