COMPARATIVE RESEARCH OF TWO MACHINING METHODS: LASER BEAM MACHINING AND ABRASIVE WATER JET MACHINING

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Abstract: *The purpose of the work was conducting comparative analysis of two methods of machining by means of concentrated energy beams. The laser beam machining and abrasive water jet machining methods were compared. Analysis of holes drilling was conducted. The surfaces processed with laser beam cutting and abrasive water jet were evaluated in terms of roundness error, surface roughness, aperture width and heat affected zone. NC6 tool steel was the material used during the experiments.*
Key words*: laser beam machining, abrasive water jet machining, roundness error, surface roughness, heat affected zone*

1. INTRODUCTION

With the continuing development of difficult-to-cut materials, there is a need to identify and develop the manufacturing techniques suitable for producing high quality products. The desire to obtain better technical and economic effects under the conditions of competitive production forces entrepreneurs to seek solutions increasing the productivity of processing as the most important economical index of production. In the processes of manufacturing machine parts, a constant trend to improve the dimension and shape accuracy and the surface quality of the objects is observed.

The conventional machining operations are difficult to apply in the processing of those difficult-to-cut materials (Anwar et al., 2013). Due to technical requirements, there are barriers to the application of the traditional method of processing by cutting. More and more often one encounters materials where cutting resistance is so high that one cannot select tool materials to overcome those resistances while maintaining rational production profitability. Many techniques are successfully used for cutting materials (Hloch et al., 2011; Kulecki 2002; Kušnerová et al., 2012; Brillová et al., 2012), but not all the technologies form complex shaped parts so that their surface is a ready-made product without additional machining (Zelenak et al., 2011). The authors' earlier investigations have been focused on research problems related to the manufacturing techniques (Krolczyk et al., 2013a; Krolczyk et al. 2013b), but those publications have not dealt with problems related to the non-conventional machining processes. The purpose of the work is to compare two methods of processing by concentrated energy beams, namely forming materials by means of abrasive water jet machining (AWJM) and laser beam machining (LBM).

The present paper presents the results of cutting test of NC6 tool steel, i.e. the material used in the production of cold working tools. Samples of that steel have been used to assess the influence of the selection of various cutting feed values on the material surface condition and the accuracy of the shape obtained. The technological suitability of a given method has been assessed with the use of the following indicators: surface roughness, roundness error, perpendicularity error, holes execution accuracy, aperture width and heat affected zone

2. EXPERIMENTAL TECHNIQUES

2.1 Workpiece

The tests have been performed on identical samples of NC6 tool steel. The chemical composition of those samples can be found in Table 1. The samples were made in the form of flat bars dimensioned 100x12x75 mm. The measured hardness of the samples was 61 ± 2 HRC.

Table 1. Chemical composition of NC6 tool steel [%]

C	Mn	Si	P	S	Cr	Ni	Mo	W	V	Cu
1,3÷ 1,45	0,4÷ 0,7	0,15÷ 0,4	max 0,03	max 0,03	1,3÷ 1,65	max 0,35	max 0,2	max 0,2	0,1÷ 0,25	max 0,35

2.2 Test stands

The process of cutting with concentrated abrasive water jet has been performed on a 55100 JetMachining Center made by OMAX. Cutting with laser beam has been effected on a laser cutter, TRUMATIC L 3040 made by TRUMPF. The holes execution accuracy has been measured on a coordinate measuring machine, UPMC 850 made by ZEISS. The UPMC 850 is an ultra-precise CNC measuring machine of a gantry structure with an active scanning head. The UPMC 850 is mainly used for calibration of touchstones, model gear wheels and for other reference measurements. The roundness error has been measured by means of a TALYROND 365 device made by TAYLOR HOBSON company. The accuracy of measurement by this device is as high as 0,02 μm. The surface texture analysis has been performed by means of the T1000 measurement device made by HOMMEL TESTER. The analysis of the heat affected zone has been performed by making microphotographs of the structure of the samples being examined. The microphotographs have been executed on an optical microscope, MA 200 made by NIKON company. The micro-hardness measurements were effected by Leco Microhardness Tester LM 700AT. Vickers indenter has been loaded with a force of 2 N and the loading time was 15 s. The measurements were performed into the depth of the heat affected zone, with repeatability of three times. The distance between the successive measurements was 0,1 mm.

