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INFLUENCE OF CUTTING TECHNOLOGY ON PROPERTIES OF THE CUT EDGES

Marek S. Węglowski, Tomasz Pfeifer

Summary

The influence of cutting technologies on the quality, mechanical properties and microstructure of the cut edges of steel is presented. The cutting technologies cover: plasma, laser beam, water jet and oxyfuel flame cutting. During investigation the measurements of perpendicularity tolerance, hardness, mean high of the profile Rz5 and metallographic examination were carry out. The results revealed that the lowest hardness was achieved by water jet cutting, whereas the highest was obtained by plasma cutting under the water surface. The lowest perpendicularity was obtained by plasma cutting under the water surface but the highest was achieved by laser and HD plasma cutting. The conducted experiments revealed moreover that the lowest roughness was achieved by means of plasma cutting over the water surface, whereas the highest by laser beam cutting.

Keywords: plasma cutting, laser beam cutting, water jet cutting, oxyfuel flame cutting

Wpływ technologii cięcia na właściwości warstwy wierzchniej stali krawędzi ciętych

Streszczenie

W pracy przedstawiono wpływ technologii cięcia na właściwości mechaniczne, mikrostrukturę i jakość warstwy wierzchniej. Technologie cięcia obejmowały cięcie: plazmą, wiązką laserową, strumieniem wody oraz tlenem. Prowadzono pomiary tolerancji prostopadłości, twardości, średniej wysokości profilu Rz5. Wykonano również badania metalograficzne. Najmniejsza twardość powierzchni po cięciu zapewnia cięcie strumieniem wody, natomiast największe cięcie plazmą pod lustrem wody. Najmniejszą tolerancję prostopadłości zapewnia cięcie plazmą pod lustrem wody, natomiast największą cięcie wiązką laserową i plazmą HD. Najmniejszą chropowatość powierzchni zapewnia technologia cięcia plazmą nad lustrem wody, natomiast największą wiązką laserową.

Słowa kluczowe: cięcie plazmą, cięcie wiązką laserową, cięcie strumieniem wody, cięcie tlenem

1. Introduction

Cutting technologies have a wide range of applications in different manufacturing processes in industry due to its necessity of cutting various elements out of sheets as both "finished products" as well as those intended for further processing. Cutting technologies are also used for cutting shapes and making openings. Usually, the geometry of cut out elements is complex. The

Address: Marek S. WĘGLOWSKI, PhD Eng., Tomasz PFEIFER, PhD Eng., Institute of Welding, Bl. Czeslawa 16-18 St., Gliwice 44-100, e-mail: arek.weglowski@is.gliwice.pl

range of cutting method applications also includes pre-weld edge preparation (bevelling) to obtain a weld groove of appropriate geometry. However, it is necessary to verify the usability of a given cutting technology in the view of meeting specific requirements.

Cutting can be manual, mechanised, automatic or carried out on robotic stations. Cutting (bevelling) can be conducted on a plane (2D) or in space (3D). The efficiency, and thus the rate of a cutting process is mostly dependent on the type of a material being cut, the thickness of a material and on the parameters characteristic of a given process. Among many different technologies the most popular are: plasma, laser beam, water jet and oxyfuel flame cutting. The different phenomena and mechanisms which occur during cutting depend on technologies. In laser beam cutting the material to be cut is locally melted and evaporated by the focused laser beam. The melt is then blown away with the aid of assist gas, which flows coaxially with the laser beam, forming a kerf. The similar mechanism occurred in plasma cutting. In this process the material is melted, sometimes evaporated, and blown from the cutting region. The quite different phenomena can be observed during oxyfuel flame cutting. During process the material is combusted and the products of these reactions are blown away. In the last cutting technology, water jet, material is abraded and then blown away.

During the selection of the proper technology many different factors should be taking into account. Firstly, grade and the thickness of a material being cut, secondly length and the shape of a cutting line, thirdly – process potential and the effect on productivity, fourthly process-related costs such as a device purchase price, operating costs, spare parts costs, cutting-related costs (energy and materials), and the above all required quality of edges cut e.g. according to standards PN-EN 1090-2 [1] and PN-EN ISO 9013 [2], sometimes the effect of a cutting process on the microstructure of a material. Managing the competitiveness of technologies particularly in the conditions of crisis aimed at improving the quality with a reduction of production costs due to the optimization of all above factors [3]. The quality inspection procedure of cutting edges acc. to standards was presented in the previous paper of the authors [4]

