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Local adjustment of surface integrity of forming tools by adaptation of tool making process

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Abstract

Within sheet-bulk metal forming manufacturing of functional elements, like e.g. gears, causes distinctive tool stresses. Since highest stresses occur at the surface of active tool components, the tool surface has major influence on the tool performance. Within the present study, the influence of a local surface treatment on the surface integrity of an AISI M3:2 PM tool steel was investigated. In this regard, a laser heat treatment was implemented in a conventional process chain consisting of WEDM and post machining by blasting and shot peening. Due to an enhancement of ductility of the surface region, higher compressive residual stresses can be achieved for the adapted process chains after the final peening step.

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1. Introduction

Forming processes enable material and energy saving manufacturing of steel based products. Growing customer expectations require higher product quality in terms of closely-tolerated as well as highly integrated functional components. Conventional forming processes often reach limits in producing those parts [1]. An innovative approach is given by the process class sheet-bulk metal forming (SBMF) which comprises the application of bulk and sheet forming processes on sheets or plates [2]. Within SBMF, the combination of sheet and bulk metal forming operations leads to globally and locally varying load conditions. The high loads result in distinctive contact normal stresses and require highly loadable tool materials in terms of hardness and compressive strength. This is why tool steels are often used as tool materials [3]. Due to the high brittleness of this material class, surface integrity, which is determined by tool making process, has a major influence on the strength of a tool. Within tool making, electrical discharge machining (EDM) represents the hard machining standard of complex tool geometries [4], which are necessary for production of functional components, like e.g. gears. The heat flux of EDM causes a thermal influenced surface layer [5]. If the layer is not fully removed by subsequent machining steps, the remaining surface defects function as origin for tool failure. The current contribution aims to improve surface integrity of forming tools by an innovative process chain within the tool making process. Within the investigations, blanks made of tool steel AISI M3:2 (1.3395) are machined by electrical discharge machining followed by a process combination consisting of blasting, laser heat treatment and peening.

2. Local adaption of tool surface for influencing tool behavior

SBMF processes include zones with high stress and strain states. This is due to the fact that components manufactured by SBMF often contain bulk formed features, like e.g. gearings (Fig. 1a). Thus, high contact normal stresses with values up to 2500 N/mm² can occur [6]. These high contact pressures cause distinctive tool stresses (Fig. 1b). Especially, at sharp radii stress concentrations in combination with tensile stresses occur. Due to the resulting notch stresses, fatigue

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represents one major risk for tool failure. The surface integrity of the tool has a strong influence on the fatigue behavior, since fatigue cracks are often initiated at the surface of a tool [7].

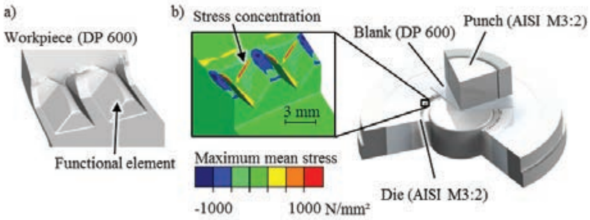

Fig. 1. (a) Functional elements; (b) Stress concentration in SBMF.

The aim of the present study is to locally improve the surface integrity of highly stressed tool regions by adaption of tool making process. A laser heat treatment was integrated in the tool making process in order to anneal the near surface region without influencing the hardness of the bulk material of the tool. At the same time, this increase of ductility can be used for a further strengthening of the top layer by strain hardening. Therefore, a combination of blasting and peening is applied. In contrast to hardening by a conventional heat treatment, peening operations have the potential for the inducement of distinctive compressive residual stresses in the top layer which have a beneficial impact on the fatigue strength of tool components.

3. Experimental setup

Tool steel represents the standard material for highly stressed tool components. Within the present paper, the PM steel AISI M3:2 (1.3395) of Erasteel was investigated. The material represents a standard tool steel for highly stressed active tool components such as dies or punches. AISI M3:2 is a PM tool steel with high carbide content (Table 1). The steel was tempered to 64 HRC which represents a standard hardness value for tool application.

Table 1 Structural properties of AISI M3:2 [8]

C	Cr	Mo	W	V
1.28 %	4.1 %	5.0 %	6.4 %	3.1 %

3.1. Specimen geometry and applied process chains

For the investigation of the influence of surface machining, a plane specimen geometry was chosen. The specimens have a height of 8 mm and a rectangular shaped surface of 19 mm x 19 mm (Fig. 2a). The present study compares three process chains: a conventional process combination consisting of wire electrical discharge machining (WEDM, strategy “E”) as well as subsequent blasting (strategy “B”) and peening (strategy “P”) and adapted process chains including a laser heat treatment (strategy “L”) (Fig. 2). WEDM causes a thermal influenced layer, the so called “white layer”, which has to be removed by subsequent process steps. Within the conventional process chain I, the white layer is post machined by abrasive blasting. The abrasive grains crack and remove the brittle surface layer. The peening process with ceramic balls strengthens the surface and induces compressive residual stresses. The influence of the laser heat treatment is investigated by the adapted process chains. Strategy “L” aims to anneal the surface layer in order to increase ductility of the near surface region. By setting the heat treatment before (II) and after (III) the abrasive blasting process, the question is answered whether the sequence of process steps has an influence on the resulting surface integrity.

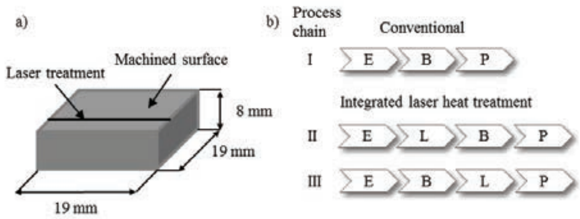

Fig. 2. (a) Specimen geometry; (b) investigated process chains.

Within the present paper, WEDM was done on a “CUT 2000 S” machine from the company GF Machining Solutions. A brass wire with a diameter of 0.25 mm was applied as electrode. The target surface quality was set to VDI step 10 which corresponds to a finished surface in tool making. Within conventional post machining, the WED-machined surfaces were blasted and shot peened. The parameters were empirically chosen according to tool making standard of the company Berner + Straller. Blasting with aluminium oxide grains and a medium grit size of 25 µm cracks and removes the white layer. In a further compressive step, shot peening with ceramic balls of a mean diameter of 188 µm strengthens the surface. Blasting and shot peening were done on a peening machine Peenmatic 770S of the company Iepco. The peening time amounted 20 s. The pressure was chosen to 2.5 bar for abrasive blasting and 2 bar for shot peening in order to guarantee sufficient material removal and strengthening of the surface. Laser heat treatment was carried out on a solid-state laser HL 4006D of the company Haas. The Nd:YAG laser emits radiation of a wavelength of 1064 nm. Within L process the laser beam was kept on a line. The feed was chosen to 5 mm/s with a laser power of 1250 W/cm². The spot size amounted 3 mm. Using these parameters, softening of the surface and a beneficial influence on the near surface residual stress state could be achieved in a preliminary study.

3.2. Applied measuring methods

The surface properties, caused by the different machining steps, are analyzed in terms of surface topography and roughness as well as the residual stress state in the top layer. The surface topography is fundamental for e.g. the tribological performance of a forming tool. In this study, the topographic analysis is used for the visualization of the surface characteristics. The machined surfaces were analysed by confocal microscopy with a µSurf microscope of the company NanoFocus. In order to get quantitative information about the profile depth, the averaged roughness height Rz was determined. The Rz value guarantees a high level of comparability to other investigations since this value represents a standard in industrial roughness measurement.