

The Influence of Plastic Bulk Deformation on Surface Roughness and Frictional Behavior during Deep Drawing Processes

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In Sheet Metal Forming (SMF) processes, friction does play an important role. This with respect to the increase of product quality demands and the ability of predicting these processes by for instance finite element simulations. The existing simulation models do not contain an adequate friction model. In SMF processes different contact situations can be distinguished. As a result different coefficients of friction are locally present, which influences the forming process.

Experiments are performed on a testing device by which it is possible to simulate the operational conditions as present in SMF processes. This test rig is a combination of a tensile tester and a friction measuring device, by which it is possible to measure the coefficient of friction as a function of the operational conditions (velocity and contact pressure) and deformation (elastic or plastic) in a well controlled way. Friction is presented in a generalized Stribeck-curve in which the different lubrication regimes can be distinguished, i.e. Boundary Lubrication (BL) and Mixed Lubrication (ML), which are also occurring during SMF processes.

In SMF processes the sheet material deforms elastically and plastically and therefore the surface roughness will change and as a consequence will influence the frictional behavior between sheet and tool. In this paper, the influence of plastic deformation on A) the surface microgeometry and B) as a consequence of that on the frictional behavior of the sheet-tool system is studied. With the aid of a 3D-surface interference microscope, the microgeometry of the deformed material has been analyzed. The result of this investigation is that the CLA-roughness due to the deformation first decreases and then increases with increasing deformation. Furthermore, friction is hardly influenced due to the change in surface roughness. No change in the shape and the level of the generalized Stribeck curve is found.

1. Introduction

The industry is very interested in simulating sheet metal forming (SMF) processes like deep drawing and bending. This to reduce the costs for the design of a new product and tools. It is also desirable that the chance a process fails is minimized in the pre-production phase of a new product. To achieve this objective, computer simulations of the process are performed. The interest of these simulations is to govern the forces acting on the tool and the stresses in the sheet material. At the University of Twente such a simulation package, called DiekA (Huétink 1986), is under development.

Still too frequently simulations do not give the proper results. One important cause for this is the friction model used which describes the frictional behavior of the sheet/tool contact. At present a Coulomb friction model is often used. In this case

a constant coefficient of friction is supposed for the different contact areas. However, depending on the deep drawing conditions, different zones of contact between sheet and tool, with locally different coefficients of friction, can be distinguished, (Schipper 1988).

This article deals with the influence of plastic deformation on the surface microgeometry of the sheet material. In literature many deformation experiments have been performed, e.g., von Stebut, Roizard & Paintendre (1989), Schey (1983) and Osakada & Oyane (1971), but the effect on the surface microgeometry, expressed by different surface parameters, is not quite clear. For this research a large number of specimen have been subjected to free plastic deformation with different strain values. This means deformation without contact of a mating surface. This is a real situation which also occurs during deep drawing

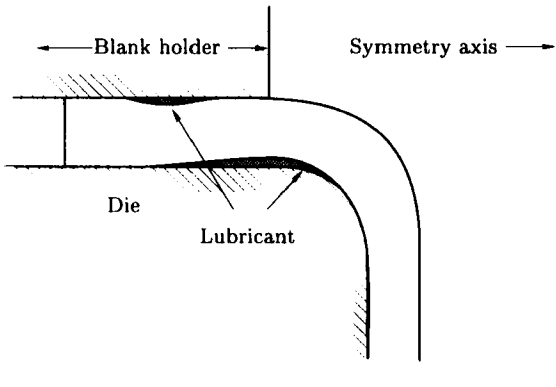


Figure 1. Schematic drawing of a deep drawing process, with different lubrication conditions.

processes, as can be seen in figure 1, adapted from Vegter (1991). There is no contact between sheet material and tool (blank holder and die) in the areas where lubricant is located.

Next to the surface microgeometry measurements, friction measurements have been performed. This to study the effect of plastic deformation on the frictional behavior between sheet and tool. For this purpose a new developed friction tester has been used.

