

# The Cutting of Steels Using Various Methods

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**Abstract:** The article describes tests of steel subjected to cutting with laser, plasma and abrasive waterjet. The research discussed in the article also involved microstructure observation and changes in hardness after cutting as well as the assessment of surface quality based on measurements of surface parameters.

**Keywords:** laser, plasma, abrasive waterjet, surface quality

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## Introduction

The cutting of materials tends to be the first operation when making structural elements. The primary issue concerning the cutting of materials is the condition of the surface layer, affecting the properties of a given product, primarily its hardness, brittleness and corrosion resistance. In addition, the surface condition may necessitate the application of finishing treatment.

Technologically advanced cutting techniques make it possible to obtain products in finished forms, where the selection of a cutting method depends on quality-related requirements as well as technical and financial possibilities of the producer [1]. Primary criteria taken into consideration when selecting a given cutting technology include the type of material and its thickness, the accuracy and time of cutting, the quality of a surface to be cut, dimensional tolerances, the shape of elements to be cut out and the cost of cutting [2]. In cases of processes which might result in local hardening, before selecting a given cutting method it is necessary to verify its usability in PN-EN 1090-2 [1]. The above-named standard specifies the maximum surface hardness for structural

steels. Depending on types of products and steel grades, the maximum hardness amounts to 380 HV or 450 HV [3].

In industrial practice, the most common cutting methods involve the use of oxygen, plasma, laser or waterjet [4]. Presently, plasma cutting is the leading method, which can probably be ascribed to high efficiency, good surface quality after cutting, the possibility of cutting thick materials (up to 150 mm) and favourable economic indicators [5]. The method can be used for cutting nearly all current conducting materials, i.e. steel, cast iron, aluminium and copper [4]. In addition, the use of special heads with independent arc extends the method application range and enables the cutting of non-metallic materials (plastics, rubber or glass) [1].

Laser cutting is characterised by the significant degree of automation as well as high efficiency and flexibility (e.g. when changing the scope of production). Another advantage of the technology is the narrow HAZ, cutting accuracy, lower hardening than that resulting from plasma cutting, a high cutting rate and the high quality of surface of the cutting process [6]. The laser cutting method can be

Table 1. Chemical composition and mechanical properties of steel S355MC

Chemical composition										
Element	C	Mn	Si	P	S	Cu	Cr	Ni	Al	Mo
Content, %	0.06	0.75	0.023	0.009	0.004	0.02	0.04	0.019	0.035	0.009
Element	Nb	Ti	N	Ca	Pb	Sn	Sb	Zn	W	B
Content, %	0.026	0.002	0.007	0.0014	0.0005	0.0014	0.0005	0.0012	0.005	0.0001
Mechanical properties										
Tensile strength, $R_m$ , MPa	Yield point, $R_e$ , MPa		Toughness at a temp. of -20°C; $K_{IC}$ , J				Elongation A, %			
430–550	355		40				23			

used for the cutting of elements made of metals, plastics, glass and insulating materials [1], the thickness of which is restricted within the range of hundredths of a millimetre to approximately 30 mm [4].

Waterjet cutting is a cold cutting process. Because of the significant duration of the process and its high costs, the method is used for the cutting of materials which cannot be cut using other methods or the cutting of which is even more expensive and difficult than waterjet cutting. Soft materials (cardboard, leather) are cut using pure waterjet, whereas hard materials (metal, glass, composites) are cut using a waterjet containing an abrasive material, primarily garnet, quartz sand, corundum and silicon

carbide. The thickness of elements subjected to cutting may reach as many as 300 mm. Waterjet cutting is characterised by many advantages including, among other things, the high quality of surface (after cutting), the lack of thermal deformations and structural transformations as well as (in many cases) the elimination of additional finishing [4].

## Individual tests

The tests aimed to determine the quality of the surface of structural TMCP steel after plasma, abrasive waterjet and laser cutting. The cutting process was shielded by oxygen and nitrogen. The tests were performed using 6 mm thick plates made of steel S355MC (Table 1) in

