Measuring and modelling surface topography changes due to material transfer

M. B. de Rooij and D. J. Schipper

March 3, 1999

Abstract

Material transfer is an important mechanism in many tribological systems. Material transfer in deepdrawing processes, resulting in the build-up of lumps on the tool surface, has been studied by measuring the change of the microgeometry of the tool surface which is caused by the built-up of lumps. Besides this, a theoretical model, describing the initiation and growth of lumps, has been formulated. Both the measurement method and the model with their results will be briefly desribed.

1. Introduction

In deepdrawing, material transfer from the sheet to the tool often does not take place in the form of a continuous film, but often in the form of separate lumps. These lumps may, during the production process, grow and cause damage to the sheet. The process is often called 'galling' and has to be avoided because is the restricts the number of products that can be produced with a forming tool without causing undesirable scratching of the products. Galling is studied experimentally by measuring the change in the microgeometry of a deepdrawing tool which has taken place during a tribological experiment, see (de Rooij 1998). It turns out that the changes of the tool surface, caused by growth of lumps, can be characterized by the change of the summit height distribution. Also, a theoretical model, focussed on predicting the change of the summit height distribution of the tool surface, has been developed. The main aspects of this model will be briefly described and some results will be presented.

2. Measurement method

Recently, a measurement method, able to measure changes at roughness scale has been developed, see (de Rooij and Schipper 1998). A measurement of the microgeometry of a surface is performed before and after a tribological experiment. After repositioning, done by means of image processing techniques is done, local height differences give information about material that is locally added or removed from the surface.

3. Measurement results

In the following, two examples related to the material transfer in (unlubricated) deepdrawing processes will be shown.

3.1. Example 1

This example showns the results of a DLC coated cylinder sliding against aluminum sheet material under the following (unlubricated) conditions:

v [mm/s]	$\overline{p}$ [MPa]	$l_{a\to b}$ [m]	$l_{a\to c}$ [m]
5	160	0.5+0.5	0.5+1

Fig. 1 (pixelsize is 1.45× 1.49 μm, measured area is 340×441 μm) shows a sequence of measurements on the same spot of the tool surface. The difference images are shown in Fig. 2. It is clear that materials is added to the lump at a certain spot and removed from the same lump at another spot.This illustrates that the total volume change is not a good measure for the severity of material transfer. Small and high lumps are potentially more damaging to the sheet than low and wide lumps. Lumps can become higher and smaller during material transfer, eventually without much volume change. Regarding the damage the lump can cause to the sheet surface, of more importance in the height increase of a certain lump, present on the tool surface.

3.2. Example 2

Fig. 3 shows a sequence of images of an (uncoated) tool surface sliding against an aluminum sheet under the following conditions:

v [mm/s]	$\overline{p}$ [MPa]	$l_{a\to b}$ [m]	$l_{a\to c}$ [m]	$l_{a\to d}$ [m]
2.5	7	1	2	3.5

The summit height distributions of Fig. 3^a, Fig.3^c and Fig.3^d are shown by in Fig. 4 (open dots) together with the equivalent Gaussian distribution of Fig. 3^a (black dots). It is clear that in particular the high-height 'tail' of the summit height distribution changes during lumps growth because of deposition of transferred material on the tool surface. According to the summit height distribution, the number of high-height summits increases, the number of middle-height summits decreases and the number of low heights does not change by material transfer.

4. Model

The aim of the model is to calculate a series of summit height distributions. Given an initial summit height distribution $\phi(s)$ and an increase of summits with an amount $\Delta(s)$ a new summit height distribution $\phi'(s)$ can be calculated by:

$$\phi'(s) = \frac{1}{\frac{d}{ds}\Delta s(s) + 1}\phi(s - \Delta s(s))$$

Calculating a series of summit height distributions will simulate the effect of lump growth on the tool surface. Of course, $\Delta s(s)$ has to be known to be able to calculate a new summit height distribution $\phi'(s)$. The height increase $\Delta s(s)$ is based on the theory, related to the wear mode diagram derived by Hokkirigawa and Kato (Hokkirigawa and Kato 1988). This diagram is, in turn, based on slipline models of sliding asperities derived by (Challen and Oxley 1979). $\Delta s(s)$ is found to be dependent on the normal load, the roughness of the tool, the geometry of the summit, adhesion between tool and sheet and the hardness of the sheet.

5. Results

In Fig. 4 calculation results (lines) are shown together with measured summit height distributions. It is evident from the figure that experimental results correspond well with calculation results.

6. Conclusions

Material transferon roughness level has been studied both experimentally and theoretically. A measurement method able to study changes in the microgeometry of the tool been developed. The method has been applied to the study of galling in unlubricated deepdrawing processes. Besides this, a theoretical model has been formulated which attempts to predict the change of the summit height distribution caused by galling. Experimental results are in good correspondence with calculations.