2. Plastic deformation of surface textures

2.1. Material properties

The sheet material used for this investigation is an uncoated cold rolled steel with a thickness of 0.7 mm. It is a standard deep drawing steel used in the automotive industry. Table 1 shows the mechanical properties of this material. The r -value is defined as the ratio between ε_2 and ε_3 , which are the transverse strains when performing a tensile test on a strip. These strains are equal only if the strip is isotropic, which in general is not the case. The n -value is the constant from the relation of Ludwik-Nadai, defined as $\sigma = C \cdot \varepsilon^n$.

Table 1
Mechanical properties.

	90 = perpendicular to rolling direction	45 = 45 degrees rotated compared to rolling direction	0 = parallel to rolling direction	mean = $(X_0 + 2X_{45} + X_{90})/4$
R_p [MPa]	90	153		
$(\sigma_{0.2})$	45	151		
	0	149		
	mean	151		
R_m [MPa]	90	308		
(σ_B)	45	306		
	0	312		
	mean	308		
r -value	90	2.6		
	45	2.2		
	0	1.7		
	mean	2.2		
n -value	90	0.222		
	45	0.229		
	0	0.230		
	mean	0.228		

2.2. Experimental procedure

The test specimen used have been punched out of the sheet material. The test specimen geometry is shown in figure 2.

The deformation of the specimen is realized by using a tensile tester. The specimen have been punched in such a way, that the rolling direction is oriented perpendicular to the deformation direction. A grid size of 2.5 mm \times 2.5 mm is applied for measuring the local deformation of the specimen after testing. The plastic deformation is expressed by the natural strain ε , defined as:

$$\varepsilon = \ln \left(1 + \frac{\Delta l}{l_0} \right) \quad (1)$$

where l_0 is the original length and Δl the increase of length.

The specimen have been deformed with different strains of 0, 0.03, 0.06, 0.09, 0.12, 0.15 and 0.18. The strain velocity $\dot{\varepsilon}$ was about 0.001 s⁻¹, so quasi-static.

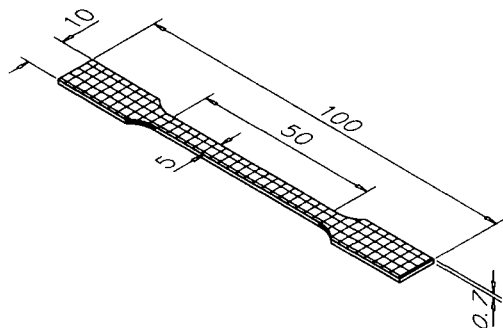


Figure 2. Geometry of the specimen, in mm.

The deformed surfaces of the specimen have been analyzed by using an interference microscope. The scanning area for the surface measurements was $766 \mu\text{m} \times 597 \mu\text{m}$. The cut-off length of the profile measurements was 0.8 mm.

Before analyzing the test specimen with the interference microscope, they were rinsed in an ultrasonic cleaner. The roughness measurements were performed on the side of the specimen without the grid. So any influence of the grid on the surface texture has been avoided.

2.3. Results

2.3.1. The influence of free deformation on the R_a parameter

The results of the profile measurements (2D) are analyzed and presented in figure 3. The values of the profile measurements are mean values of 9 measurements. The results show a large standard deviation on the mean values. The roughness values overlap, so no significant differences can be observed.

The surface measurements (3D) on the other hand show significant differences, presented in figure 4.

