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A comparison of laser cutting and water-jet cutting

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ABSTRACT

Purpose: This article presents the quality aspects of both laser and water-jet cutting methods.

Design/methodology/approach: Laser cutting was made with Laser $C0_2$ TruFlow 6000 machine. Cutting abrasive jet was held on the water-jet. Cases on cutting stainless steel EN 1.4016/AISI 430 of different thicknesses are discussed in a comparison study. Following the tests, the surface roughness of the machined surface was measured by using optical profilometer. Using high-resolution optical microscope the kerf taper ratio and kerf wideness were measured.

Findings: The study included examination of thermal deformation and burr formation. Water-jet technique is devoid of thermal effects and burr formation are very small, since a little heat generated by the water-jet is absorbed by the water. Laser technology thermally deformed material, which is growing with the increase in thickness of the material.

Research limitations/implications: The cut surface roughness, waviness and taper cutting surface are higher in the hydro-abrasive technology than the laser cutting. Cutting speed for laser and water-jet were compared. Laser cutting technology has proved to be faster than water-jet cutting. Finally, was carried out the analysis 3D surface topography. New generation of instruments enabling a non-contact 3D assessment of a surface quality profilometer.

Originality/value: The selection of the appropriate cutting technique is important, therefore, a thorough examination of kerf allows to select the correct cutting technique.

Keywords: Water-jet cutting; Laser cutting; Stainless steel; Surface roughness; 3D surface topography

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MANUFACTURING AND PROCESSING

1. Introduction

Laser cutting and water-jet cutting are two major cutting process stainless steel, which are able to keep a good quality after the cutting process. Depending on the thickness of material used to cutting the final result of cutting can be varied. Along the change of the thickness cutting steel, material can deform differently. The selection of the appropriate cutting technique is important, therefore, a thorough examination of kerf allows to select the correct cutting technique.

In this paper move a following problem, which of these two technique is best suited for cutting thin stainless steel EN 1.4016/AISI 430 to a thickness of 3 mm. This article compares cutting stainless steel in view of kerf width, thermal deformation, burr formation, surface roughness [1] and productivity cutting thin stainless steel. In the present study, cutting properties of stainless steel by using laser cutting and water-jet cutting were investigated. Cutting speed were varied with a change in thickness of the cutting material. Paper has been supplemented by 3D surface topography measurement, which characterization of surfaces allows for easy and intuitive interpretations. With a proper set of parameters it is possible to quantify the surface functionality for a given application [2,3].

Abrasive water-jet cutting (AWJ) is a rapidly developing technology that is increasingly used in industry for a number of applications. AWJ is the method of cutting the material by the use of thin water jet under high pressure with added abrasive used to cut the target material by means of erosion [4]. The fast development of water-jet cut method was starting in USA early ‘80s. But idea of water-jet cutting is began in 1935 when the idea of adding an abrasive to the water stream was developed by Elmo Smith for the liquid abrasive blasting [5]. The final impetus for the development of technology has given dr. Hashish who coined nomenclature and who led an engineering research team, which develop the modern abrasive water-jet cutting technology [6,7]. Moreover, this technique of cutting has various distinct advantages, such as no thermal distortion, high machining versatility, high flexibility, minimum stresses on the work piece, and small cutting forces [8-10]. This is minimally invasive technique compared to other methods of machining materials.

Laser cutting is one of the thermal cutting processes, which using the high-point of the cutting jet by the introduction of energy and technical gas of high purity [11,12]. Laser technique enables to cut of various materials relatively cheaply and quickly. Advantages of laser cutting are: narrow kerf widths, high repeatability, minimal material distortion [13,14]. The first experiment in laser cutting was conducted in 1967 when used an oxygen assist gas to cut steel sheet with a focused CO_2 laser beam.

2. Experimental procedure

2.1. Material

The material considered in this study is stainless steel EN 1.4016/AISI 430 of different thicknesses (1 mm, 1.5 mm, 2 mm, 2.5 mm and 3 mm). Chemical compositions of the material used were shown in Tab. 1.

Table 1.
Chemical compositions stainless steel EN 1.4016/AISI 430 [15]

C	Mn	Cr	Si	P	S
≤0.08	≤1.0	16.0-18.0	≤1.0	≤0.04	0.015

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but it is not fully stain-proof, especially high-salinity and under low-oxygen, or poor-circulation environments [16]. Stainless steels contain sufficient chromium to create a passive film of chromium oxide. This form prevents further surface corrosion, blocking oxygen diffusion to the steel surface and blocks corrosion from spreading into the metal's internal structure. Oxide and steel ions have the similar size which causes that they bond are very strongly and remain attached to the surface [17]. Stainless steel differs from carbon steel by the amount of chromium. The shape of the specimens shown Figure 1. Dimensions are in millimetres. The special shape of the samples had shown the heat affected zone.

