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Research Article

STUDIES ON SELECTED PROPERTIES OF SURFACE LAYER OF C45 STEEL OBJECTS AFTER LASER CUTTING AND MILLING

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ABSTRACT
The article presents the results of studying the effects of technological parameters of milling upon surface roughness and microhardness of C45 steel objects after laser cutting. The metallographic structure formed as an effect of cutting by laser was also analyzed. The milling was performed on a FV-580a vertical machining centre. Depth of cut and feed per tooth were changed within the following range: a_p = 0.09–0.18 mm and f_z = 0.02–0.17 mm/tooth. To measure the surface roughness a Surtronic 3+ profile graphometer was used, whereas microhardness was measured with the use of a Leco LM 700AT microhardness tester. The surface roughness was significantly improved as a result of milling. The laser beam input and output zones were eliminated. Only a part of the layer hardened by laser cutting was removed while milling, in effect of which after milling the hardness of surface layer is much higher than hardness of the core.

Keywords: milling, laser cutting, surface roughness, microhardness.

INTRODUCTION

Laser cutting is a process, in which laser radiation (continuous or impulse) beam can cause melting of the material in the cutting crack, simultaneous melting and evaporation of the material or melting and/or combustion of the material [10].

The effect of coherent beam during cutting causes the formation of discrepancies on the surfaces and edges of the cut [19]. The occurrence of discrepancies hinders or prevents applying a given part in the subsequent stage of production. According to [19] discrepancies should mean irregularities or deviations from a specific shape or position of the shearing line. The following groups of discrepancies can be distinguished: discrepancies on cutting edges, discrepancies on surfaces, fractures, cinder and other discrepancies. The source of the resultant discrepancies is only the laser cutting process [19].

The assessment of the state of surfaces and edges is accomplished by means of the following indicators: surface roughness, perpendicularity tolerance (distance between two parallel straight lines, between which cutting profile is inscribed [18]), as well as that of cutting surface inclination, width of heat-affected zone (HAZ), kind of changes introduced by cutting, as well as mechanical and corrosive properties of the material [10, 18].

Surface roughness, formed as an effect of laser cutting depends upon striae, being formed on a cut surface as a result of laser beam fluctuation, is gas flow and hydrodynamic flow of the melted material [7]. On the treated surface two zones of differentiated roughness can be distinguished, which are separated from each other by the so-called boundary layer separation point (BLS) [6, 10]. The geometrical structure of the surface after laser cutting reveals parallel direction. The surfaces resulting from cutting should be classified as anisotropic random, less frequently as anisotropic periodical [17].

During laser cutting process, the beam, going deep into the material, gets deviated from perpendicularity. Depending on cutting conditions, deviation can equal from 0.3 mm to 0.75 mm, which should be considered at working out the subsequent technological operations [4].

The phenomena, which are unavoidable during cutting process are thermal changes within the area of cutting line, the formation of scale and flash on the opposite side to the position of laser [4]. On the cut through surface also shallow discontinuities and highly fragile fractures can be observed [1, 15]. The effect of thermal beam causes the formation of hardened layers in the surroundings of cutting crevice and cutting surface quenching. The hardened layers do have small thicknesses, but especially at the edges and quoins they are quite hard. The cutting edge surface is also oxidized [5, 13].

Laser cutting process is accompanied by high temperature gradient in the area of laser beam influence, which results in the formation of residual stress. The residual stress is deposed down to the depth of 2 mm from the cutting surface. Stress formation enhancing factor is also high cooling velocity. Crucial points in elements cut with a laser are areas near the cutting edge and corners [16].

In the effect of laser cutting the decrease of fatigue strength ranges from 40% to 65%, depending on the cut material, with reference to cutting with a stream of water and milling [11].

Currently one can meet technological solutions that reduce the formation of negative effects of laser cutting. They include correct selection of laser cutting parameters [2], covering the lower surface of cut sheet with a special chemical substance reducing the formation of metal overhang [4], as well as mechanical and manual removing of the formed scale and burrs [4]. Removing the metal overhang most often takes place with the use of belt grinders, manual files, wire brushes and by means of milling process dedicated for objects with larger dimensions and more complex shapes.