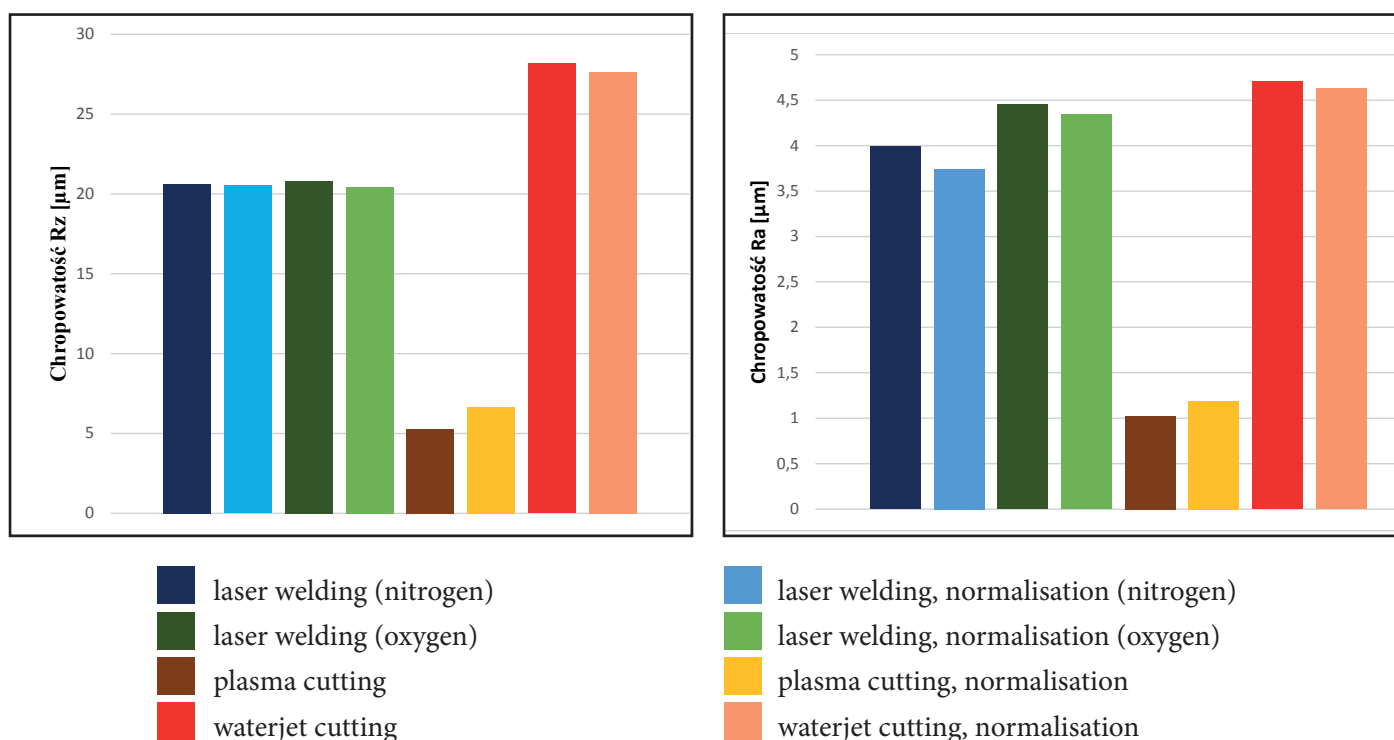


Fig. 1. Measurement results in relation to roughness Rz (a) and deviations from mean line Ra (b)

the as-received state and after normalising at a temperature of 950°C for 30 minutes.

Plasma cutting was performed using a Jantar device (Eckert), a current of 60 A, an arc voltage of 125 V and a cutting rate of 1.8 m/min. Abrasive waterjet cutting was performed using an Eckert-made machine, garnet abrasive, a water pressure of 380 MPa, a cutting rate of 0.12 m/min, a nozzle having a diameter of 0.91 mm and the distance of the nozzle amounting to 3 mm. Laser cutting was performed using a TLF 5000 machine (Trumpf). Oxygen-shielded laser cutting was performed using a laser power of 4800 W, a cutting rate of 3.3 m/min, a shielding gas pressure of 0.08 MPa and a nozzle having a diameter of 1.2 mm. Nitrogen-shielded laser cutting was performed using a laser power of 500 W, a cutting rate of 2.6 m/min, a shielding gas pressure of 1.8 MPa and a nozzle having a diameter of 2.3 mm. In both cases the pulsation frequency amounted to 20 000 Hz.

## Quality of the surfaces subjected to cutting

The assessment of surface quality was based on the measurements of roughness  $R_z$  and deviations from mean line  $R_a$ . The tests were performed using a Mahn MarfSurf ps10 machine. The results of the measurements are presented in Figure 1.

## Hardness measurements

Hardness measurements were based on the Brinell test and involved the use of a Zwick Roel ZHV10 hardness tester and a load of 98 N. The hardness of the material in the as-received state

amounted to 186 HB. The hardness of the material after normalising amounted to 129 HB. The hardness measurements were performed in three lines, starting from the cut edge. The test results are presented in Figure 2.