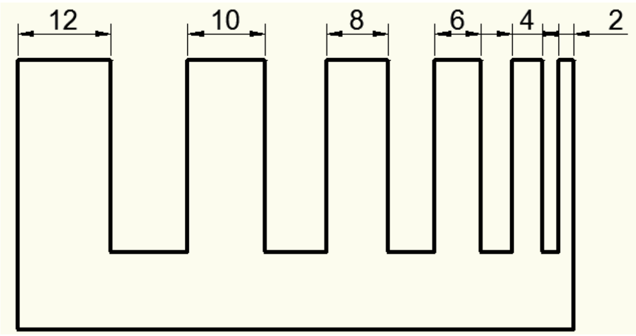

Fig. 1. The shape of the specimens for laser and water-jet cutting

2.2. Equipment

The equipment used for machining the samples was water-jet APW 2010BB and laser TRUMPF TruFlow 6000. Water-jet was equipped with ultrahigh pressure pump with the designed maximum pressure of 300 MPa. The machine is equipped a work piece table with dimension of 2000 mm x 1000 mm. The parameters that were kept constant during tests included for AWJ the water pressure (265 MPa), mass flow rate (6 g/s), standoff distance (2 mm), orifice diameter (0.35 mm), nozzle length (76.2 mm), nozzle diameter (1.02 mm), abrasive material (80 mesh garnet particles with the density of 4200 kg/m^3) and average diameter of abrasive particles (0.18 mm). Garnet consists of chemically 37% FeO, 31% SiO_2, 21% Al_2O_3, 7% MgO, 1% TiO_2, 2% CaO and 1% MnO_2. Laser TRUMPF TruFlow 6000 is fast axial flow CO_2 laser with power 6000 W, and wear-free gas circulation and capacitive radio-frequency excitation.

3. Experimental results and discussions

AWJ cutting for 1 mm thickness reached 1.337 µm for cutting diameter at the entrance to the material, and 1128 µm for kerf width. In the case of 2 mm thickness it was 1389 µm for cutting diameter at the entrance to the material and 1102 µm for kerf width. For 3 mm results achieved 1412 µm – cutting diameter and 1124 µm for kerf width. Results obtained with a laser was different, since used other beam diameter: 0.7 mm. The appearance of the water-jet cutting diameter for 2 mm thickness samples are visible in Fig. 2.

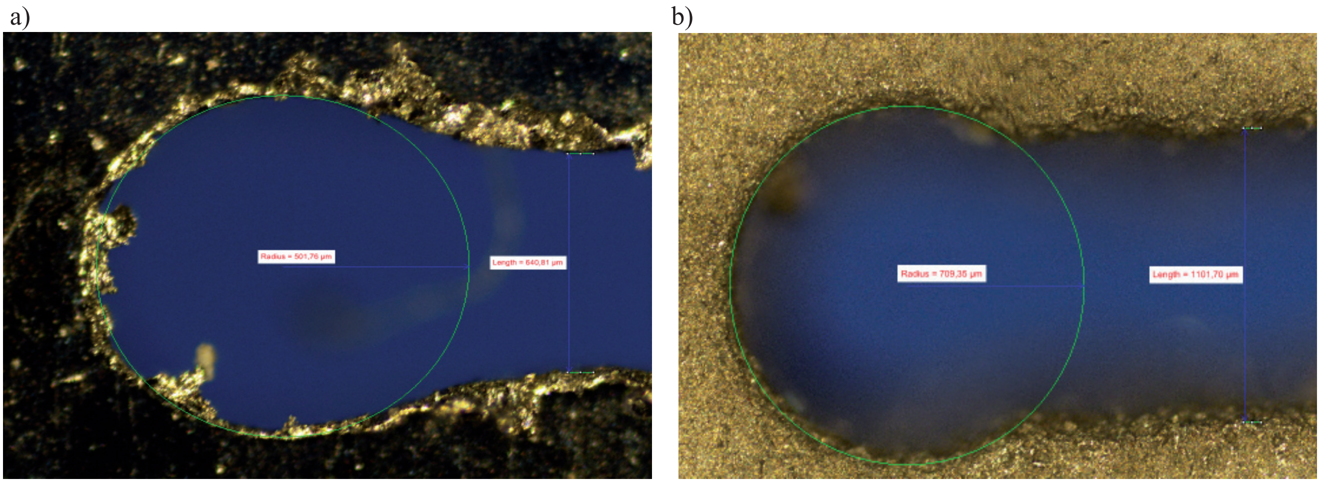

Fig. 2. Appearance of water-jet cutting diameter stainless steel for 2 mm thickness, a) top view b) bottom view

