Impact of Laser Machining on the Structure and Properties of Tool Steels

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Abstract. The paper presents the results of research of the impact of laser treatment on the properties of the surface layer of tool steel. Two grades of tool steel were qualified for the tests and they were subjected to a pulse laser and a continuous-mode laser treatment. In order to analyze the influence of laser beam impact on the properties of the surface layer of the studied material, metallographic investigations and microhardness profile tests were carried out in the surface layer.

Introduction

These laser machining technologies are used primarily in the machining of components from difficult-to-machine construction plastics, as well as in the manufacture of components with very complex shapes, whose production with the use of traditional method would be very labor-intensive and time-consuming. A characteristic feature of beam technologies is that materials are processed as a result of the influence of concentrated energy stream. By controlling the energy stream, we can process selected areas of a workpiece. The diameter of the spot of the influence of energy stream varies from a fraction of nanometers to several tens of centimeters [1, 2]. It depends on the basic physical phenomenon occurring in a given technology [3, 4]. Heating with a laser beam is used in the industry to modify the surface layer, e.g. hardening, tempering or modification of the microstructure [5, 6]. The remelting process also allows for changing the chemical composition of a surface layer, which is used in alloying cladding. Combined methods are also used, for example, in a thermo-chemical treatment in a fluidized bed and further laser treatment [7, 8]. Laser technologies associated with remelting require a higher density of radiation power (10^4-10^{10} W / cm^2) than the modification of a surface layer without remelting and the time of interaction of the beam with the material of 10^{-1}-10^{-9}s. High power lasers Nd: YAG and CO_2 with a continuous and pulse operation are mainly used [6]. The modification of a surface layer using laser technology is based on the process of rapid remelting and crystallization of a thin layer at the surface of the material [9, 10].

Research material

Two steel grades were used for the tests: tool steel for cold work 1.2379 and steel for hot work 1.2343. The chemical composition is shown in Table 1.

Table 1. The chemical composition of steel 1.2379 and 1.2343

steel 1.2379							
C	Mn	Si	P	S	Cr	Mo	V
1.77	0.29	0.16	0.02	0.02	11.84	0.85	0.75
steel 1.2343							
0.40	0.52	0.14	0.02	0.02	5.22	1.35	0.41

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The microstructure of 1.2379 steel after softening annealing is shown in Figure 1. It consists of ledeburitic carbides, as well as of carbides of M_3C, MC and $M_{23}C_6$ type carbides in the ferrite matrix, whereas the steel 1.2343 microstructure is a ferrite alloy with separations of coagulated spheroidal alloy carbides. Visible banding is a result of the rolling process.

Machining parameters

Samples of steel 1.2379 in the softened state were given laser treatment with a pulsed laser with the following processing parameters: pulse energy 60 J, density energy 489.79 J/cm^2, frequency 48.5 GHz, power $2.91 \cdot 10^{12}$ W, power density $2.37 \cdot 10^{13}$ W/cm^2, exposure time $2.06 \cdot 10^{-11}$ s, area of impact of a single pulse 3.5 x 3.5 mm.

For the processing of steel 1.2343 in the softened state, a molecular laser with a wavelength of 10.6 µm and a power of 800W was used. Laser processing was performed by reducing the value of re-focus Δf and speed 12mm/s. The diameter of the beam equals 22.4 mm. The radiation was focused on a lens with a focal length of f = 96mm.

Research results and discussion

As a result of hardening with a pulsed laser of 1.2379 steel after softening annealing, a four-zone model of the surface layer structure was obtained.

In this model, we can distinguish three zones. The first zone (light-white) in which hard-to-digest hid acicular martenite was found and large amounts of residual austenite were found. The thickness of this zone depends on the heat dissipation rate from the surface layer and reaches 0.06 mm. Research confirms that this zone will be characterized by low hardness. When using this technology for machining tools, e.g. cutting knives machining will be necessary to remove this zone. The second zone contains martensite, primary carbides and residual austenite. The last third zone is a zone of heat influence, which was created as a result of the influence of heat coming from the laser pulse. Microscopic images of the zonal structure of the surface layer suggest that the energy distribution in the impulse is homogenous, which manifests itself with the same width of individual zones in a given sample. In the surface layer, we obtained a uniform martensite structure, which is related to the absence of the phenomenon of tempering of the material between successive areas of the laser pulse.

