LASER HARDENING OF MILLING HEADS WITH EMPHASIS ON MINIMAL DEFORMATION

HRUŠKA Matěj, VOSTŘÁK Marek, SMAZALOVÁ Eva

University of West Bohemia, Pilsen, Czech Republic, EU, maslej@ntc.zcu.cz

Abstract

Hardening of contact surfaces of milling head is centerpiece of this study. The most important point is to maintain defined processed part geometry. This precise processing was performed using the scanning laser hardening method. The scanning method uses a small laser spot in combination with a scanning head. The method is based on a very fast laser beam sweeping perpendicularly to the main laser treatment trajectory, allows better control of energy distribution and optimization of treating pattern. Disk laser with maximum power of 5.3 kW was used for heat treatment. Surface hardness and depth of hardened layer were evaluated. 3D profiles of hardened parts were measured on 3D scanner Alicona before and after laser processing. Geometrical deformations were assessed using the method of differential analysis.

Keywords: Laser hardening, laser quenching, laser scanning, surface treatment, deformation

1. INTRODUCTION

Laser hardening has proved to be a very competitive method of material heat treatment [1,2,3]. It differs significantly from the conventional methods of heat treatment. The important feature of the laser hardening is the absence of a cooling medium. Laser radiation acts as a heat source and it heats up rapidly the surface of a part under the laser spot during a short time of the laser-surface interaction [4]. Consequently, the heat absorbed in the surface layer is conduced immediately into a material bulk. The part can be hardened by the laser radiation only in a surface layer, approximately to one tenth of material thickness. The hardened surface can reach a very high hardness due to very rapid heat dissipation. The maximum achievable depth of hardened layer is about 2 mm without melting of the surface (in dependence on the treated material properties, geometry of the part and laser beam parameters) [5,6].

Laser hardening with scanner is a new method of laser processing, which is especially useful for processing of small parts or hardly reachable places [7,8]. Using laser beam scanning method makes possible to achieve a very precise and fast processing of 3D parts, it helps to achieve a minimal heat affected zones and it minimizes distortions. Gaussian spot with smaller size from hundreds of micrometers, to several millimeters in focus is used in contrast with a standard laser hardening beam profile [9,10]. It allows higher control over the process. Hardened area is heated rapidly by quick scanning of the laser beam. Even very complex regions of limited size can be processed as a whole piece. It is necessary to choose the right amplitude, oscillation frequency and traverse speed. Burns occur at the edges of the processed area (oscillation amplitude peaks) due to the limited dynamic of the scanning optics. The burns can be eliminated by switching off the laser on the edges or by the beam defocusing.

The scanner is able to deflect a laser beam with speed above 20 m/s, **Fig. 1a**. High traversing speed is assured by rotating mirrors, with a very low mass and inertia. Only a slight rotational movement of mirrors is converted to very quick linear movement of laser beam on a treated surface, **Fig. 1b**. Difficult to reach areas can be treated thanks to a large working distance. These systems are used mainly in the automotive industry currently. Processes like remote laser cutting, welding or marking are executed by the scanners, which are often fixed to a wrist of an industrial robot for these applications [8].