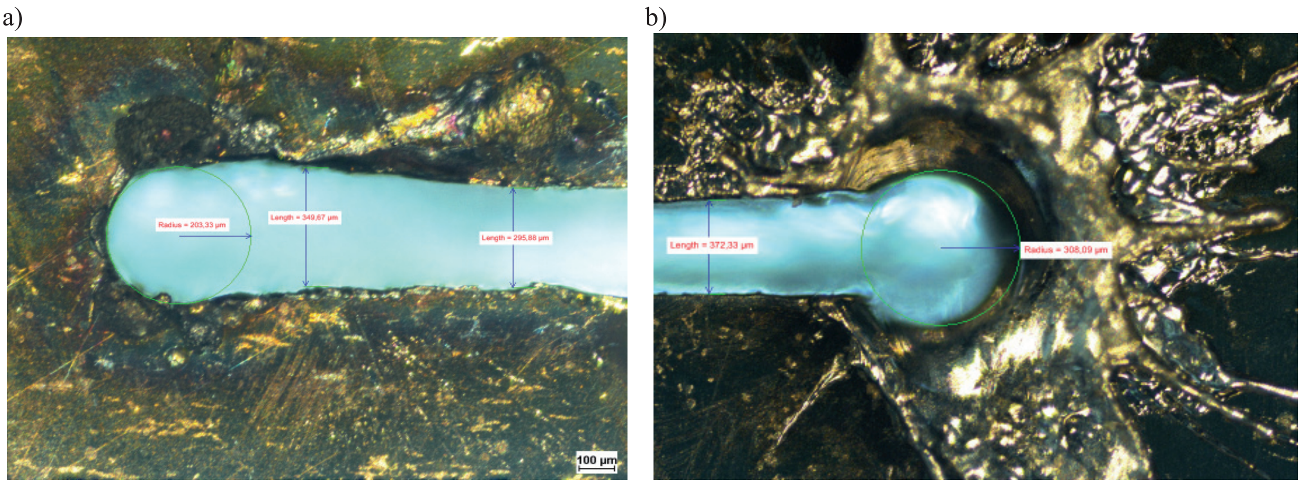

Fig. 3. Appearance of laser cutting diameter stainless steel for 2 mm thickness, a) top view b) bottom view

Laser cutting for 1 mm thickness was 582 µm for cutting diameter at the entrance to the material and 358 µm for kerf width. In the case of 2 mm thickness reached 616 µm for cutting diameter and 372 µm for kerf width. For 3 mm results achieved 649 µm for cutting diameter and 426 µm for kerf width. The appearance of the laser cutting diameter for 2 mm thickness samples are visible in Fig. 3.

A little heat generated by the AWJ process is absorbed by the water and carried into the catch tank. The material itself experiences almost no change in temperature during machining. Only water-jet nozzle has a high temperature. In the point of passage of the abrasive stream through the material there are no dross, but it was observed a small loss of material.

The laser beam emits heat, which deforms the material. With the increase in the thickness of the deformation of the cut material is also growing and reaches the value 177 µm for 3 mm stainless steel. Remelting zone are visible in the corners and dross occurs. The biggest deformation take place at the point of passage of the beam through the material, which reach a few millimetres sizes.

The burr formation was minimal in AWJ and the phenomenon decreases with increasing thickness of the material being cut, as demonstrated by the following results. For 1 mm of thickness reached 133 µm. In the case of 2 mm thickness reached 113 µm and for 3 mm results achieved 66 µm The situation is the opposite for laser cutting where the burrs are growing with the increase of the thickness of cutting stainless steel. Burr formation for 1 mm thickness reached 177 µm, for 2 mm results achieved 200 µm and in the case of 3 mm thickness reached 247 µm. Conclusion of it is following: for thicker materials, laser cutting technique will getting worse as compared to hydro abrasive jet cutting.

The cut surface roughness is higher in the hydro-abrasive technology than the laser cutting. Roughness average for stainless steel is 4.09 µm and for the laser is 0.75 µm (data for the material which thickness is 3 mm). The difference is 3.34 µm. In contrast to stainless steel 2 mm difference in the roughness between the cutting techniques is 4.18 µm. Furthermore to a thickness of 1 mm were observed difference in roughness of 3.31 µm for the benefit of the laser. The results were very similar.

The next issue analysed in the article was to compare the taper cutting surface. At the water-jet cutting was noted bigger inclination of taper cutting surface for all types of sheet thicknesses (4.69 degrees for sheet thickness of 3 mm). In the laser cutting tapers were invisible and were located in the border of approximately 1 degree.