In connection with the occurrence of heat effect zone of a laser beam upon an object, the hardened layer milling process can be compared to quenched steel processing. The processing parameters selection depends upon the hardness of processed material.

In the paper [14] the effect of technological parameters of milling upon surface roughness was analyzed. It was found that cutting depth does not affect the roughness of the machined surface. It was also noticed that with the increase of cutting velocity v_c the decrease of surface roughness takes place. That is connected with mechanical vibrations, whose amplitude decreases with the increase of cutting velocity.

During machining of quenched materials quite true representation of the tooth edge shape occurs. At small feed values and slight disturbances „jaggedness" of cutting edges can have a much greater effect upon the machined surface roughness than the geometric-kinematical representation [8].

The object of the studies performed by the authors of this paper [3] was the assessment of the effect of milling parameters upon microhardness of stainless and unalloyed steel surface layer. The studies reveal that with the increase of cutting and feed velocity the surface layer microhardness increases. The depth of changes taking place equals about 120 μm and depends upon mechanical and thermal effects that take place.

Our previous studies [12] revealed that milling the surface after laser cutting is a complex process. The forces occurring during treatment of surface layer are larger than during milling the core material. What still remains to be analyzed is the kind of metalographic structure, microhardness and geometric structure of the surface (GSS) shaped by milling of the layer after laser cutting. For this purpose the studies of assessing the state of surface after laser cutting and then after finishing milling were undertaken. Knowledge of this problem is demanded. This results from the necessity of applying a given element in subsequent stages of production or assembly.

The purpose of milling was to remove negative effect of cutting process (striae on the cutting surface, error of contour shape and roundings of cutting edge). The cutting depth was selected in such a way as to leave a part of hardened layer, formed during laser cutting process.

METHODOLOGY OF RESEARCH

In the studies C45 steel samples were used (marking according to PN-93/H-84019) (Table 1). Samples of the dimensions 5×8×100 mm were made with the use of laser cutting system Amada 3000 W, with the application of standard parameters. Oxygen was used as a working gas.

Before the operation of cutting, a metal sheet was subjected to homogenizing annealing in the temperature of 860 °C within 30 minutes to reduce the state of residual stresses.

The milling process was conducted on vertical machining center FV-580a. Sandvik double – bit flycutters of the diameter of 20 mm with insert

Table 1. The chemical composition and strength properties of the C45 steel

Non-alloy steel C45								
C	Mn	Si	P	S	Cr	Ni	Mo	Fe
0.48	0.74	0.36	0.011	0.01	0.09	0.02	0.002	rest
Yield Point					R_e = 430 MPa			
Tensile strenght					R_m = 740 MPa			
Hardness					250 HB			

215880 APKT10 covered with TiN coat were used as tools. During milling cooling-lubricating liquid Mobil Cut was used. The examined samples were fixed in a special handle, which was put in a special vice so that the machined surface was, positioned parallel to the axis of machine tool spindle. The vice was fixed on the machine tool table.

Milling was performed for the following parameters: v_c= 102 m/mim; a_p= 0.09–0.18 mm, f_z= 0.02–0.17 mm/tooth. Figure 1 shows the kinematics of milling process and characteristic dimensions.

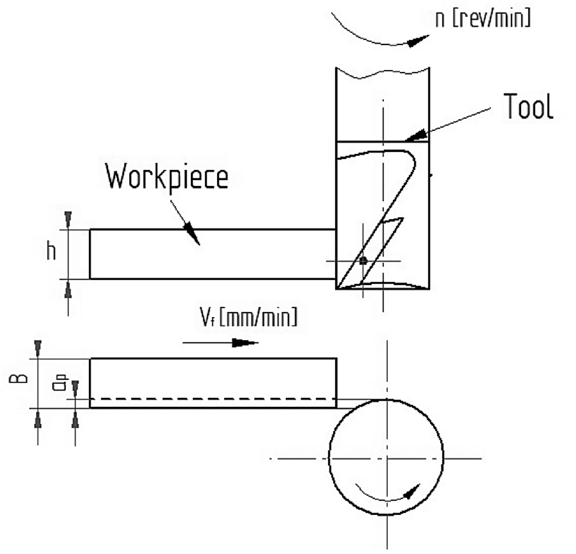


Fig. 1. Schematic illustration of milling process: B – sample width, h – sample height, a_p – cutting depth