In the case of steel 1.2343, the top layer consists of three following spheres: a light white zone, created from the remelting material, a hardened warp zone and transition zone. All zones together have a total thickness of 162.5 µm, while the total width of the hardened zone at the surface is 1.15 mm. The light white zone has a fine-grained martensite structure that was created as a result of melting of the material. This zone reaches a depth of 37.5 µm. The second zone, which is a layer of a hardened matrix material, is 24.5 µm thick. Carbides, martensite and residual austenite are the structures of this zone. The transition zone between the hardened layer and the warp is about 100 µm.

In order to confirm the zone structure and determine the area of occurrence of individual zones, microhardness tests were carried out in the area of the surface layer. The microhardness tests were carried out in accordance with EN ISO 6507-3:2007 standards, hardness measurement with the Vickers method below HV 0.2. The load of 0.4903 N was used in the tests. At a distance of 0.5 mm from the edge of the sample in the middle of the pulse, a microhardness measurement was carried out for steel 1.2379 in a line perpendicular to the surface of the sample, passing through successive zones of heat influence. The profile of microhardness of the surface layer of steel 1.2379 is shown in Figure 1.

The microhardness tests confirmed the existence of a zoned structure of the surface layer of the material after the pulse laser processing of steel 1.2379. A slight increase in hardness to the level of approximately 550 HV005 is observed at the surface, in the next zone we observe an increase in hardness to the level of about 800 HV005, which confirms the occurrence of hid acicular martensite and residual austenite. The next zone is characterized by a decrease in hardness in relation to zone 2. The last zone is a zone of heat influence.

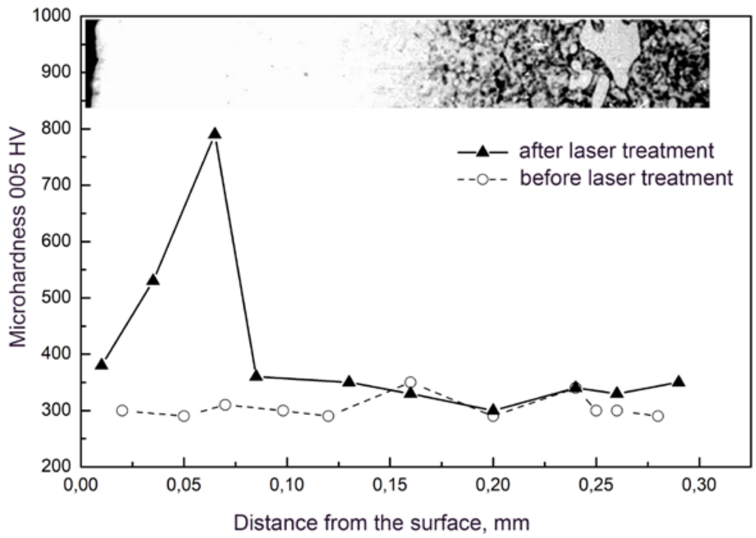

Fig.1. Profile of microhardness of steel 1.2379

In the case of steel 1.2343, a microhardness measurement was made perpendicular to the surface along the center line (laser beam impact paths). The conducted research confirmed the zonal structure, the first zone of fine-grain martensite has hardness of above 1000 HV005. In the second zone we observe a decrease in hardness. In this zone there are carbides, martensite and residual austenite. In the third zone, we still observe a decrease in hardness associated with a decrease in the share of martensite. The profile of microhardness of the surface layer of steel 1.2343 is shown in Figure 2.