2.3 Testing methodology

The selection of the cutting parameters with the abrasive water jet on the OMAX 55100 machining centre consisted in assigning one of a number of available cutting classes to the contours. OMAX 55100 machine tool offers 5 classes for cutting, from the worst-first one to the best – fifth one. The tests have been performed in three classes, i.e. the third one, the fourth one and the fifth one. For each of the three main classes, one sample has been assigned in which three edges and six holes have been made. The samples were cut with an abrasive water jet of a constant pressure of 350 MPa. As the abradant, mineral garnet with the grain size of 80 mesh was used. The samples were cut with the use of a Max-Jet nozzle with the diameter of 0,75 mm. The nozzle was located at a distance of 1,6 mm from the object under machining. The cutting speed for the individual classes can be seen in Table 2.

Table 2. Cutting speed for the different classes of AJW

Cutting class	Cutting speed [mm/min]
3	143,4
4	110,3
5	68,2

Laser cutting, like the abrasive water jet operation, has been performed in three ranges of cutting speed *v* (Table 3).

Table 3. Cutting speed of for the LBM

No	Cutting speed [mm/min]
1	150
2	200
3	250

For each cutting speed, a sample has been selected in which three cuts and six holes have been made. The process of burning a gap in the object has been performed by means of a concentrated laser beam generated in an optical resonator, in the atmosphere of laser gas which was nitrogen. The density of the beam energy (I) in the focus of 0,3 mm diameter was $5x10^4$ MW/m^2. The power (P) of the laser cutter, TRUMATIC L 3040 has been set to 3050 W. The position of the beam focus has been set at the height of 1/6 of the material thickness from its top surface, i.e. about 2 mm. The holes diameter measurements have been performed in two locations of the processed surface, at l_1 = 1 mm and l_2 = 11 mm respectively (Fig. 1).

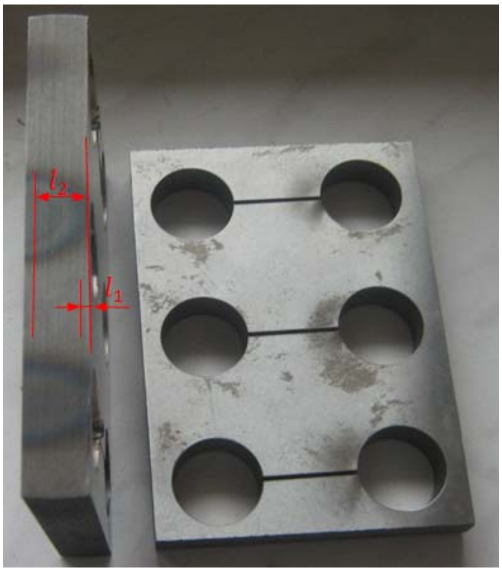

Fig.1. Holes diameter measurement locations; measured from the side of the concentrated energy beam incidence

3. RESULTS AND DISCUSSION

3.1 Dimensional accuracy of the execution of holes

The major problem in the assessment of the investigated methods of machining with concentrated energy beams in respect of the possibility of precise forming of material is the selection of an adequate index allowing us to assess them properly.

The comparison of the methods under consideration has been begun with the analysis of the hole execution accuracy. Fig. 2 and Fig. 3 present the average values of the diameter *D* of the holes made with concentrated energy beams for the samples under examination.

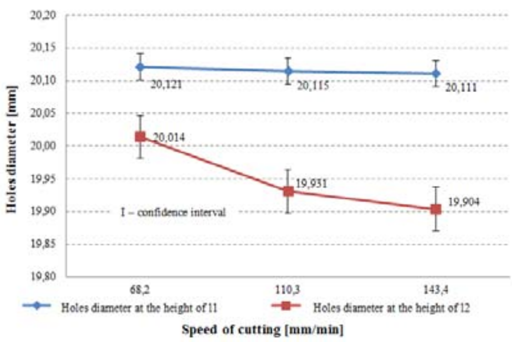

Fig.2. The influence of abrasive water jet cutting speed on the diameter *D* of the executed holes

In the case of abrasive water jet cutting, no significant difference in the hole diameter was found in length l_1 when the cutting speed was changed. In length l_2, on the other hand, the differences are significant and exceed the values of measurement errors. For the tested cutting speeds, the diameters on length l_1 are characterized by larger values as compared to those in length l_2. With the increase of the abrasive water jet cutting speed, the diameter of the hole decreases in the lower part of the material being cut. Basing on this, it is concluded that, when the cutting speed is increased with the other machining parameters invariable, the width of the cutting gap influences the value of the diameter of the holes. The diameters decrease with the increase of the cutting speed.