Surface roughness measurements were performed with the use of laboratory prophilographometer Surtronic 3+ by Taylor Hobson, whereas topography and contour – with the use of T8000 RC120-400 appliance by Hommel-Etamic. The measurements were performed on the surface after laser cutting, approximately perpendicularly to the direction in which the radius acted. In connection with the occurrence of two characteristic zones, the measurements were performed in radius input and output zones. The same scheme was assumed for milled samples.

For the assessment of material structure the metalographic microscope Nikon MA 100 was used.

Microhardness measurements were performed on perpendicular microsections using Vickers's method at the bob weight equal to 100 g (HV 0.1), in accordance with the standard concerning hardness measurement with the use of Vickers's method. Microhardness tester LM700AT by Leco was used for these measurements For the obtained results of microhardness measurements the degree of strain hardening e from the relationship was determined:

$$e = 100 \cdot \frac{HV_{max} - HV_0}{HV_0} \ \% \qquad (1)$$

where: HV_{max} – maximum microhardness for machining,
HVo – microhardness of material core (steel C45 before laser cutting).

Figure 2 shows the way of determining HV_0 and HV_{max}. The degree of strain hardening includes the effect of laser cutting and milling.

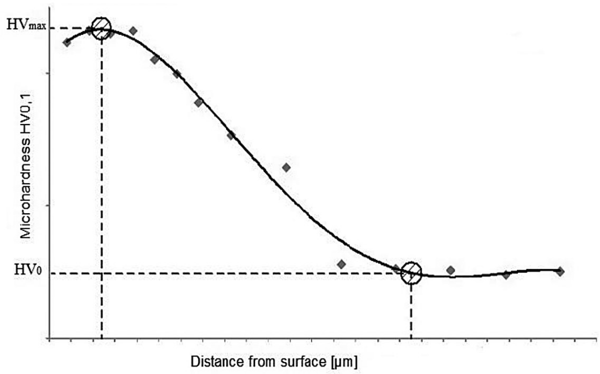
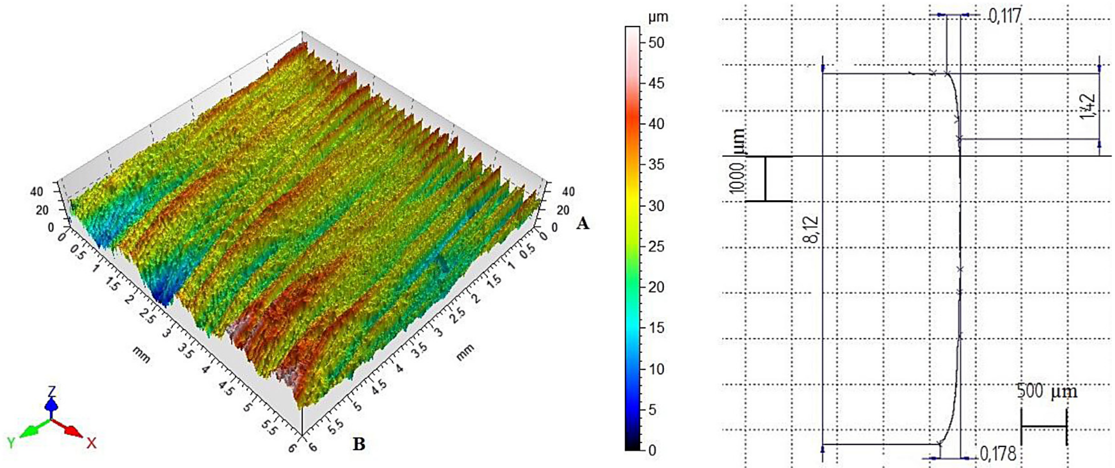


Fig. 2. The way of determining the microhardness distribution surface layer after laser cutting

STUDY RESULTS

Having finished the studies we analyzed the obtained results of surface roughness and surface layer microhardness measurements in the function of applied technological parameters of milling.



