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Improvement of tool life in cold forging by locally optimized surfaces

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Abstract

Cold forging tools are exposed to extremely high loads. Depending on the most critical combination of the dominant factors characterizing the load which can be different even within the same tool, different damaging mechanisms will be initiated at least one of which is finally limiting tool life by either wear or fatigue. Since these failure mechanisms are mostly initiated on the tool surface the adjustment of surface properties to the local effective load combination might improve tool performance and increase tool life. In this paper, three different methods are being investigated: hard roller burnishing, laser beam treating and surface texturing. The determination of the tool load is a precondition for the selection of the appropriate surface treatment method. Thus, to find out which of the three methods can be used for tool surfaces in selected case studies, process simulation by finite-element-analysis becomes mandatory. Accordingly, FEA is used to select the optimum surface treatment which is then applied and tested in industrial applications.

Keywords: Tool life; Cold forging; Surface treatment; Finite-element-analysis; Hard roller burnishing; Laser beam treating; Surface texturing

1. Introduction

In cold forging tools are exposed to extremely high loads due to the high forming stresses and the strain hardening of the workpiece material. Therefore, the improvement of tool technology plays a key role for increasing the tool life which will improve the innovation and competitiveness of the companies as well as open up new product ranges [1,2]. The tool surface subjected to contact stresses of more than 1000 MPa is of particular importance for the two dominating damage causes, fatigue and wear, limiting tool life [3]. Fatigue is due to the cyclic loading of the tool. Fatigue cracks appear even at a very early stage and can lead to disruption at the tool surface and thus to the failure of the tool [4]. Wear is caused by the combination of high contact stress and cumulating sliding length and affects in general the accuracy and surface quality of the workpiece [5]. The subject of the research presented in this paper concerns highly loaded cold forging tools, where both of the damaging mechanisms are observed limiting the tool life. In order to open up new potentials to increase tool life, the objective is to find an optimized tool surface which is locally adapted to the tool load by means of different methods like hard roller burnishing, surface treatment by laser and surface texturing.

2. Fundamentals

This chapter contains a short description of the three surface treatment methods in consideration.

2.1. Hard roller burnishing

Hard roller burnishing is a flexible method in which a ceramic ball is rolled on the machined surface under high pressure flattening the topography by local plastification.

Burnishing can generate residual compressive stresses throughout the surface layers even if tensile residual stresses exist on the prior machined surfaces [6]. The basic principle of hard roller burnishing is schematically shown in Fig. 1.

The hydrostatically supported burnishing ball is in contact only with the surface to be burnished and free to roll with low friction. After a short period of time (10–30 s) the burnishing pressure p_B reaches a predefined value that is directly proportional to the burnishing force F_N. The burnishing speed v_B depends on the rotation speed of the axially symmetric tool in the turning lathe. The burnishing feed rate f_B can also be set to a constant value in the turning lathe. In this process, due to the local plastification, a surface layer of a certain depth will be subjected to work hardening, thus affecting the distribution of residual stresses. The maximum compressive stress typically occurs in a depth of 120 μm below the surface, curve (a) in Fig. 2. This is quite different to the residual stress distributions

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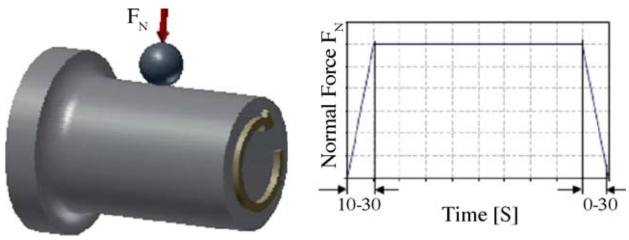

Fig. 1. Hard roller burnishing on a tool surface.

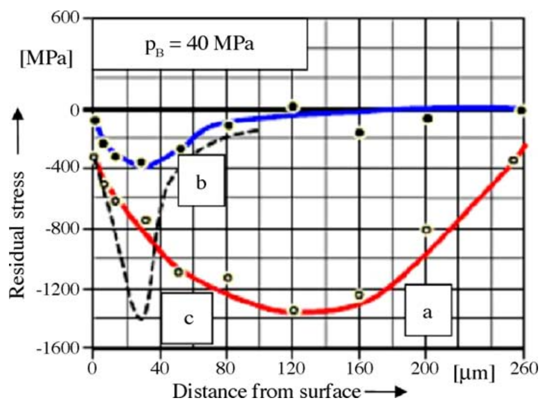

Fig. 2. Course of residual stresses of a hard roller burnished (a), a turned (b) and a shot-peened (c) surface [7].

of turned (b) respectively, shot-peened (c) workpieces where the maxima are found at a depth of about 30 µm. A tool specially adapted for the requirements of hard roller burnishing on high strength materials (e.g. cold forging tools) is used in this work.