The standard deviation is smaller, in spite of the fact that the values are mean values of 5 measurements instead of 9 measurements in case of the profile measurements. Measurements on surfaces with natural strains of 0.2 and 0.24 are

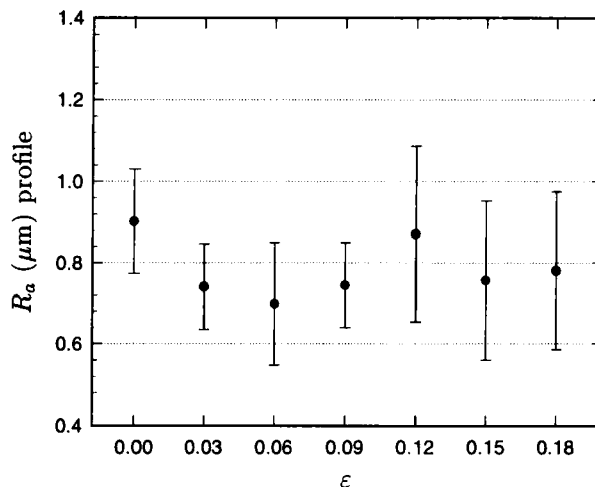


Figure 3. R_a roughness profile measurements in the direction of deformation (perpendicular to rolling direction) as a function of the natural strain.

also performed.

For small natural strains (until 0.06), the surface roughness parameter R_a decreases. For larger strains the surface becomes rougher with larger strains.

2.3.2. The influence of free deformation on the average slope

The average slope parameter is a so called hybrid microgeometry parameter. It incorporates both height and spacing information. In literature some investigators have found this type of parameter useful in friction and wear descriptions, (Whitehouse 1994). For sheet metal forming processes they are of interest as well, because of the influence of the rolling on the height distribution of the surface texture and the influence of the bulk deformation on the horizontal spacing. The average slope (Δ_a) is defined as:

$$\Delta_a = \frac{1}{L} \int_0^L \left| \frac{dz}{dx} \right| dx \quad (2)$$

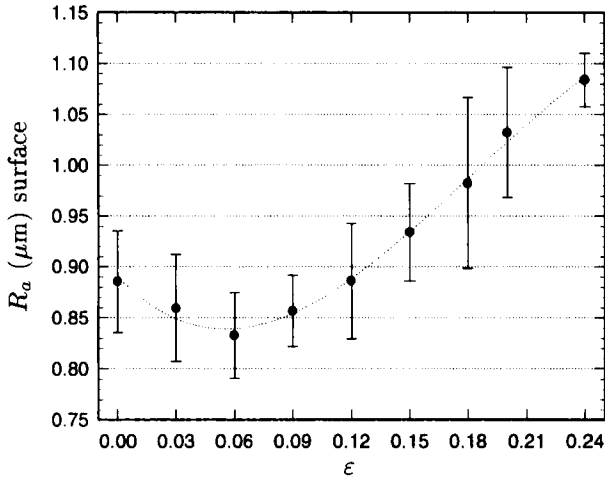


Figure 4. R_a roughness surface measurement as a function of the natural strain.

where $\frac{dz}{dx}$ is the instantaneous slope of the profile. The measurement equipment calculates the mean slope of a large number of profile measurements next to each other of the measured 3D surface area.

Figure 5 shows the slope parallel to the deformation direction as a function of the natural strain. The presented mean values are derived from 5 measurements.

The figure shows a significant influence of the deformation on the average slope, corresponding with the R_a roughness parameter. The values of the average slope decrease for low strains until 0.06, for larger deformations the slope parameters show also higher values. Next to the surface R_a roughness parameter, also the slope parameter demonstrates to be a good parameter to represent the influence of plastic deformation on the microgeometry.

An unexpected trend of the different parameter values is the decrease for low strains. A possible explanation for this behavior could be the loss of the initial orientation of the microgeometry, originated during the rolling process, due to light distortions of the grains. For larger strains the