The earlier investigation of the cutting process revealed that the roughness value of laser cutting edge increases as the cutting speed increases and it decreases as the other parameters increases for stainless steel. Moreover the upper kerf width increases as the laser power, nitrogen pressure and nozzle diameter increase, and it decreases as the cutting speed and focal position increase. However, the cutting speed is the main factor affecting the upper kerf [5]. The opposite results was achieved by the Powell J. [6] et al. - at lower speeds the roughness is higher for mild steel. Ma and Deam [7] revealed that the roughness of the water jet cut profiles is higher at the highest cutting speeds. Bini et al. [8] showed that the high quality parts (unevenness class 2, according to PN-EN ISO 9013) can be obtained as a result of an experimental investigation aimed at selecting the proper values of process parameters for high tolerance plasma arc cutting system. Borkowski at al. [9] pointed out that increase in the cutting speed caused the increase of the roughness. Simultaneously, the increase of the water pressure caused the decrease of the roughness. Pfeifer [10, 11] provided evidence that the heat-affected zone (HAZ) was primarily affected by the cutting rate and the environment in which a process was carried out. This dependence is connected with a heat input to the material. The lower is the cutting rate, the greater is the heat input, and consequently, the greater is the HAZ width for plasma cutting of steel. Pakos [12] revealed that, the greatest increase of hardness of cutting edge of S690QL steel was obtained for air plasma and laser beam cutting, about 452HV. The author noted that the nonfulfillment of standards requirements leads to reject the cutting technology. Zebala at al. [13] pointed out that the values of the selected surface roughness parameters decreases with increasing of the laser cutting speed.

The main goal of this work is to determine the relationship between thermal cutting technology and quality of the cutting edges. The factors of quality taken into account were as follows: the mean height of the profile Rz5, perpendicularity tolerance, hardness of cutting edges, and HAZ microstructure.

2. Experimental procedure

Non alloyed steel in sheet form of standard grade of S355J2+N was used as workpiece material with thickness of 10 mm. Trial runs of cutting were performed by the sample presented in Figure 1. The parameters of the processes are given in Table 1. The process technological conditions were selected after taking into consideration the thickness and grade of a material.

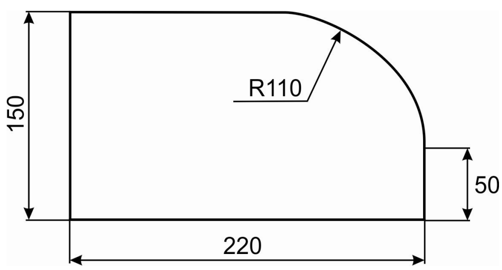

Fig. 1. Test sample for surface quality inspection after cutting

The quality assessment based on the requirements of PN-EN 1090-2 PN-EN ISO 9013 standards after cutting the samples were carried out.

Table 1. Cutting technologies used during testing

Test piece no.	Cutting technology	Device	Cutting rate m/min	Remarks
1	oxyfuel flame (propane)	Messer Alfa	0.42	Oxygen pressure during heating 0.2 MPa, cutting pressure 0, 4, 5 MPa
2	High definition plasma (HD)	HD3070 by Hypertherm	0.7	Oxygen as cutting gas
3	Laser beam	Trumatic 2600 (Trumpf)	1.2	
4	Plasma above a water surface	CP200 (Instytut Spawalnictwa)	1.6	
5	Plasma above a water surface		2.25	
6	Plasma under a water surface		1.6	
7	Water jet	WaterJet NC3015	0.13	Australian sand used as powder
8			0.16	
9			0.18	

The quality inspection procedure of cutting edges covered the following measurements: the mean height of the profile Rz5, perpendicularity tolerance, hardness of cutting edges, and examination of HAZ microstructure. The height of the profile Rz5 factor was determined in accordance with the PN-EN ISO 4288:2011 [14] standard using a surface roughness measuring tester SJ210 (Mitutoyo) at the following parameters: the number of sampling lengths – 5, the travel rate was 0.5 mm/s, and the total shift amounted to 17.5 mm.

The hardness measurement was carried out on metallographic specimens prepared perpendicular to the cutting edges, as well as directly on the cutting edges surface at a load of 98.1 N. During hardness testing the indentations were randomly made on the matrix without marking the specific phases. Hardness measurement of the steel was performed by using the Brickers 220 hardness tester (EN ISO 6507 [15]). The indirect Leeb method was also used to determine the hardness of cutting edges. In this method a carbide ball hammer is throwing into surface by spring energy. An electronic sensor measures the velocity of the hammer as it travels towards and away from the surface of the sample. The Leeb value is the hammer's rebound velocity divided by the impact velocity times 1000. The result is Leeb hardness from 0 to 1000 was recalculated to Vickers hardness scale.

