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Influence of an angular hatching exposure strategy on the surface roughness during picosecond laser ablation of hard materials

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Abstract

Innovative chip breakers for cutting tools made of very hard materials require laser ablation and demand a high quality regarding the manufactured surface. When processing materials such as polycrystalline cubic boron-nitride or tungsten carbide the surface roughness by laser ablation reaches S_a = 1,0-2,9 µm compared to S_a = 0,42 µm achieved by grinding. Therefore in the presented research the influence of the hatching exposure strategy on surface roughness during picosecond laser ablation of tungsten carbide is examined. The areal, layerwise ablation process is separated into its elements which are represented by intersection zones between single and multiple laser vectors. Thus two mechanisms of roughness formation are identified and described by model functions. Further the mechanisms are transferred to areal ablation in which surface roughness decreases due to improved hatching angles compared to a commonly used one of φ= 0°/90°. With this approach the roughness is reduced by approximately factor 2,0-3,5 to S_a = 0,82 µm. In conclusion guidelines are derived which present favorable settings for high quality laser ablation processes.

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Keywords: picosecond laser ablation; hatching angle; surface roughness; hard materials; tungsten carbide

1. Introduction

Short- and ultrashort pulsed laser ablation of hard materials is used for manufacturing of geometries in the micrometer range for cutting tools, dental implants, injection molds or in post-processing and finishing of 3D-printed parts [1-4]. Furthermore laser processing by ultrashort laser radiation enhances the manufacturing of very small

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geometries for example for chip breakers in cutting tools from hard materials such as tungsten carbide (TC) or polycrystalline cubic boron nitride (PCBN) [5].

Chip breakers in cutting materials of high hardness are conventionally manufactured by grinding or electrical discharge machining (EDM). Nevertheless in these manufacturing methods the geometrical freedom is limited by the shape and size of the grinding wheels or electrodes and a critical heat affected zone (HAZ) is present [6]. Laser ablation, in contrast to the conventional methods, enables a non-contact, and thus force- and wear-free processing. The geometric diversity is significantly less subject to limitations and areas normally difficult to access can be machined. In this context laser ablation enhances innovative cutting tool designs which are able to realize new potential for improved chipping processes with higher cutting speeds and reduced tool wear when machining ultrahigh strength steels or titanium alloys.

For cutting tools and chip breakers from hard materials there occur high demands regarding the surface quality. Here conventional processes are still superior. While the surface roughness S_a of tungsten carbide after grinding amounts $S_a = 0{,}42$ µm the surface roughness by laser ablation reaches $S_a = 1{,}0\text{-}2{,}9$ µm when processing in axial direction of the laser beam. Nevertheless when a specifically tailored and adjusted surface roughness is required laser ablation is advantageous [2].

To further utilise the benefits offered by laser ablation the roughness needs to be reduced. The influence on the surface quality of laser parameters such as average power, pulse frequency, scan speed, focal position et cetera is described in multiple studies [7-10]. Besides by laser parameters the surface roughness is significantly influenced by the hatching exposure strategy. In this context the hatching angle becomes important to the eventual surface roughness of the chip breaker cavity.

During laser ablation voluminous geometries such as chip breakers are processed by a layerwise, areal material removal. In each layer the cross-sectional area is filled with parallel laser vectors and thus a constant track distance (*TD*) and pulse distance (*PD*) is maintained. The hatching angle describes the angle between laser vectors of two consecutive layers.

This research considers the central questions which quantitative influence of the hatching exposure strategy on the final surface roughness can be characterized and how the appearance of roughness through exposure strategies can be explained. Therefore the influence of specific hatching angles on the surface quality during picosecond laser ablation of hard materials is examined and affecting mechanisms of roughness formation are identified. Further the concluding question is answered which setting has to be applied as a favorable hatching angle for a high quality laser ablation process.

2. State of the art

The influence of an angular hatching exposure strategy on the surface roughness is only marginally analyzed. In recent studies during laser ablation with the objective to reduce the surface roughness of 3D-printed parts Campanelli et al. (2013) used a 45° hatching angle [10]. However, the angle was not varied further and in the analysis only laser parameters were taken into account as a factor of influence on roughness. During laser finishing of metallic materials Koch (2011) was applying a hatching angle on copper when working with a $t_p = 100 – 500$ ns pulsed $P = 16$ W Nd:YAG-Laser [11]. The process result was improved when following layers are not congruent. A congruence equates a hatching angle of $\varphi = 0°$. With an alternating hatching angle between each layer ($\varphi_n = 0°$ and $\varphi_{n+1} = 90°$) a roughness of $R_a = 3{,}3$ µm was achieved after ablation of $n = 10$ layers and with a hatching angle of $\varphi = 60°$ a roughness of $R_a = 2{,}5$ µm was measured. Koch (2011) assumes that the smaller the hatching angle the more homogenous the overlap of laser tracks and thus the higher the surface quality. At the $\varphi = 0/90°$ setting an oriented, microscopic structure was observed which affects the surface roughness. The structure was not present on the $\varphi = 60°$ setting in Kochs (2011) study. Nevertheless the examination of further angular settings is neglected and detailed mechanisms of roughness formation are not described.

Other technological approaches to reduce a surface roughness by laser processing can already realize a high surface quality. With laser polishing Rosa et al. (2015) were able to achieve a roughness of up to $S_a = 0{,}79$ µm and Temmler et al. (2011) could even reach $R_a < 0{,}1$ µm [12-13]. However this polishing process uses laser remelting. Material on the surface of workpieces is molten and a smooth surface is created by surface tension of the melt. Therefore the process is not feasible for materials with no distinguished melting point such as carbon-fiber-