Sa = 4.63 μm, Sv = 27.5 μm, Sp = 24.5 μm, Sz = 52 μm

Fig. 3. Surface topography and contour after laser cutting

Figure 3 presents the topography of the surface and contour after laser cutting. There are visible zones of differentiated surface roughness. In the laser radius input zone (A) there occur uniform, rectilinear striae in small spaces between each other, whereas in the output zone (B), there are noticeable curvilinear striae, deviated from the intended track of laser beam relocation. Ra and Rz parameters for input zone equaled: Ra = 3.62 μm, Rz = 19.05 μm, for output zone: Ra = 4.21 μm, Rz = 21.11 μm.

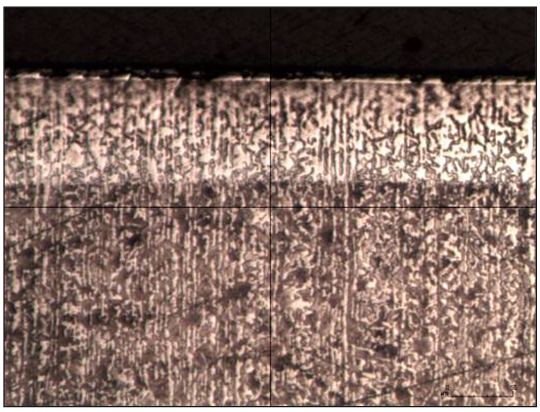
In the case of contour a rounding of cutting edge is visible, as well as contour shape error, the maximum value of which is u_{max}= 0.178 mm (u – perpendicular dimension, describing the distance between two parallel straight lines, between which cutting profile is inscribed [18]).

C45 steel before laser cutting process had ferretic-pearlitic structure, of a band system. In the effect of laser cutting structural transformations take place. In the region of the cutting crack a heat affected zone (HAZ) was created, the width of which equals ca. 0.3 mm (Fig. 4a). In result of strong heating up of the material with a laser beam, and then cooling it down, quenching of the material took place in that zone. In HAZ martensite needles are visible, as well as bainite (near the cutting edge) (Fig. 4b), then ferrite+ martensite (in the middle of HFZ) and the structure of native material.

Figure 5 shows the distribution of C45 steel surface layer microhardness. In effect of laser cutting surface layer microhardness increases more than two times in the edge zone, then slowly decreases to achieve the value of core microhardness. The depth of changes taking place equals more than 300 μm.

In the graph showing the effect of machine cutting depth upon surface roughness (Fig. 6) a slight decrease of Ra parameter in the scope of

a)



b)

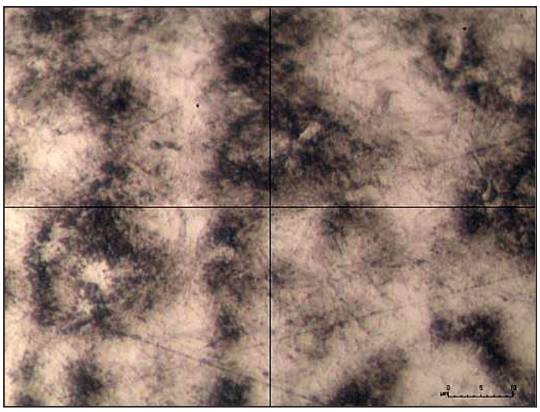


Fig. 4. Microstructure of C45 steel after laser cutting: a) edge-zone + core (magnification × 50)
b) heat affected zone (magnification × 500)