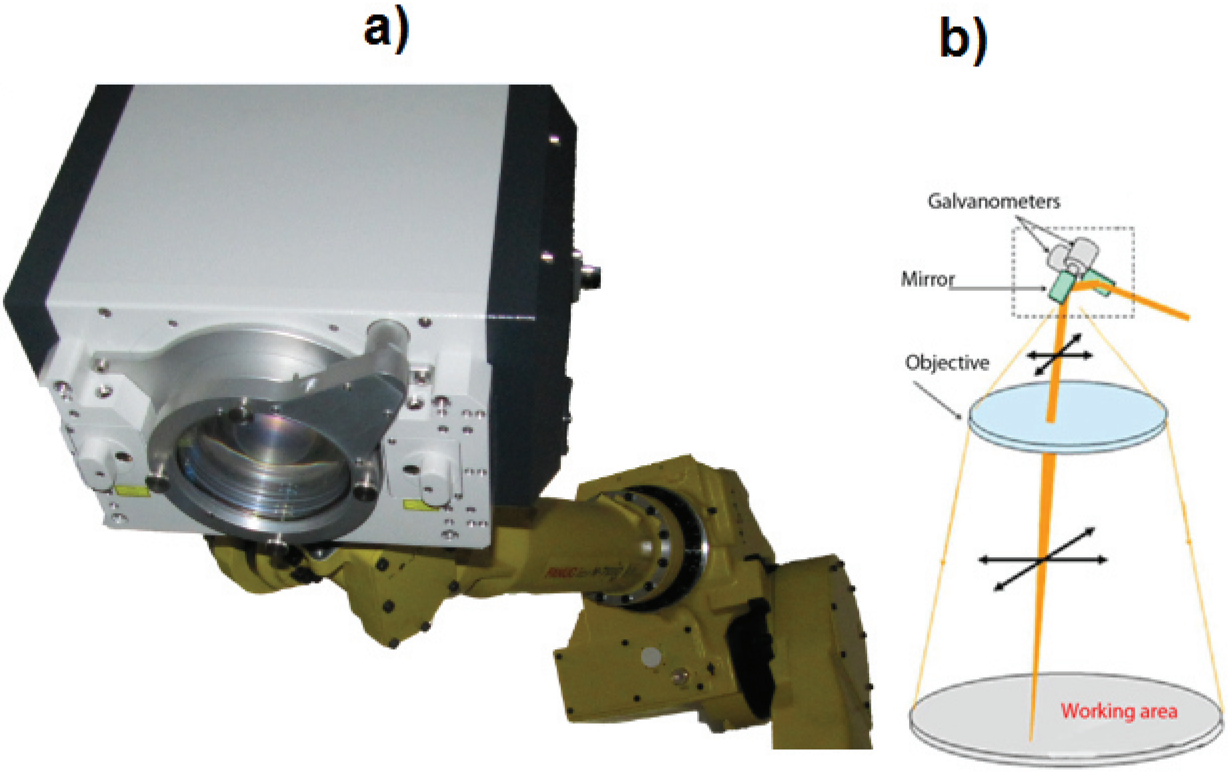

Fig. 1 (a) Scanner mounted on the arm of industrial robot for remote processes; (b) Basic schema of a scanner system

The scanning method is convenient especially for processing of complex parts. The scanner allows changing a width of the processed area easily during the process. Scanning software allows very precise control of energy distribution in the processing area and thus very complex treating patterns can be produced. Spot size can be modified using a varioscan (z-axis movement) [8].

Heat treatment results in geometrical deformations of processed part. Laser hardening is one of the least invasive techniques because the amount of the heat input is low. Subject of this study is to prove applicability for processing of precious parts with highly defined proportions.

2. EXPERIMENTAL PROCEDURE

2.1. Laser system

Laser system for surface treatment consists of Trumpf disk laser Trudisk 8002 and 3D-scan system ScanLab intelliWELD 30 FC V (scan head - **Fig. 1a**). The laser emits a beam of wavelength 1030 nm. Spot size 800 um was used for application tests. The maximum laser power is 5.3 kW. Working distance of the scanning optics is 544 mm and the focal length is 460 mm. The scan head is able to process an elliptical image field of dimensions 385 x 270 mm, the maximum laser beam deflection speed is 21.5 m/s. The scan system collimation in z-axis is allowed in range of ± 70 mm. The scanning procedure is controlled by SAMLight software. Positioning of the scanning head is realized by industrial robot Fanuc M-710iC.

2.2. Laser process

Laser scanning hardening method was applied to milling head processing [8]. Milling head has very complex geometry and cannot be processed using standard laser hardening method [10]. Material of the milling head is 34CrNiMo6 (ČSN 16343, DIN 1.6582). Hardening process had to be preciously programmed because of inhomogeneous heat dissipation. The objective was to harden three bearing areas of the milling head. In the case of complex geometry it was necessary to divide heterogeneous area into several parts and process these parts separately, **Fig. 3**. Notice 3D model of milling head and three contact areas which were laser hardened, **Fig. 2**. The area A had to be divided into four parts, which were processed differently. The scanning amplitude of laser beam is an important factor for parameter selection. Areas 2 and 3 (**Fig. 3**, **Table 1**) were processed using lower power in comparison with areas 1 and 4 (**Fig. 3**, **Table 1**), where higher scanning amplitude can be used. Shape of processing patterns had to be optimized to achieve high-quality results and ensure homogeneous energy density over the entire hardened area.

