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Laboratory test simulation of galling in cold forming of aluminium

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ABSTRACT

Cold forming of aluminium is a group of very efficient methods, which are successfully used in a number of industrial applications. Two of the major factors limiting the tool life and restricting the shapes and sizes possible to produce, are *galling*, i.e. transfer of work material to the tool surface, and *high stresses* occurring when forming complex shapes. Both phenomena are closely related to the friction and adhesion in the tool to workpiece interface.

The present paper investigates the influence of several surface parameters to the tendency to galling. This is done by forming aluminium using tool steel in a geometrically simplified lab test. The test scans over a wide load interval while monitoring the coefficient of friction. The corresponding transfer of work material to the tool surface is studied in the SEM after testing. The test is focused on the initial tool contact and also on the number of contacts before a critical friction level is reached.

The test set-up comprises two crossed cylinders in sliding contact, one made of tool steel and one of work material. Three commercial tool materials were included, each prepared to two surface finishes. The aluminium workpiece cylinders of AA6082 were prepared by two different pre-treatments, solid lubrication followed by soft annealing and pickling, respectively.

The respective importance of the tool material, preparation of the tool surface finish and the aluminium surface pre-treatment are compared with respect to initial galling tendencies and friction stability. The practical implications for real forming applications are discussed.

1. Introduction

Cold forming of aluminium is a group of very efficient manufacturing methods, which are successfully used in a number of industrial applications, including deep drawing, extrusion and bending. The cold forming process in focus of this study is performed at ambient temperature with the use of a two-piece tool, a die and a punch. The forming starts from a solid metal blank that is placed in the die and forced by the high pressure from the punch to deform plastically into the new shape defined by the volume between the die and punch. The method has several advantages compared to other methods: no scrap material is produced, a decorative surface finish is achieved and many complex shapes may be formed [1,2]. Friction is important in the forming since it does not only influence the forming force but also the forming limitations, spring-back and exterior quality [1].

Cold forming is a fast process, and a great number of products should be possible to form without interruption for service or exchange of tool. However, aluminium is a complicated material to form, since it has a tendency to adhere to the tools during forming. Two of the major factors limiting the tool life and restricting the shapes and sizes possible to produce are galling and high stresses, while wear of the tool is not a problem. Galling is adhesion and subsequent transfer of aluminium work material to the tool surface followed by hardening of the adhered aluminium by oxidation, work hardening or grain refinement. The hardened aluminium scratches the next pieces to be formed in a repeated forming cycle. The deviation for the final products escalates, since the tool is modified by the adhered aluminium and the surface roughness is increased.

Correspondingly, an increase in friction force during forming is often an indication of galling [3]. The high stresses occur when forming complex shapes requiring large scale plastic deformation. Both phenomena are closely related to the friction and adhesion in the tool to workpiece interface.

Several parameters are known to affect galling. The risk of galling is reduced with decreased surface roughness, addition of lubricants, minimisation of sliding distance, decreasing contact pressure or coating the tool with a suitable ceramic [3]. If galling occurs, the tool has to be dismantled and pickled to remove the adhering aluminium.

For stainless steels, also known to easily cause galling, an upper limit has been found for the surface roughness under which no, or

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Table 1
Main alloying elements and hardness of the tested tool steels.

Tool steel	Steel type	Hardness [HRc]
Grade A	5Cr–Mo–V	50
Grade B	5Cr–Mo–V	55
Grade C	9V, 4.5Cr–Mo–W	60

very little, galling occurs [3,4]. It would be very valuable if such a value could be found also for aluminium.

The present paper sets out to investigate the influence from tool material, tool surface roughness and aluminium workpiece surface preparation on the tendencies to galling. The tools of interest form different three-dimensional objects of varying shapes and sizes, corresponding to different degrees of deformation, sliding distances between tool and work material, forces and so on. A simplified test rig giving contact conditions representing these forming operations was used. In this so-called load scanning rig the tool and workpiece are represented by two crossed cylinders [3,5,6]. The tool cylinder slides against the workpiece cylinder during increasing load, resulting in an increasing degree of plastic deformation. The friction force is continually monitored and the corresponding surface damage and possible galling is evaluated by scanning electron microscopy after the test.

The test was run in two modes:

- Single passage mode, representing the very first contact between the tool and workpiece.
- Multiple strokes mode, representing the ability of the system to keep a low friction and avoid severe galling after repeated contacts. In this mode the test was interrupted when a threshold friction force was reached.

The validity of using the number of strokes to reach the threshold as a measure of the galling tendency of the tested material pair was investigated.

