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Characterisation of the flattening behaviour of modelled asperities

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ABSTRACT

In metal-forming processes tribological conditions between tool and workpiece are of greatest importance for process quality and process feasibility. This is even truer for microforming applications, where at least two dimensions of the workpiece are in the sub-millimetre range, due to increasing friction when process dimensions are scaled down. This effect can be explained by the model of open and closed lubricant pockets characterising the workpiece surface and the invariance of topography to scaling. As the number of workpiece asperities contacting the tool is drastically reduced the flattening behaviour of single asperities is of major interest for characterising tribology in microforming processes in more detail. Especially, a topography emerging on top of flattened asperites, the so-called nanotopography and its impact on the friction conditions has to be considered. Modelled asperities represented by pyramids with a base area of $120\,\mu m \times 120\,\mu m$ and a height of $32\,\mu m$ are flattened with a high-resolution experimental setup which enables in situ observation of the contact area. In-process measurement is complemented by post-process analysing the topography by confocal microscopy and scanning probe microscopy. This paper will show that a nanotopography on top of flattened asperities can emerge under certain geometrical conditions and that it has an impact on the friction conditions in the tool/workpiece interface. The detailed knowledge about the evolution of surface topography is relevant in particular to microforming but also for an improved understanding of tribological phenomena in general.

1. Introduction

1.1. Mechanical–rheological model

Tribology in metal-forming processes plays a significant role for the quality of the produced part, the tool lifetime as well as the process stability. Due to high contact pressures in the tool/workpiece interface, mixed friction is predominant. Therefore, the appearing real contact area has a major influence on the frictional conditions. Besides the normal stress and the mating materials, the topography of the workpiece and the existence of lubricant are important factors for the appearing real contact area, thus the friction conditions. For predicting and manipulating friction in forming processes, a functional characterisation of the surfaces is necessary. Standardised 2D roughness parameters are hardly able to fulfil this task. Concerning a single measured profile for example, there is no information about the spatial dimensions of a roughness valley, thus a pit is indistinguishable from a scratch. Hence, for the characterisation of the tribological behaviour of the workpiece surface during forming processes, 3D measurements and 3D roughness parameters are mandatory. At the Chair of Manufacturing Technology, 3D surface parameters have been derived from the model of open and closed lubricant pockets [1]. According to this model, the forming load is transmitted from an ideal flat tool to a lubricated workpiece surface by three different bearing ratios (Fig. 1(a)). These are the real contact area (RCA), closed (CLP) and open lubricant pockets (OLP). During the plastic deformation of the asperities due to the external forming load, the lubricant which is trapped in the roughness valleys is pressurised. As CLPs have no connection to the edge of the contact area, a hydrostatic pressure is built up and a part of the external forming load is transmitted reducing the normal pressure on the RCA, thus decreasing friction. In contrast, as OLPs have a connection to the edge, the lubricant is squeezed out resulting in a hydrodynamic pressure whose ability for transmitting the forming load is negligible compared to the hydrostatic pressure in CLPs. It can be summarised that CLPs reduce friction in contrast to OLPs. The ratio of RCA, CLP and OLP is determined numerically by several equidistant penetrations of a plane between the highest and the lowest point of the topography. Typical courses of the bearing ratios are shown in Fig. 1(b). As former investigations in the press shop have shown [2], two distinctive parameters can be derived from the course of the closed void area ratio for characterising sheet metal: the maximum ratio of the closed void area (α_{clm}) and by integrating the curve, the normalised closed void volume (v_{cl}).

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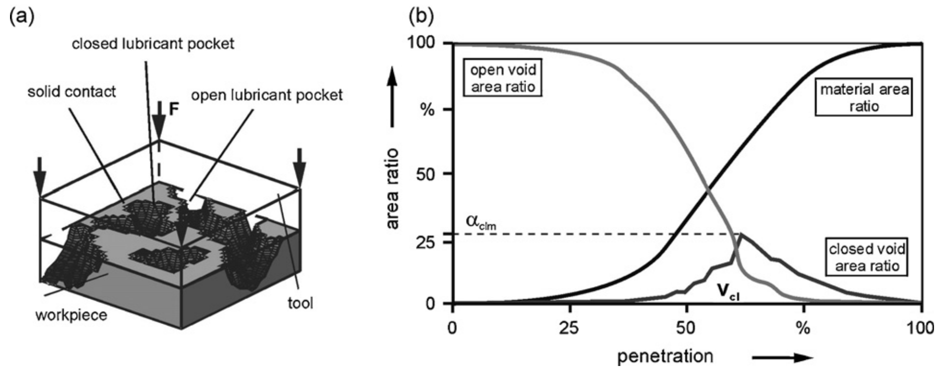

Fig. 1. (a) Mechanical–rheological model; (b) surface fractions as a function of vertical penetration.