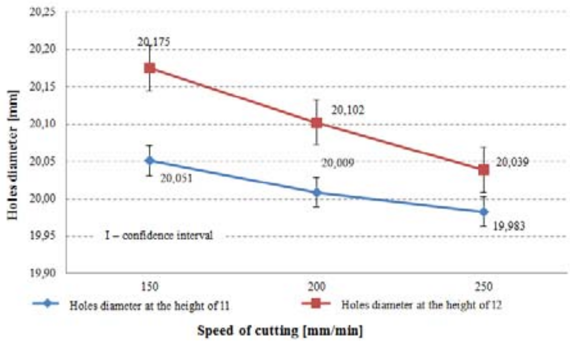

Fig.3.The influence of laser beam cutting speed on the diameter *D* of the executed holes

In the case of laser beam cutting, the diameters in length l_1 are always smaller than those in length l_2 regardless of the cutting speed. With the increase of cutting speed, the difference of diameters at the individual heights decreases. In length l_1, the change of the diameter with the change of cutting speed is small; a significant difference of those values has been found in length l_2.

Another matter reflected in industrial practice is analysis of roundness error. The deviation of roundness has been defined in relation to the average circle. To the assessment of roundness, deviation of roundness *RONt* has been adopted. Figures 4 and 5 show the dependence of the cutting speed on the average *RONt* roundness deviation.

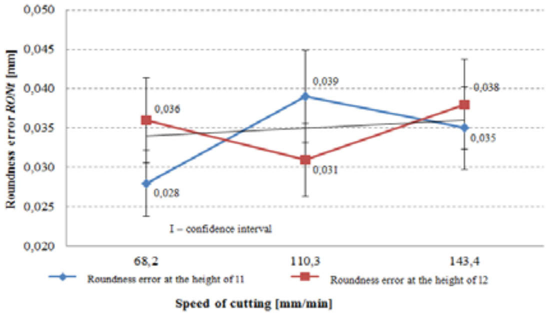

Fig.4. The influence of abrasive water jet cutting speed on the average values of roundness deviations *RONt*

Much larger values and *RONt* roundness deviation differences for the individual cutting speeds occur in laser beam processing (Fig. 4). The cutting conditions for all the methods applied were similar; the relatively large roundness deviations when using the laser beam were probably due to thermal deformations.

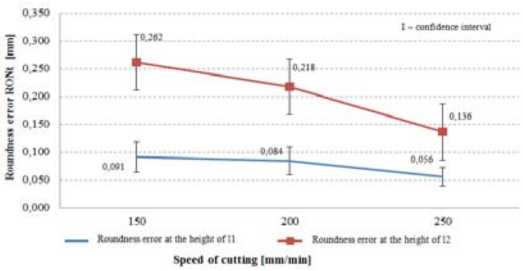

Fig.5. The influence of laser beam cutting speed on the average values of roundness deviations *RONt*

Cutting with a laser beam is a process of acting on the processed material thermally, therefore thermal deformations as result of the process are inevitable. The magnitude of those deformations was closely related to the time of heat affection. With the increase of the cutting speed, the time of laser beam penetration into the processed material, hence the parameter of roundness deviation *RONt* decreased.

Dimensional and shape accuracy are important criteria of the quality assessment of the object being processed. The criteria often determine the suitability of the given way of material forming. Figure 6 shows the values of roughness parameter *Ra* obtained in abrasive water jet processing for the particular cutting speeds.

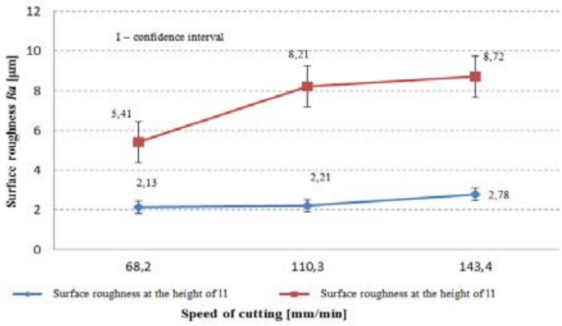

Fig.6. The influence of abrasive water jet cutting speed on surface roughness parameter *Ra*