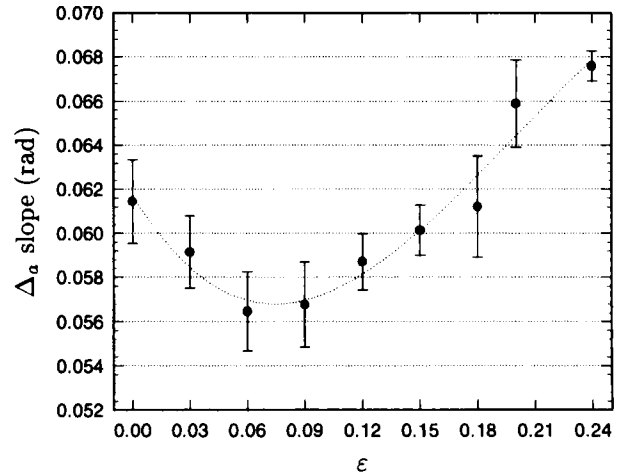


Figure 5. Δ_a slope parallel to deformation direction (perpendicular to rolling direction) as a function of the natural strain.

grains distort more and more and turn out of the surface, which causes roughening of the surface microgeometry.

3. Friction measurements

3.1. Friction tester

As indicated in the introduction, friction measurements have been performed to study the effect of deformation on friction. ter Haar, Schipper, de Vries, Vegter & Broekhof (1994) reviewed a number of test rigs used to study friction in SMF processes known from literature and concluded that most of them do have important disadvantages. Therefore, a new testing device has been developed.

In figure 6 the test rig is schematically presented. This test rig is a combination of a tensile tester and a friction measuring device. With this device it is possible to measure the coefficient of friction as a function of the operational conditions, velocity and contact pressure in combination with deformation (elastic or plastic) in a well controlled way. The deformation (elastic and plastic) of the sheet material is controlled by