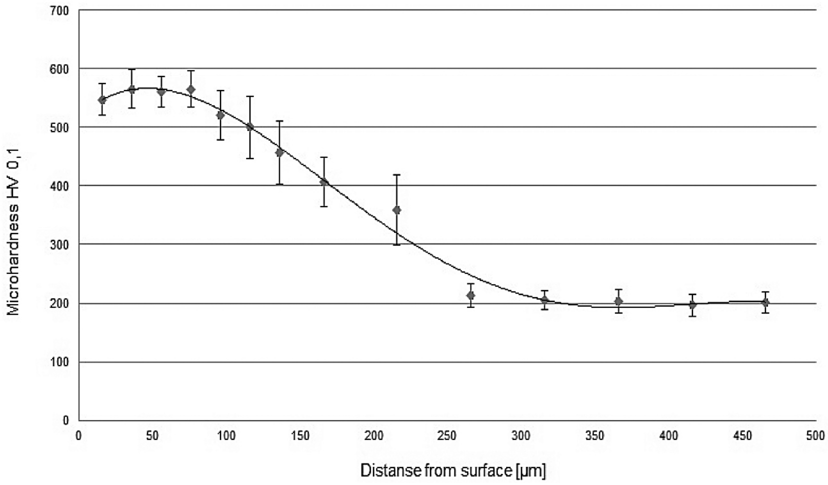


Fig. 5. Microhardness distribution of C45 surface layer after laser cutting

a_p = 0.09–0.12 mm, and for larger cutting depths the Ra parameter increases.

Greater value of Ra parameter for a_p = 0.09 mm is probably related to larger share of plastic and elastic strains of the surface layer occurring in the process of removing the thin layer of material. Roughness of surface after milling is a few times smaller than after laser cutting. It is difficult to indicate the input and output zones . The differences between zones are slight.

Figure 7 shows the effect of feed upon surface roughness. In accordance with our suppositions, with the increase of feed per tooth the Ra parameter slightly increases. Higher value of surface roughness for f_z = 0.02 mm/tooth may be caused by elastic return of unremoved part of the cut layer.