Statistical analysis of the obtained values indicates that there is no difference between the average values of parameter *Ra* for the samples on length l_1. Measurements performed on length l_2, on the other hand, show an increase of the value with an increase of the processing speed.

a) b) c)

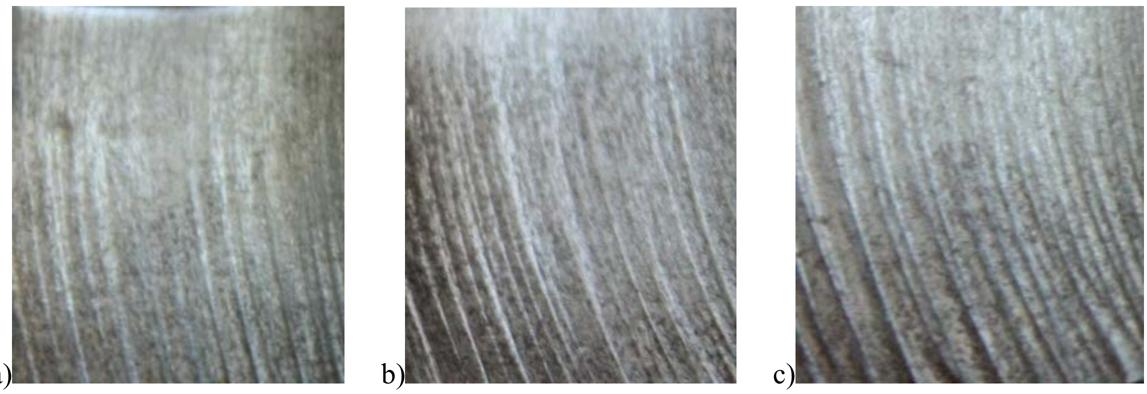

Fig.7. Photographs of holes surfaces after abrasive water jet cutting for cutting speeds of: a) 68,2 mm/min; b) 110,3 mm/min; c) 143,4 mm/min

Analysing the photographs of the processed surfaces (Fig. 7), one can see that the cutting surfaces can be divided into two areas: a zone with smooth structure and the remaining surface.

In the smooth zone comprising length l_1, the roughness values are relatively stable and that is why the lowest *Ra* roughness parameter values were found in that zone. In the other zone, significant deterioration of the surface quality is observed. The surface shows a corrugated, grooved structure. During abrasive water jet cutting, the concentrated beam impacting the surface undergoes disintegration. Below the top surface starts scattering, which results in deformation of the surface under processing. The grooves are slightly rounded, oriented opposite to the direction of feed. There is a fluent transition between the two zones and the portion of the smooth surface increases with reduction of the cutting speed.

Figure 8 shows the values of the roughness parameter *Ra* obtained in laser beam processing for the particular cutting speeds on length l_1. Below length l_1 the roughness parameter values exceeded the measurement capacities of the profilograph. The surface cut with the laser beam has a structure similar to that of an unprocessed surface. In an analysis of the values shown in Fig. 8, it has been found that roughness decreases with the growth of cutting speed.

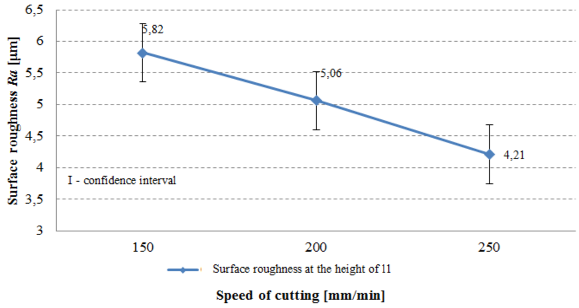

Fig.8. Influence of laser beam cutting speed on the surface roughness parameter *Ra*

Reduction of the cutting speed has resulted in an increase of the surface roughness. In Fig. 9 one can see photographs illustrating the influence of cutting speed on the appearance of material surface after laser beam cutting.