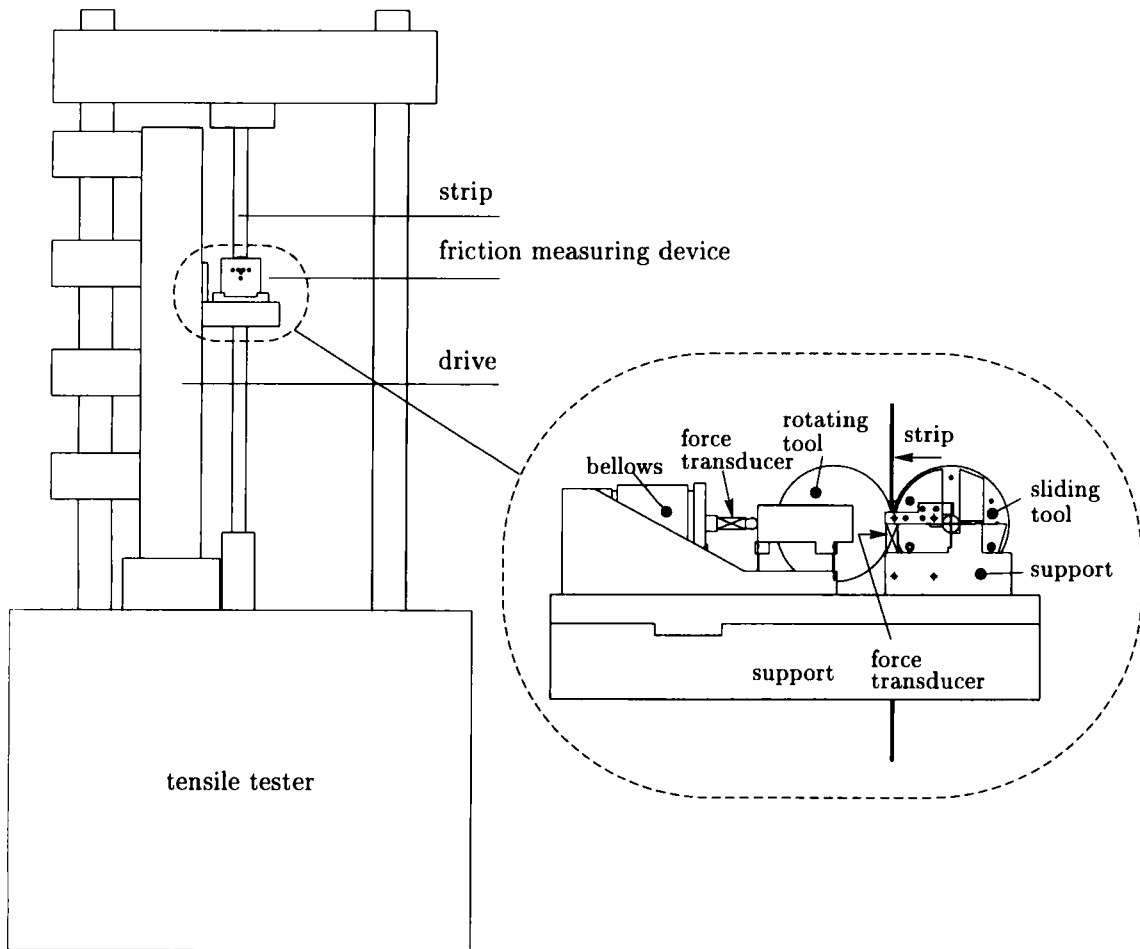


Figure 6. New developed friction tester, (ter Haar et al. 1994).

the tensile tester, whereas the friction measuring device measures the normal force acting on the contact and the friction force between the sliding tool and the sheet by means of piezo-electric force transducers.

3.2. Experimental procedure and results

The coefficient of friction is presented as a function of the operational parameters, combined in a dimensionless lubrication number L . This dimensionless lubrication number L is expressed

by:

$$L = \frac{\eta_{inl} \cdot v_{sum}}{\bar{p} \cdot R_a^*} \quad (3)$$

where η_{inl} is the inlet viscosity of the lubricant, v_{sum} the sum velocity of the interacting surfaces, in this case the sliding speed, \bar{p} the mean contact pressure and R_a^* the combined centerline average (CLA) surface roughness, defined by:

$$R_a^* = \sqrt{R_{a1}^2 + R_{a2}^2} \quad (4)$$

The friction experiments were performed by keeping temperature, and therefore the inlet vis-