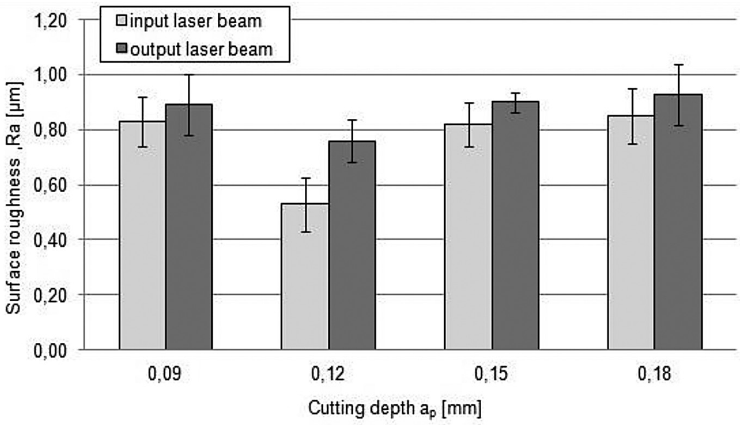


Fig. 6. Surface roughness parameters Ra as function cutting depth a_p

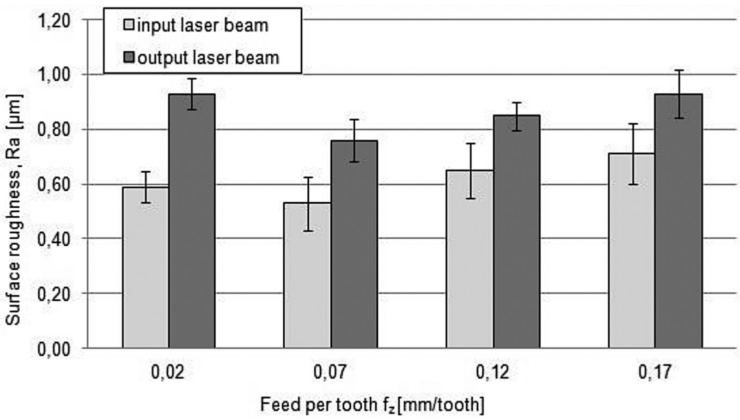


Fig. 7. Surface roughness parameters Ra as function feed per tooth f_z

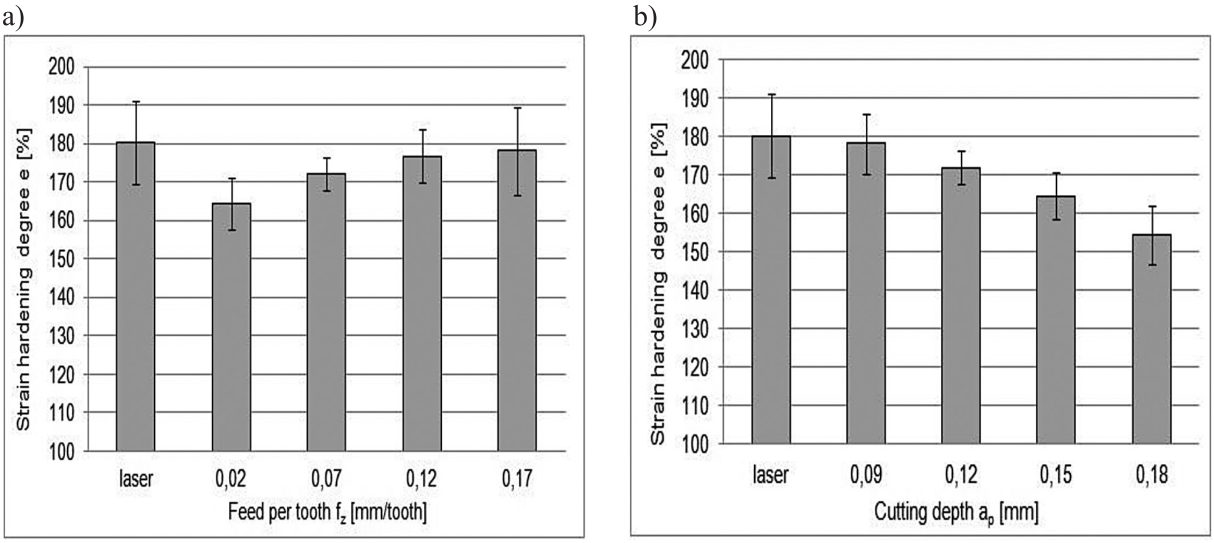


Fig. 8. Strain hardening degree as function a) feed per tooth f_z b) cutting depth a_p

The results of studies on the effects of milling parameters upon microhardness of surface layer are shown in Figure 8.

The increased feed per tooth causes slight increase of surface layer microhardness. That is probably caused by the increased chip thickness and higher passive forces (Fig. 8a). The strain hardening degree for samples after milling is lower than for a sample after laser cutting, because a part of the hardened layer was removed. Changes in the strain hardening degree are slight indeed, but that proves the mechanical effect of the tool teeth upon the machined surface after laser cutting.

Analyzing the influence of cutting depth upon the strain hardening degree (Fig. 8b), one can notice the decrease of strain hardening degree together with the increase of cutting depth. Milling with the increasing cutting depth causes removal of the thicker hardened layer as a result of laser cutting (the biggest hardening occurs down to the depth of about 120 μm), which leads to the decrease of surface layer hardness.

Microhardness of surface layer after laser cutting and milling probably results from the influence of two opposite phenomena: drawing the hardened layer, which causes hardness reduction and/or secondary reinforcing through the mechanical effect of teeth [9].

SUMMARY

In this study the effect of milling technological parameters upon surface roughness and microhardness of C45 steel after laser cutting were examined. Also the structure formed in the effect of laser cutting was examined. The following conclusions sum up the results of performed studies.

In the effect of milling the roughness was highly improved. Differences in surface roughness occurring after laser cutting (radius input and output zone) were eliminated. No significant effect of machining parameters upon surface roughness was found.

After laser cutting process edge zone was quenched. A non-easily treatable martensitic-bainitic zone was formed. Milling caused removal of a part of the layer, which was hardened in the laser cutting process.

Feed and depth of cut do not significantly affect the microhardness of surface layer. A slight accretion of microhardness is observed with the increased feed.

C45 steel milling after laser cutting makes it possible to remove the negative effects of cutting process (striae on the cutting surface, contour shape error, as well as rounding of the cutting edge), which allows for the improvement of the surface geometrical structure, simultaneously leaving a small layer of hardened material.

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