## Metallographic tests

The objective of the metallographic tests was to determine structural transformations taking place in the material as a result of the cutting process. Observations of metallographic specimens were performed using an Olympus

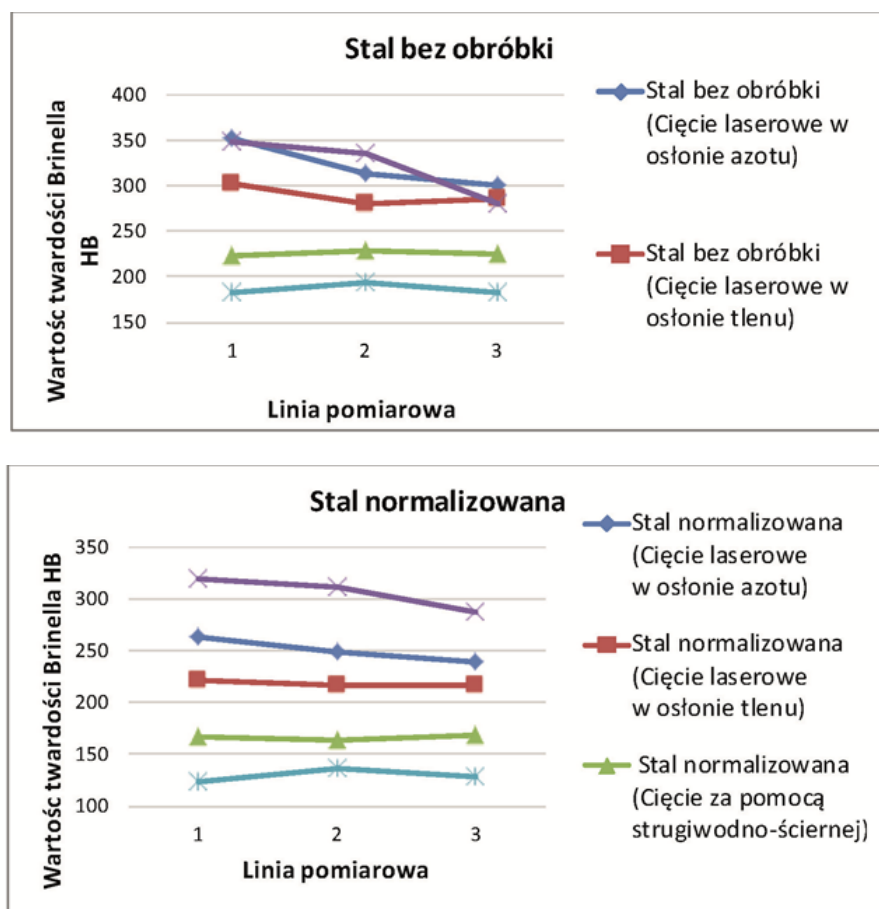


Fig. 2. Results of steel hardness measurements after cutting performed using various methods (a) in the as-received state and (b) after normalising

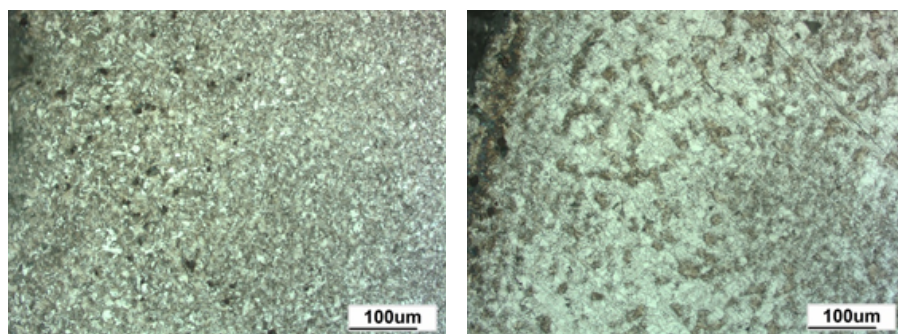


Fig. 3. Structure of the edge after nitrogen-shielded laser cutting: a) before heat treatment and b) after normalising



IX 70 microscope (at a magnification of 200x); the specimens were etched in the 5% solution of  $\text{HNO}_3$ . Figures 3–6 present the structure of the material formed in the cut edge.

## Analysis of test results

The tests revealed significant changes in the structure and hardness of the cut edge. Nitrogen-shielded cutting led to the formation of the acicular structure, the hardness of which amounted to 350 HB. Normalising performed before cutting resulted in the formation of the ferritic-pearlitic structure at the cut edge, characterised by a significantly lower hardness of 260 HB. The use of oxygen as shielding gas resulted in the lower hardening of the material at the edge (300 HB); the structure contained fine-grained bainite. Also in the above-named case, the initial heat treatment resulted in a decrease in hardness by approximately 100 HB. Similar hardening was observed after cutting with plasma, where the normalising process did not significantly affect the hardness of the material. Abrasive waterjet cutting did not trigger structural changes in the steel, containing mostly ferrite with a slight amount of pearlite. The hardness at the cut edge amounted to 220 HB. After normalising, hardness amounted to 160 HB.