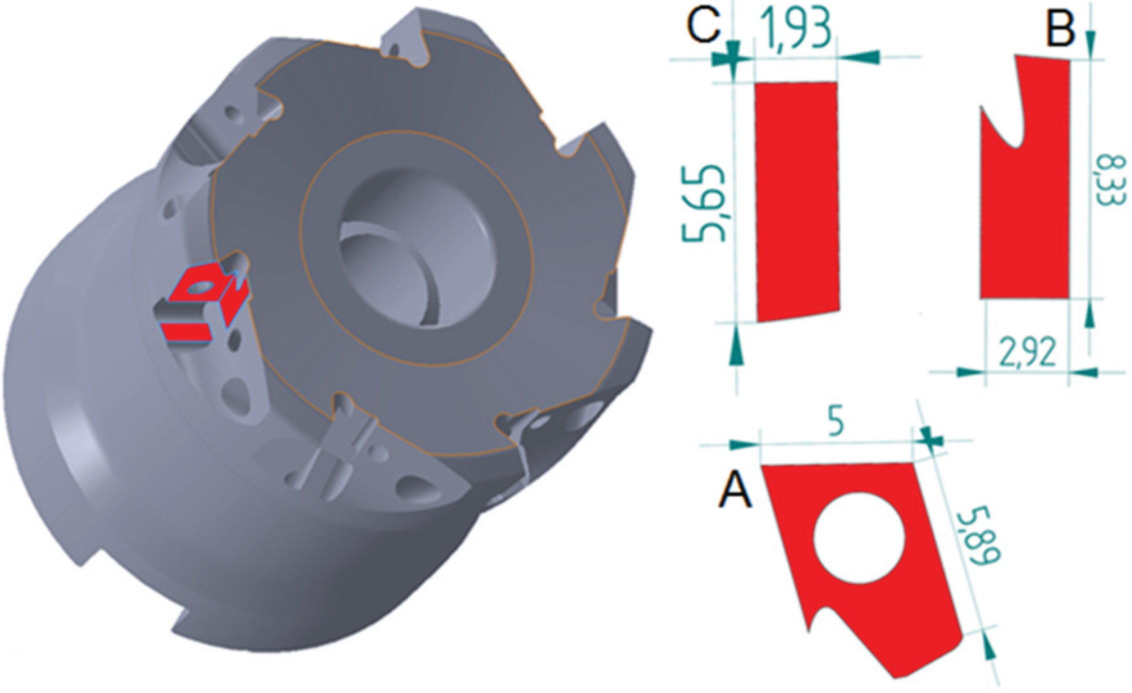

Fig. 2 Milling head and laser hardened areas

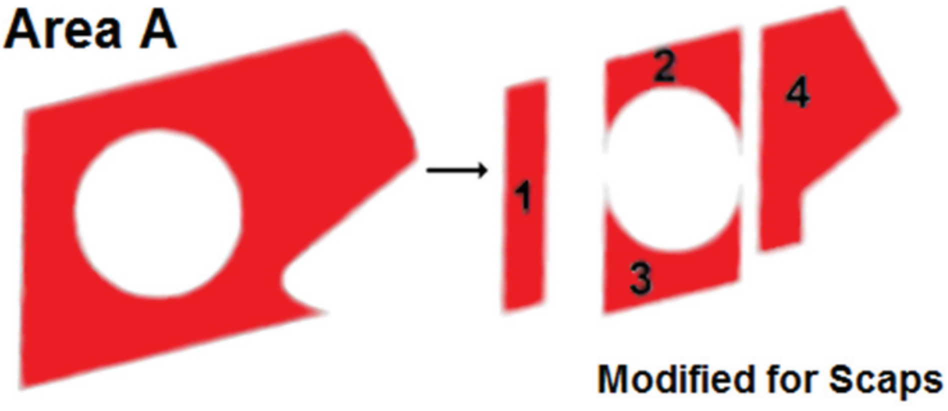

Fig. 3 The area A and its modification for precious processing

Process parameters are noted in **Table 1**. From **Table 1** it is obvious, that low laser power was applied, but short processing time was achieved.

Table 1 Parameters used for processing of milling head, size A is parallel to processing direction (laser beam oscillates with an amplitude of size B)

Area		Power [W]	Size A [mm]	Size B [mm]	Process speed [mm/s]	Processing time [s]
A	1	580	1.7	5	4000	0.34
	2	260	2.3	2	4000	0.42
	3	260	2.3	2	4000	0.42
	4	480	1.9	5	4000	0.74
B		640	3.2	8	4000	0.62
C		480	3	5,5	4000	1.04

2.3. Deformation measuring system

Deformations were measured by stationary optical microscope Alicona InfiniteFocus. The system is applied to a high resolution surface metrology in 3D (a form and roughness measurement) and allows a vertical resolution of up to 10 nm. Alicona InfiniteFocus is used in industrial branches like machinery, papermaking, typography, medical technology or material science, forensic science and micro electronics.

Method of differential analysis was used for comparison of milling tool 3D profile before and after processing.

3. RESULTS AND DISCUSSION

3.1. Hardness

The surface hardness and the depth of the hardness profile were evaluated. Depth of hardened layer was measured from 50 um to 500 um, **Table 2**. Surface hardness was measured in four points for all processed areas and last row in **Table 2** shows average value for given area. High surface hardness has been achieved but the depth of hardened layer is not fully satisfying. Surface hardness was measured on the edges of hardened areas, because there is going to operate the maximum workload. Zone around the threaded hole was not hardened, to avoid its degradation.