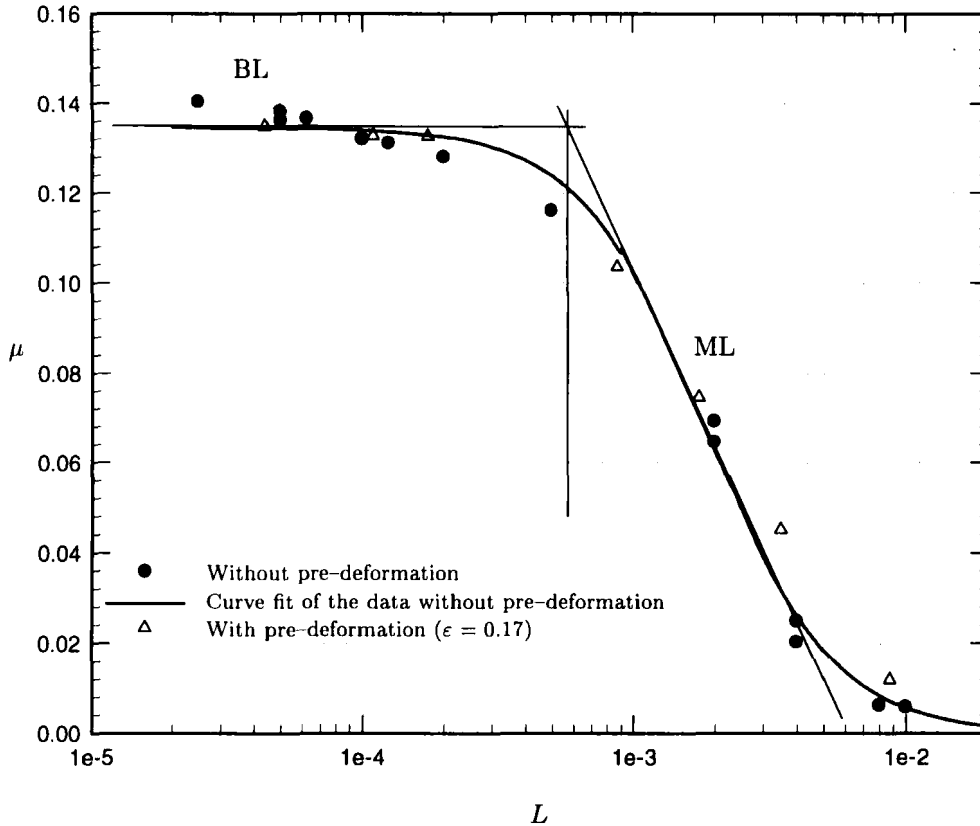


Figure 7. Generalized Stribeck curve.

cosity, as well as the contact pressure constant and changing the sliding velocity. Values of these parameters are listed in table 2.

Table 2
Operational parameters.

η_{20°	[Pa·s]	1.2
\bar{p}	[MPa]	71.5
v_{sum}	[m·s ⁻¹]	0.0125–0.5

The tests were performed with the direction of sliding perpendicular to the rolling direction of the sheet material.

In figure 7 the results of the friction measurements are shown. In this figure the generalized Stribeck curve is shown for undeformed strips (continuous line). From this curve, two different lubrication regimes can be distinguished, Boundary Lubrication (BL) and Mixed Lubrication (ML). Next to these experiments with undeformed strips, a number of tests have been performed with pre-deformed strips. Before these friction measurements were carried out, the strips were deformed quasi-statically until a natural strain of $\epsilon = 0.17$. These measurements are reflected by the Δ -symbols. Here the L parameter has been corrected for the changed surface roughness as a result of the plastic deformation of the strips. The R_a roughness for the undeformed

strips was $0.89 \mu\text{m}$, for the deformed strips $R_a = 0.95$. From figure 7 it is clear that pre-deformation hardly influences the coefficients of friction for both the BL regime and the ML regime if the generalized Stribeck curve, i.e. μ as a function of L , is used.

4. Conclusions

From the presented results, the following can be concluded:

- 3D surface measurements show significant differences in the surface parameter R_a whereas the 2D profile measurements did not show this.
- The slope is a good parameter to represent the influence of plastic deformation on the microgeometry.
- For small deformations, a decrease of the slope and roughness parameters is measured, for larger deformations, the roughness and slope parameters increase with increasing deformation.
- Bulk deformation of the sheet material hardly influences the frictional behavior between sheet and tool. The generalized Stribeck curve (μ as a function of L) remains the same.

5. Acknowledgements

The authors acknowledge Dr. H. Vegter of Hoogovens groep B.V. and Dr. N.L.J.M. Broekhof of Quaker Chemicals B.V. for their financial support and the supply of materials for this project.

REFERENCES

- Huétink, H. (1986), On the simulation of thermo-mechanical forming processes, PhD thesis, University of Twente.
- Osakada, K. & Oyane, M. (1971), 'On the roughening of free surface in deformation processes', *Bulletin of JSME* **14**, 171-177.
- Schey, J. A. (1983), *Tribology in metalworking*, American Society for Metals.
- Schipper, D. J. (1988), Transitions in the lubrication of concentrated contacts, PhD thesis, University of Twente.
- ter Haar, R., Schipper, D. J., de Vries, E. G., Vegter, H. & Broekhof, N. L. J. M. (1994), Friction measurements under sheet metal forming conditions, in G. Stachowiak, ed., 'Conference Proceedings of Austrib 1994', Perth, Australia.
- Vegter, H. (1991), On the plastic behaviour of steel during sheet forming, PhD thesis, University of Twente.
- von Stebut, J., Roizard, X. & Paintendre, B. (1989), The influence of bulk plastic deformation on die/sheet friction during strip drawing of hot dip galvanized sheets, in 'IDDRG WG-Meeting', Budapest, Hungary.
- Whitehouse, D. J. (1994), *Handbook of surface metrology*, Institute of Physics Publishing Bristol and Philadelphia.