1.2. Tribology in microforming

When miniaturising forming processes from conventional length scale to the micro-scale, i.e. at least two dimensions of the part are in the sub-millimetre range, several specifics have to be taken into account. Due to size effects, a drastic increase in friction in microforming applications is observable [3,4]. This phenomenon can be explained by the scale invariance of the topography due to the production process of the raw parts. When scaling down forming processes, the contact area is reduced significantly while the size of single topography features remains approximately constant. Therefore, the ratio of CLPs is reduced drastically and the external load will be transmitted more and more by the RCA which consequently will increase leading to an increase in friction (Fig. 2). Additionally, the total amount of asperities is reduced. Thus, for a functional topography characterisation for microforming applications, the flattening behaviour of single asperities has to be investigated in detail. Especially, the assumption of the complete flattening of the RCA cannot be maintained. Instead, the possibility of the emergence of a sub-topography or nanotopography within the flattened RCA – as it has already been proposed by [5] – has to be considered. The interaction between this nanotopography and liquid lubricant and its impact on the tribological behaviour has not been analysed yet.

2. Experimental setup

For the detailed analysis of the flattening behaviour of a single asperity and the evaluation of the contact state within the real contact area, upsetting tests have been performed with the test rig shown schematically in Fig. 3(a). It consists of a piezoelectric actuator with an integrated position sensor enabling a vertical movement of the specimens in 10 nm steps. The required force for flattening the asperities is measured by a high-sensitivity load cell. The upper tool is made of quartz glass and is designed as a frustrum with a nominal diameter in the contact area of 1.2 mm. Thus, the flattening behaviour and the evolution of the contact area can be observed in situ with a telecentric objective and a CCD camera.

Technical surfaces which are produced by turning or grinding for example, are not very well suited for basic investigation

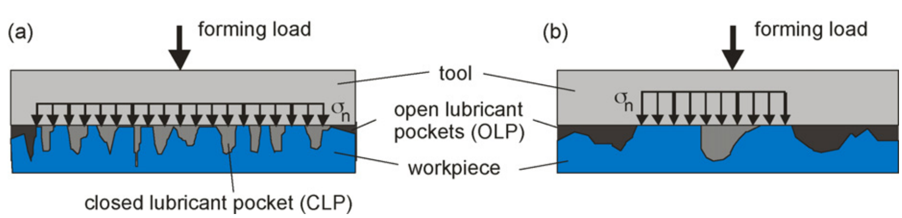

Fig. 2. (a) Contact state at conventional length scale; (b) contact state in microforming processes.

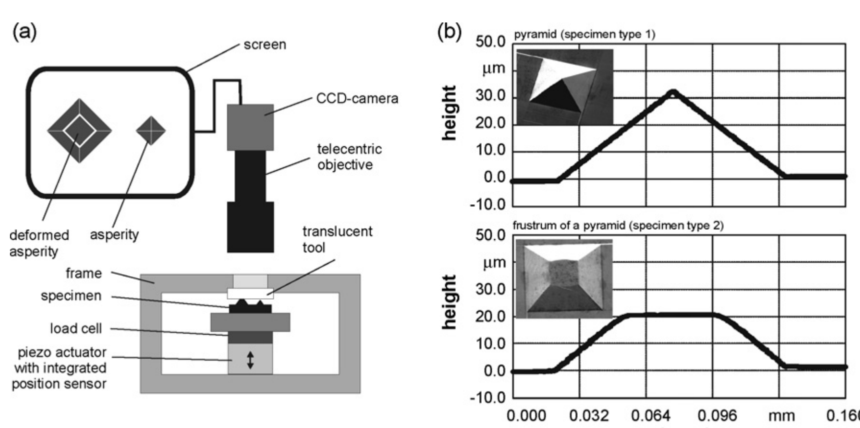

Fig. 3. (a) Schematic drawing of the test rig; (b) SEM image and profile of specimens.