Microstructural examinations were carried out by the light microscope Eclipse MA 200 (Nikon). The cross-sections were mechanically ground and polished, and chemically etched with Nital reagent (2% nitric acid – for light microscopy).

The measurements of perpendicularity tolerance were made using a dial gauge with an accuracy of 0.01 mm. A test plate moved in relation to the gauge with a rate of 15 mm/min.

Results and discussion

The main goal of the research was to assess the quality of the cutting edges based on the requirements of PN-EN 1090-2 and PN-EN ISO 9013 standards. To this end, the mean height of the profile Rz5, perpendicularity tolerance, hardness of the cutting edges, and the HAZ microstructure were determined.

The measurements were carried out on a specimens presented in Figure 2 in four points (arrows marked). The results of perpendicularity tolerance measurements are shown in Figure 3. It can be concluded that the lowest perpendicularity tolerance (the highest cutting quality) was obtained for laser beam cutting and HD plasma cutting, whereas the highest (the worst quality) for cutting above a water surface at a cutting rate of 1.6 m/min. High energy density of electric arc in HD plasma and beam in laser cutting ensures better surface quality after cutting. It should be noted that in the case of HD plasma and laser cutting the rate of cutting is relatively high (0.7 and 1.2 m/min respectively) in comparison with oxyfuel flame or water jet cutting. However, lower than the rate of traditional plasma cutting (e.g. 1.6 and 2.25 m/min).

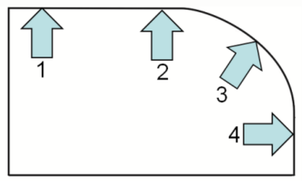

Fig. 2. Location of the measurement points on the specimen

The one of the requirements of PN-EN 1090-2 standard is permissively level of hardness of cutting surface. The results of measurements, based on Vickers, and Leeb methods after convertion are shown in Figure 4. The place of measurements are shown in Figure 5. The presented results indicated that the highest hardness is observed for specimen subjected to plasma cutting under a water surface. Short cooling time $t_{8/5}$ caused by fast heat dissipation of surrounded water leads to formation of martensitic-bainitic microstructures (Fig. 6). This microstructure is characterized in S355 steel by higher hardness. On the other hand, the basic advantage of cutting under a water surface is the improvement of work conditions on the workstation and the elimination of the detrimental effect of the plasma arc. The use of water reduces the emission of fume, ozone and noise (significantly) [16].

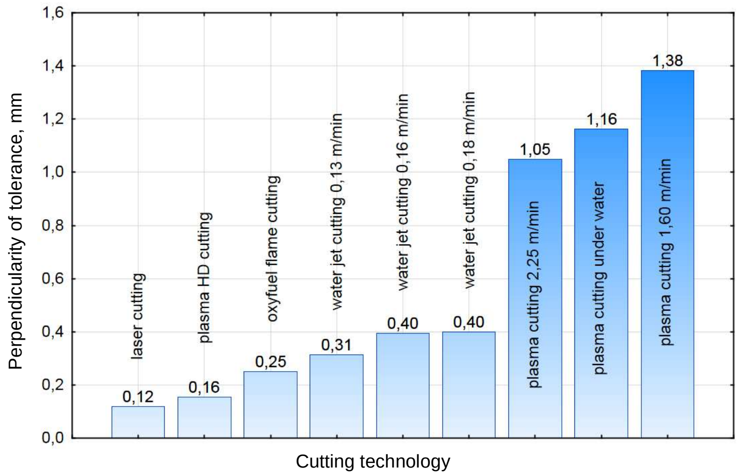

Fig. 3. Results of perpendicularity tolerance measurements, mean value of four points presented in Fig. 2