Table 2 Depth of hardened layer and surface hardness of three processed areas

Depth of hardened layer					**Surface Hardness**		
Depth [µm]	Area A [HV0,3]	Area B [HV0,3]	Area C [HV0,3]		Area A [HV1]	Area B [HV1]	Area C [HV1]
50	510	511	495		619	590	616
100	511	526	467		632	706	611
200	467	481	467		685	678	627
300	454	269	467		728	622	634
500	246	221	257	A	666	649	622

3.2. Deformations

Deformations could be caused by melting sharp edges or spatial deformations can be initiated by residual stresses. Melting could be inhibited by optimization of processing technology, but residual stresses cannot be totally avoided. Residual stresses are generated by two dominant mechanisms during laser hardening, phase transformation mechanism during part cooling and thermal deformation mechanism [11]. Phase transformation mechanism features compressive residual stress and thermal deformation mechanism result in tensile residual stress. These two mechanisms actuate one against the other. Consequent residual stress depends on mechanism, which prevails. Laser hardening nearly always leads to compressive residual stress in hardened layer.

Deformations are in this case on a very low level, **Table 3**. Shape differences were measured close to the corners of processed areas.

Table 3 Measured deviations

Deviation	Area A [um]	Area B [um]	Area C [um]	Average deviation [um]	Maximal deviation [um]
1	15.9	17.31	18.82	from **-19.8** to **+27.9**	from **-19.8** to **+106.3**
2	-19.79	3.21	16.71		
3	10.71	5.03	0.41		
4	56.27	106.29	52.71		

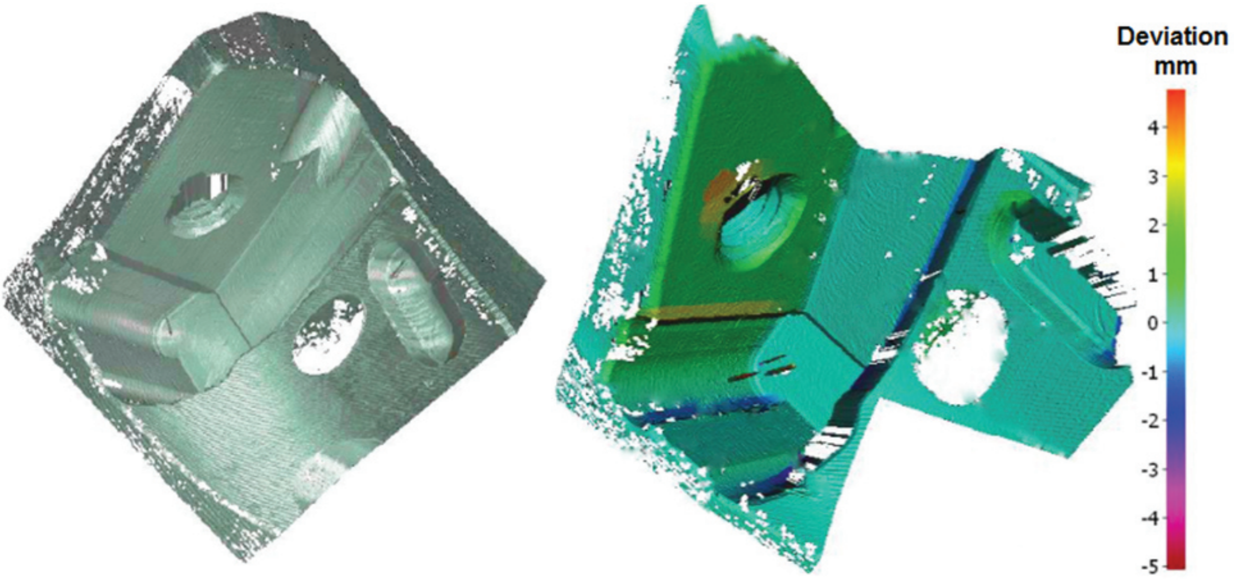

Fig. 4 3D profile measured by Alicona InfiniteFocus before processing (left side) and after processing with deviations (right side)

4. CONCLUSION

Contact surfaces of milling head were hardened. The processing results in required surface hardness values. Depth of the hardened layer is lower, because the most important factor was to achieve the lowest possible deformations of processed areas. The applicability of the hardened milling head can be approved only by setting in manufacturing process. The functional tests demonstrate if the depth of the hardened layer is wide enough. Manufacturing process can be partly simulated by some fretting tests.

Measured deformations are on satisfying level. Selected technological procedure was optimized to reach the lowest affection of processed areas. Melting of edges had to be avoided. Process parameters had to be adjusted to harden edges adequately but do not melt them. The highest hardness was achieved around the edges inner hardened area is a little softer. But the highest workload is just applied around the edges, so the distribution of hardness is demanded.

3D scanning hardening is an innovative technology with high potential, which is convenient especially for processing of complex parts like milling head. This paper proves that it is possible to reach satisfactory hardness with very low deformation, which does not create obstruction for part application.

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