Laser cutting technology is faster than water-jet cutting. Although, should take into consideration that the cutting speeds were adjusted in such a way to cut the material and then investigate the quality parameters of intersection. Less important were cutting with a low speed (in particular the water-jet technique) that contribute to a high quality.

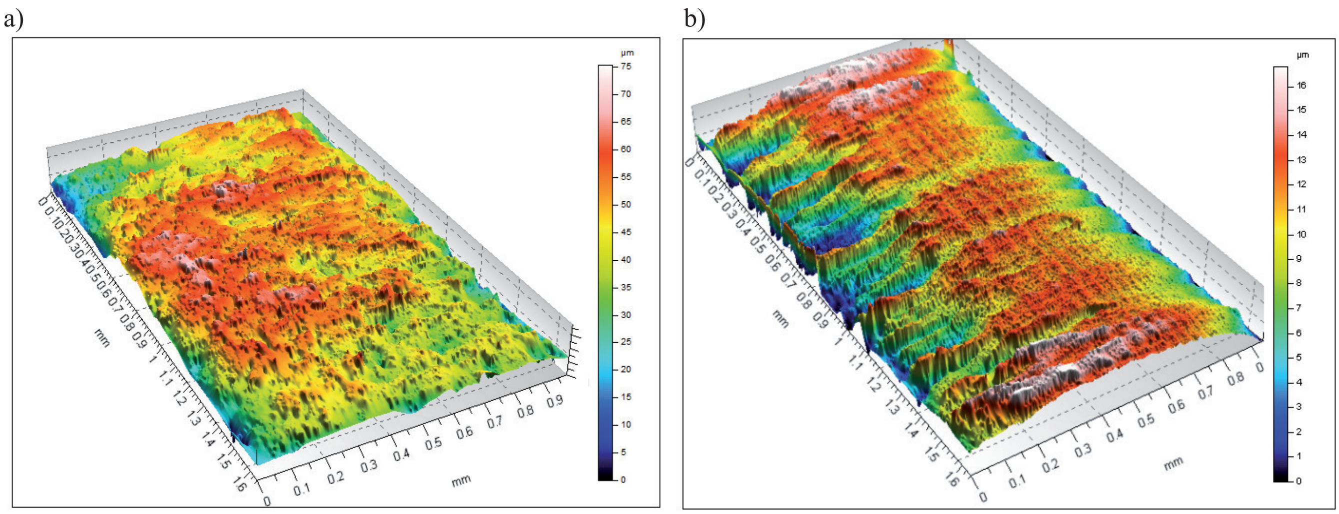

Fig. 4. 3D surface topography stainless steel for 1 mm of thickness a) water-jet cutting b) laser cutting

The steel sheet was cut into water-jet with the following speeds: for thickness 1 mm – 480 mm/min, for 2 mm 360 mm/min and for 3 mm 240 mm/min. Laser cutting speeds were as follows: for thickness 1 mm – 9500 mm/min, for 2 mm – 6600 mm and for 3 mm – 4000 mm/min. Laser speed cutting were many times higher (for 16 to 19 times faster depending on the thickness of steel) than technique hydro-abrasive cutting. The samples of the 3D surface topography shown in Fig. 4.

The 3D surface topography analysis showed the characteristics of cutting surface. The measurement was made by using a needle having a radius of rounding of the contact blade 2 µm. Water-jet cutting surface possessed indications of erosion, with numerous indentations. Sa (average roughness) and Sq (root mean square roughness), which may be used to indicate significant deviations in the texture characteristics, for 1 mm thickness reached Sa = 7.72 µm and Sq = 9.80 µm. For the same thickness of material cutting by using laser technology parameters reached Sa = 2.94 µm and Sq = 3.63 µm. Parameters Sz (max height of surface) for water-jet amounted Sz = 75.42 µm, but for laser cutting was over four times less and was as high as only Sz = 16.8 µm.

4. Conclusions

The laser cutting technology has proved to be better than water-jet for cutting thin sheet of stainless steel EN 1.4016/AISI 430. Laser cutting process is primarily much faster and causes less surface roughness intersection. The phenomenon of taper is virtually invisible. Moreover, the kerf width is smaller. AWJ technology does not result in thermal deformation and burr formation is low. It decreases with increasing thickness of the cut sheet. Hydro-abrasive cutting allows to cut precisely along a straight line and in the corners of the material of any thickness, as opposed to a laser which does not preserve the straightness of the cut. With the increase in thickness of the cutting material, there is misalignment in the cutting and the wavy surface is formed. 3D surface topography after laser cutting and water-jet are different. All 3D parameters for laser technology are much smaller than water-jet machining, which indicates a more smooth cutting surface after laser cutting.

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