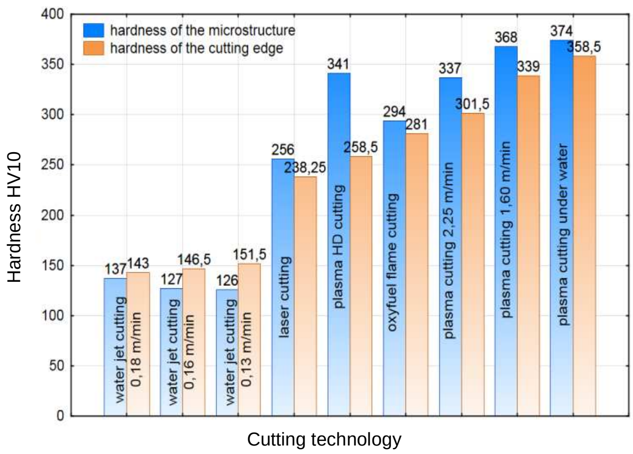

Fig 4. Results of hardness measurements on the metallographic specimen and cutting edges

The lowest hardness was achieved for the specimens subjected to water jet cutting. In this case there is no heat source, the process of cutting is connected with abrasive micro-machining, the microstructure does not change (Fig. 8) and the hardness corresponds to that of the base metal (about 140 HV10).

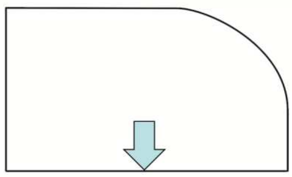

Fig. 5. Tested element with the marked place of hardness measurements

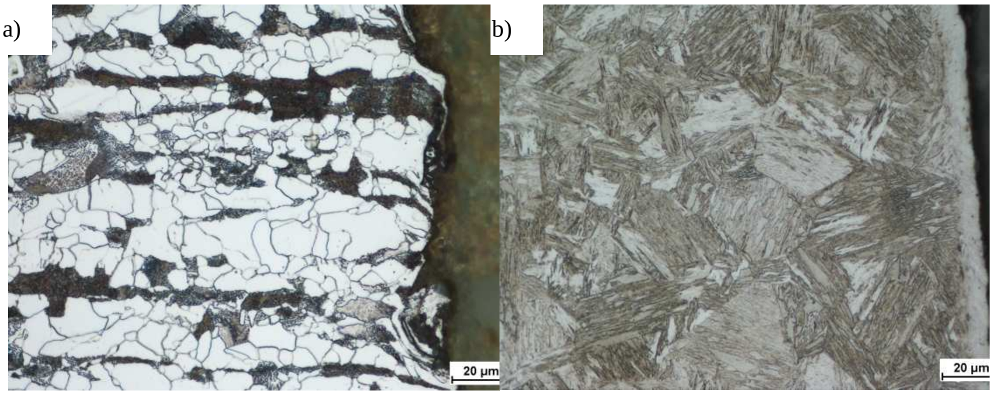

Fig. 6. Microstructure of the HAZ of the area cut: a) water jet cutting, b) plasma under a water surface cutting

The conducted research also covered investigation of the effect of a cutting technology on the width of HAZ. On the basis of the conducted measurements it is possible to state that the widest HAZ was obtained with oxyfuel flame cutting (Fig. 7), whereas the narrowest (the lack of HAZ) was obtained in the case of the surface cut with a water jet (Fig. 8).

An important parameter as regards the correctness of a cutting process is the mean height of the profile Rz5 of the cutting edge. The results of measurements are presented in Figure 9. The measurements were carried out on the test element in 4 points (Fig. 2). The results revealed the highest Rz5 parameter for the element cut with a laser beam, and the lowest for the element cut with plasma over a water surface at a cutting rate 2.25 m/min. The overview of cutting edges for laser and plasma cutting are shown in Figure 10.

The greater value of the Rz5 parameter for the laser cutting surface results from the cyclicity of the cutting process itself. The process of cutting with a laser beam is connected with the multiple start and extinction of a combustion reaction in the upper part of a metal. The process of oxidation (the cutting process involved the use of oxygen as a cutting gas) leads to the formation of ducts in the material. For a lower cutting rate (in the test the cutting rate was 1.2 m/min) the ducts are “thicker” and less concentrated [17].