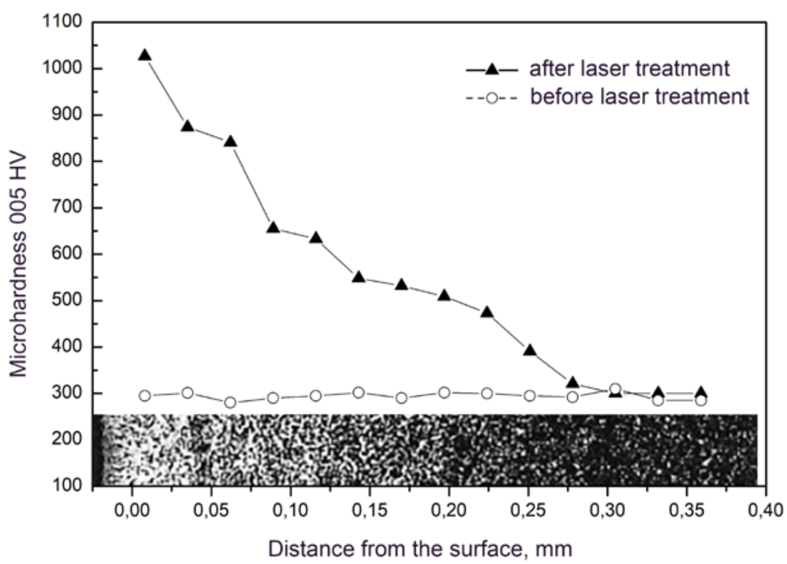

Fig. 2. Profile of microhardness of steel 1.2343

Summary

The amount of energy introduced into a material depends on the energy distribution in the beam, the time the beam interacts with the material and the absorption coefficient. The use of a pulsed laser enables obtaining an even distribution of energy in the beam, which was confirmed by metallographic and microhardness measurements. The interaction of the laser pulse ensures the formation of a homogeneous martensite structure in the top layer. As a consequence, we obtain a uniform state of stress, there is no phenomenon of material separation between the areas of impact of the impulse. Steel 1.2379 treated with pulsed laser has a zone structure described by a four-zone model. In case of steel 1.2343 and continuous laser treatment, there are thermal interactions with the stress fields. Also in this case there is a zone construction described by the three-zone model. The highest hardness was noted in the area of fine-grained martensite resulting from remelting. Between the paths, the phenomenon of tempering material was noted. To sum up, the properties of the surface layer of the material treated with a laser beam are characterized by a higher resistance to wear in relation to the starting material and in relation to conventional machining methods.

References

[1] P. Szataniak, R. Ulewicz, F. Novy, HSLA steels - comparison of cutting techniques, 23rd International Conference on Metallurgy and Materials, Metal (2014) 778-783.

[2] N. Radek, B. Antoszewski, I. Pliszka, J. Świderski, J. Pietraszek, Production of heterogeneous surfaces by ESD and LBM, Production Engineering Archives 13 (2016) 44-48. https://doi.org/10.30657/pea.2016.13.10

[3] M. Scendo, J. Trela, N. Radek, Influence of laser power on the corrosive resistance of WC-Cu coating, Surface & Coatings Technology 259 (2014) 401-407. https://doi.org/10.1016/j.surfcoat.2014.10.062

[4] M. Bramowicz, S. Kulesza, T. Lipiński, P. Szabracki, P. Piątkowski, Fractal analysis of AFM data characterizing strongly isotropic and anisotropic surface topography, Solid State Phenomena 203 (2013) 86-89. https://doi.org/10.4028/www.scientific.net/SSP.203-204.86

[5] A. Wrońska, A. Dudek, Characteristics of surface layer of sintered stainless steels after remelting using GTAW method, Archives of Civil and Mechanical Engineering, 14/3 (2014) 425-432. https://doi.org/10.1016/j.acme.2013.10.011

[6] YC. Zhang, L. Yang, TY. Chen, WH. Zhang, XW. Huang, J. Dai, Investigation on the optimized heat treatment procedure for laser fabricated IN718 alloy, Optics and Laser Technology 97 (2017) 172-179. https://doi.org/10.1016/j.optlastec.2017.06.027

[7] J. Lago, O. Bokuvka, F. Novy, The weld toe improvement of advanced HSLA steel by laser remelting, Materials Today-Proceedings, 3/4 (2016) 1037-1040. https://doi.org/10.1016/j.matpr.2016.03.043

[8] N. Radek, J. Pietraszek, B. Antoszewski, The Average Friction Coefficient of Laser Textured Surfaces of Silicon Carbide Identified by RSM Methodology, Adv. Mater. Res.-Switz. 874 (2014) 29-34.

[9] M. Sebek, L. Falat, F. Kovac, I. Petryshynets, P. Hornak, V. Girman, The Effects Of Laser Surface Hardening On Microstructural Characteristics And Wear Resistance Of Aisi H11 Hot Work Tool, Archives Of Metallurgy And Materials, 62/3 (2017) 1721-1726. https://doi.org/10.1515/amm-2017-0262

[10] E. Schmidova, P Savada, Behavior and Degradation Of Stabilized Corrosion Resistant Steel, 41. Mezinarodni Konference O Naterovych Hmotach, KNH (2010) 281-288.