2.2. Surface heat treatment by laser

This is a flexible method to modify surface properties selectively by martensitic transformation yielding locally improved wear resistance. Additionally, due to the gradients in thermal expansion occurring during the treatment, residual compressive stresses can be induced. Fig. 3 shows the set up for the used diode laser.

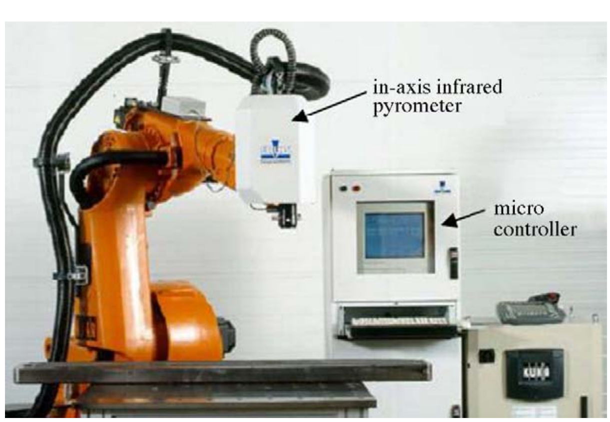

Fig. 3. 4.6 kW diode laser system for temperature controlled hardening, in-axis two-colour infrared pyrometer with micro controller, jointed-arm-robot with a payload of 30 kg and a repeatability of 0.15 mm.

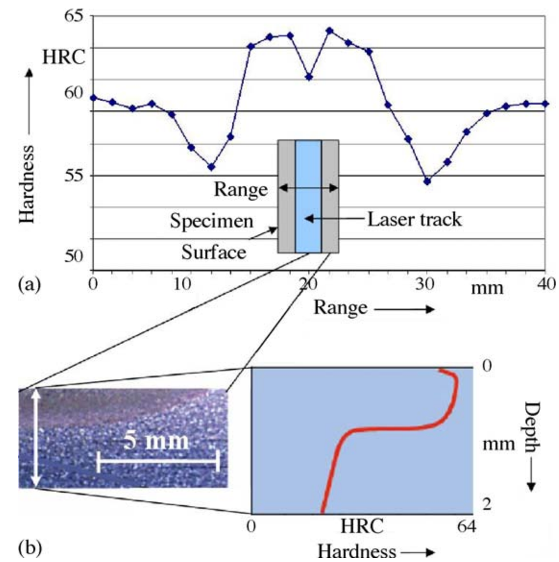

Fig. 4. Hardness profile on the surface (a) across the track, and (b) perpendicular to the surface.

The laser spot guided along a certain track by a well defined speed heats up the workpiece locally at a high heating rate. During the immediately following self-quenching process the heated regions transform from austenite to martensite yielding the high hardness [8]. From basic investigations the cross section of a laser treated track in a steel block (1.3343) as well as the resulting hardness penetration profile can be seen in Fig. 4. The laser track width is 20 mm and the hardness penetration depth is 1 mm.

2.3. Surface texturing

Surface textures can improve the tribological state by so called lubricant pockets (see Fig. 5). The excimer laser material processing provides the possibility to generate such pockets on tool surfaces, uncoated as well as coated, and with a high flexibility considering the arrangement and geometry of the textures.

Lubricant pockets are shown schematically (b, left) and real lubricant pockets (b, right) on a tool surface.

Surface texturing is proved already in some industrial applications to increase tool life distinctly, e.g. for punches in back-

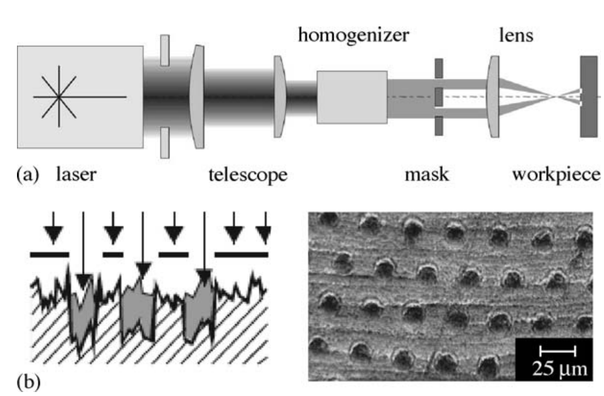

Fig. 5. Principle of excimer laser material processing with the mask projection technique (a and b, left).