2. Experimental

2.1. Specimens

Three types of tool steel were tested, see Table 1. Grade A is an ingot-cast conventional hot forming tool steel (H13) of matrix type (very low content of carbides), Grade B is also an ingot-cast matrix tool steel (modified H13), and Grade C is a powder-metallurgical high speed steel (PM HSS) with nominally 24 vol.% of carbides.

Aluminium samples of an industrially important alloy, AA6082 (1.2% Si and 0.8% Mg), were produced by soft annealing and lubrica-

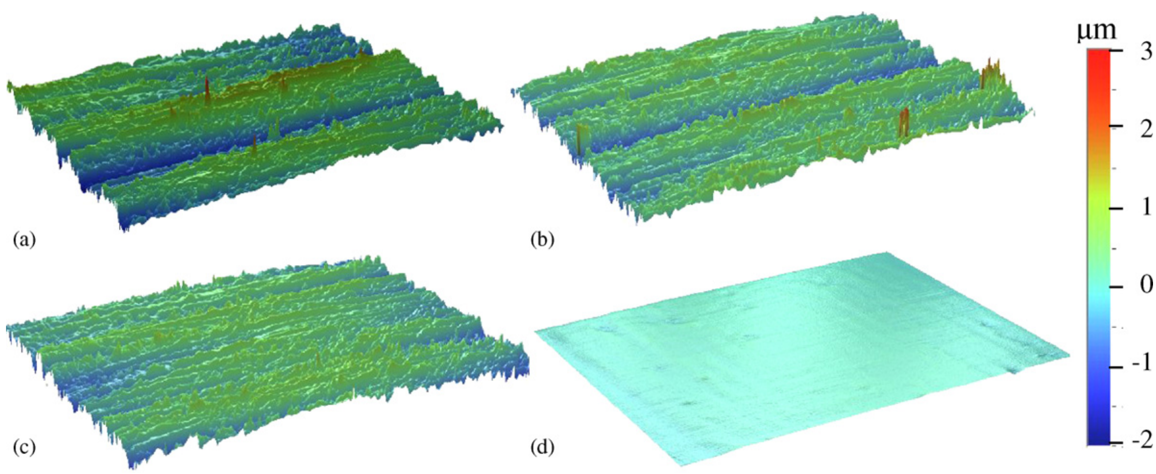

Fig. 1. Roughness images of the rougher tool surfaces (white light interferometry). 120 µm × 91 µm. (a) Grade A, (b) Grade B and (c) Grade C. (d) For comparison a smooth Grade A sample (59 µm × 45 µm) is shown using the same height scale. The analysed area is identical to the one in Fig. 2a.

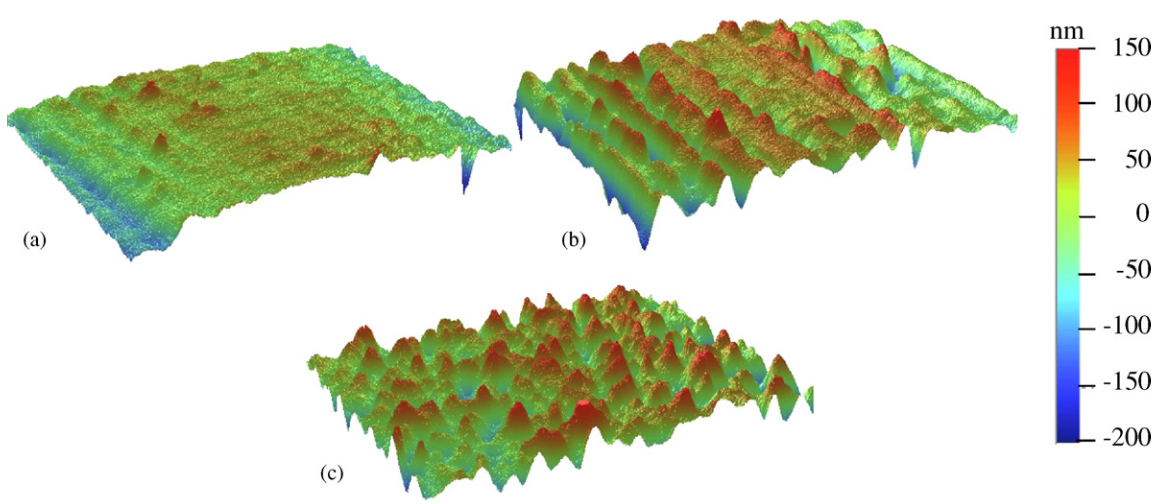

Fig. 2. Roughness images of the smoother tool surfaces (white light interferometry). Note that the height magnification is much higher than in Fig. 1. 59 µm × 45 µm. (a) Grade A, (b) Grade B and (c) Grade C.