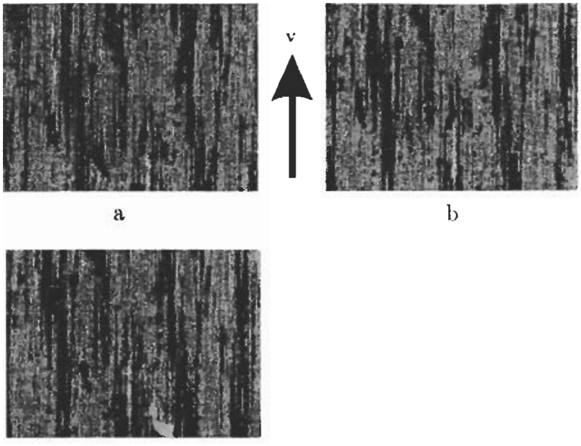
References

Challen, J. M. and Oxley, P. L. B.: 1979, An explanation of the different regimes of friction and wear using asperity deformation models, *Wear* **53**, 229–243.

de Rooij, M. B.: 1998, *Tribological Aspects of Unlubricated Deepdrawing Processes*, PhD thesis, University of Twente.

de Rooij, M. B. and Schipper, D. J.: 1998, A wear measurement method based on the comparison of local surface heights, *Wear* **217**, 182–189.

Hokkirigawa, K. and Kato, K.: 1988, An experimental and theoretical investigation of ploughing, cutting and wedge formation during abrasive wear, *Tribology International* **21**(1), 51–57.

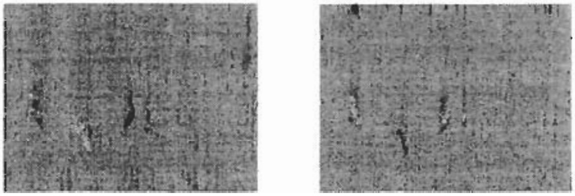


a

b

c

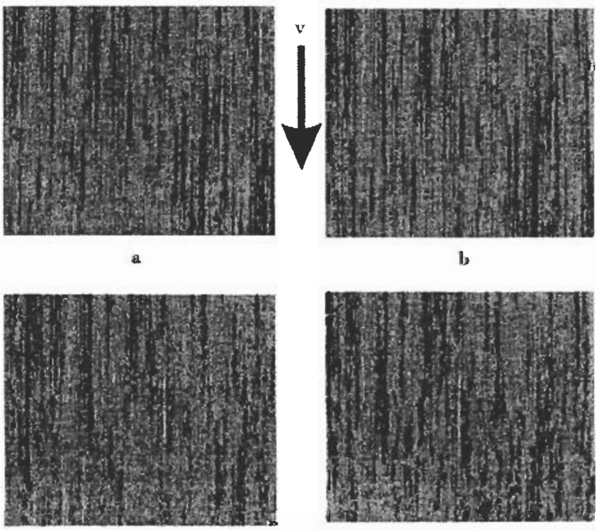
Fig. 1: A sequence of measurements performed on the same spot of a DLC coated tool surface



a

b

Fig. 2: Difference images obtained from the measurement data shown in Fig. 1



a

b

c

d

Fig.3: A sequence of measurements of an uncoated tool surface

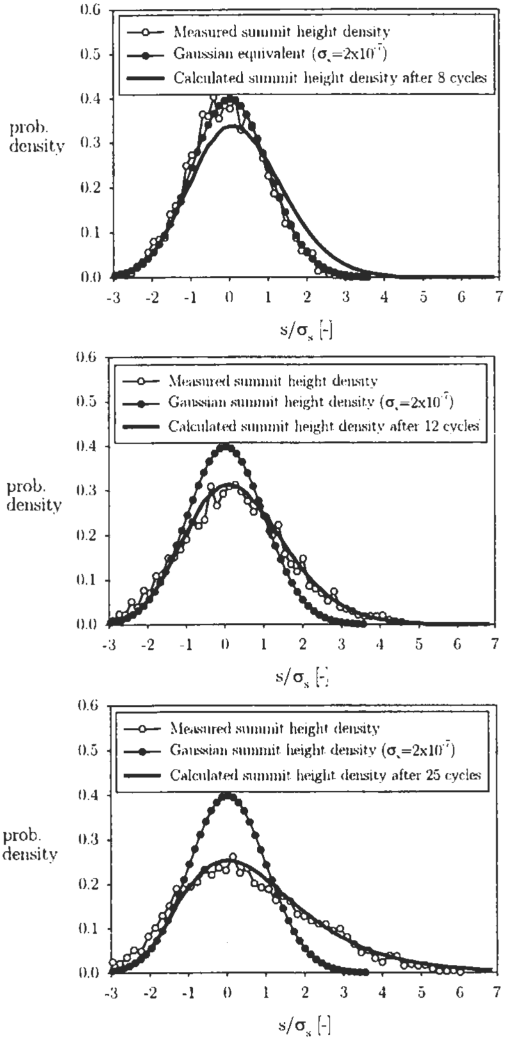


Fig. 4: Measured and calculated summit height distributions