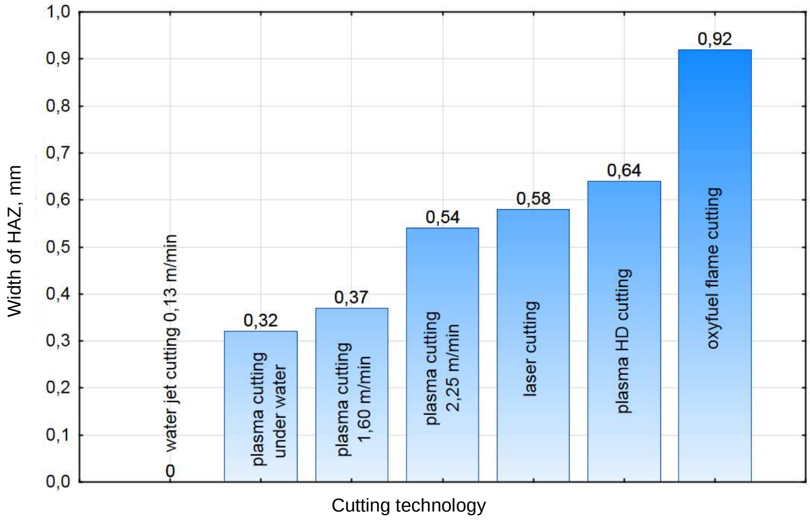

Fig. 7. Effect of a cutting technology on the HAZ width of catting edges

a) 

b) 

Fig. 8. The HAZ near the cutting edge: a) oxyfuel flame cutting,
b) water jet cutting

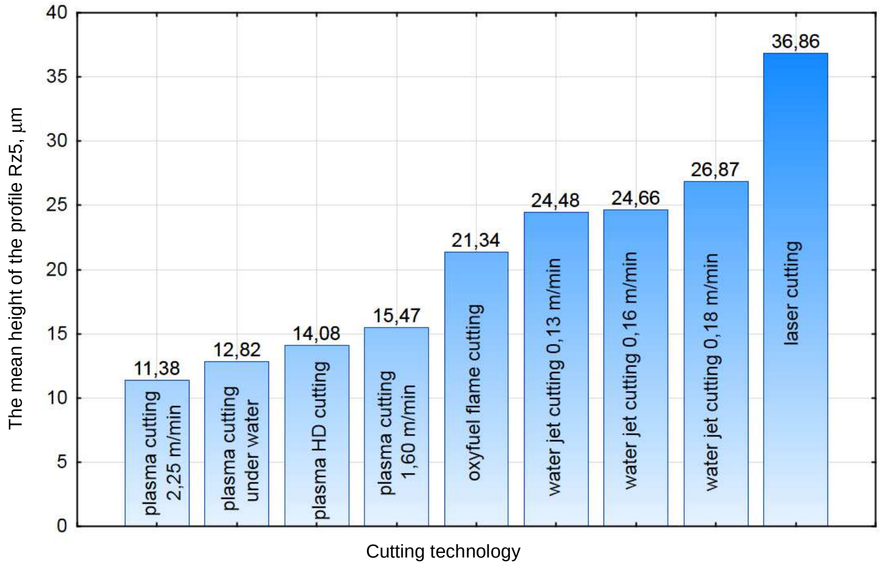

Fig. 9. Results of the mean height of the profile Rz5 measurements

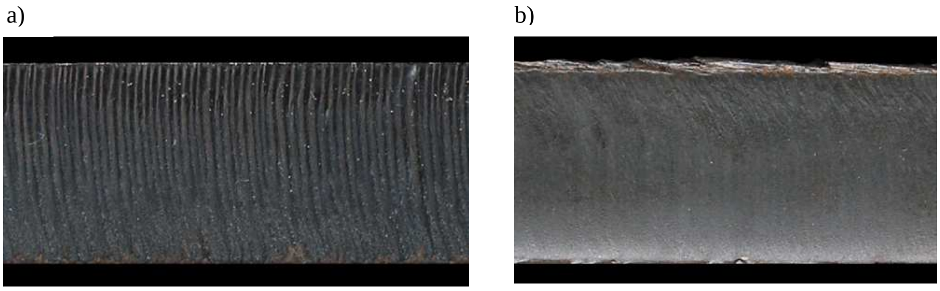

Fig. 10. The overview of cut edges roughness a) laser, b) plasma (v = 2.25 m/min)

Conclusions

The obtained results can be summarized as follows:

- lowest surface hardness following cutting is ensured by water jet cutting, whereas the highest is obtained using cutting under a water surface,
- lowest mean height of the profile Rz5 is ensured by plasma cutting over a water surface and the highest by cutting with a laser beam,
- lowest perpendicularity tolerance is obtained by plasma cutting under a water surface 1,6 m/min, whereas the highest by laser beam cutting and plasma HD cutting,

• the widest HAZ was obtained with oxyfuel flame cutting, whereas the narrowest (the lack of HAZ) was obtained in the case of the surface cut with a water jet.

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