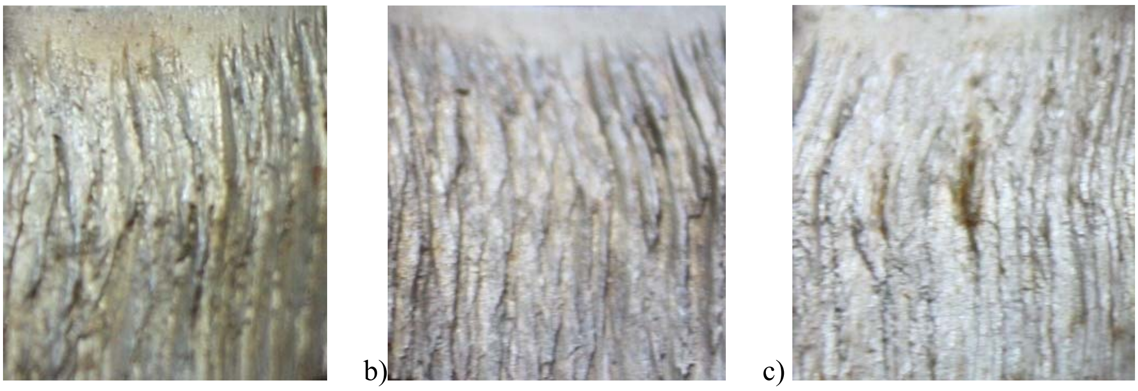

Fig.9. Photographs of holes surfaces after laser beam cutting for cutting speeds of: a) 150 mm/min; b) 200 mm/min; c) 250 mm/min

3.2 Heat affected zone

An important criterion of evaluating the suitability of a given processing method is the width of the heat affected zone, i.e. the width of the top layer near the edge with the structure and properties modified under the influence of a concentrated stream of energy (in the case under discussion). In the samples cut with the laser beam, there is an apparent heat affected area. The structure of the samples consists of a melted, secondarily hardened zone and a tempered zone which changes going into core (Fig. 10).

Fig.10. Arrangement of heat affected zones of NC6 steel cut with a laser beam: a) melted zone, b) secondarily hardened zone, c) tempered zone, d) core

In all the examined cases, the individual zones transition was much like the one shown in Fig. 10. Nearer to the laser beam exit from the material, growth of the portion of melted zone and the tempered zone was observed.

The results of microhardness measurement for laser beam cutting can be seen in Fig. 11. The measurement has been performed on the side of the laser beam exit from the material. Analysing the results, one can state that the microhardness of the melted zone is by 28 - 38% lower than that of the core; the hardness of the secondarily hardened zone is close to the microhardness of the core; that of the tempered zone is by 24 - 30% lower. Microhardness changes due to laser processing reach the depth of 2,4 mm for the cutting speed of 250 mm/min. The various values of temperatures obtained in the cutting area are the cause of various widths of the heat affected zones. With the reduction of cutting speed, the temperature grows and, consequently, the participation of the melted and tempered zones in the material grows also.

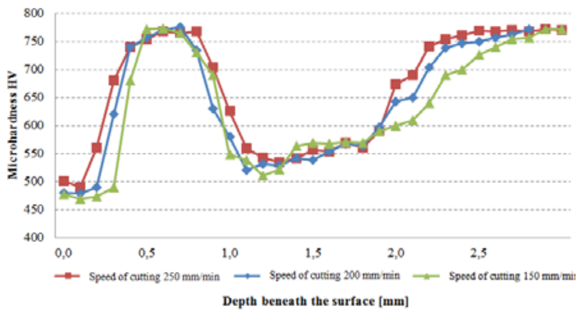

Fig.11. HV microhardness of the surface layer of NC6 steel processed with a laser beam

The measurement of the heat affected zone for abrasive water jet processing has been limited to the check of hardness in the zone of processing. The measurement results have proved that abrasive water jet processing does not cause thermal acting on the material (no heat affected zones).

4. CONCLUSIONS

The experimental examinations performed have allowed us to elaborate the following conclusions concerning cutting NC6 steel with abrasive water jet and with a laser beam:

1. In the process of cutting holes, the methods under analysis have caused formation of a cone on the surface of the processed NC6 steel. With the increase of the cutting speed, the cone decreases for laser beam cutting and grows when abrasive water jet is used.
2. Thermal action of laser beam on the NC6 steel results in a larger roundness error *RONt*, as compared to the abrasive water jet processing. The *RONt* roundness error parameter for laser processing reduces with the growth of cutting speed. Shortening of the time of laser beam influence on the material is of significant importance.
3. Analysis of the *Ra* roughness parameter indicates that, with the increase of the cutting speed, the value of the *Ra* increases in abrasive water processing and decreases in laser processing. For 12 mm thick NC6 steel sample, after laser beam cutting, most surface structure has an appearance of a not machined surface.
4. Laser beam cutting process influences modification of the NC6 steel properties changing the surface layer microhardness values. The microhardness values change with the change of heat affected zones.

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