The measurements of roughness  $R_a$  and  $R_z$  revealed that the best quality was obtained after cutting with plasma; parameter  $R_a$  of the material in the as-received state and after normalising amounted to approximately  $1\text{ }\mu\text{m}$ , whereas parameter  $R_z$  amounted to  $5.5\text{ }\mu\text{m}$  and  $7.2\text{ }\mu\text{m}$  respectively. Equally good quality was obtained

after laser cutting, where certain minimum differences were observed in relation to the shielding gas used in the process. Roughness  $R_a$  in relation to nitrogen-shielded laser cutting amounted to  $4.33\text{ }\mu\text{m}$ . Roughness  $R_a$  in relation to oxygen-shielded laser cutting amounted to  $4.13\text{ }\mu\text{m}$ . Parameter  $R_z$  amounted to  $20.32\text{ }\mu\text{m}$  and  $21.68\text{ }\mu\text{m}$  respectively. The highest roughness was observed after abrasive waterjet cutting, where  $R_a$  amounted to  $4.75\text{ }\mu\text{m}$  and  $R_z$  amounted to  $28.23\text{ }\mu\text{m}$ . Normalising performed before the process did not significantly affect the quality of surface.

The measurement results related to laser cutting and abrasive waterjet cutting were very

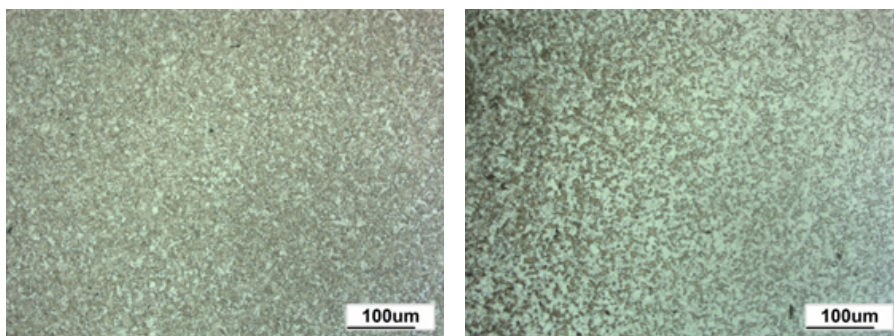


Fig. 4. Structure of the edge after oxygen-shielded laser cutting:  
a) before heat treatment and b) after normalising

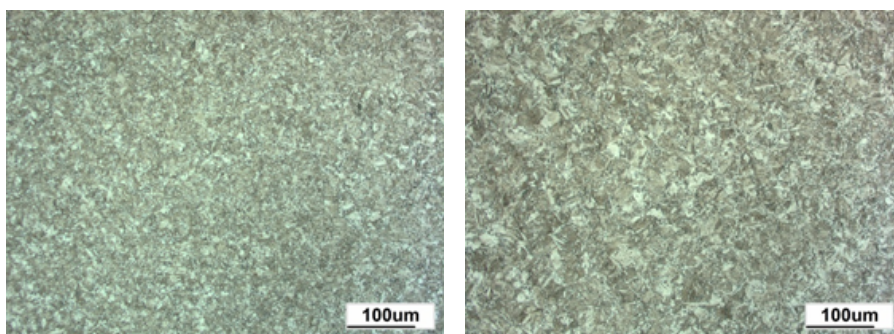


Fig. 5. Structure of the edge after plasma cutting:  
a) before heat treatment and b) after normalising

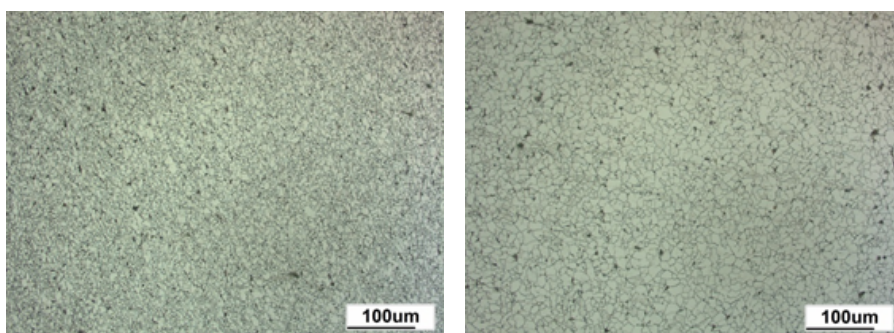


Fig. 6 Structure of the edge after abrasive waterjet cutting:  
a) before heat treatment and b) after normalising

similar. In turn, cutting with plasma resulted in a significant decrease in roughness, which could be ascribed to the high temperature of the process, leading to the partial melting of the material, and, consequently, to the smoothing of the cut edge.

## Summary

When cutting TMCP steels, in addition to determining surface parameters, it is also necessary to analyse structural transformations in the material as cutting process-related heat may result in the loss of properties obtained in the steel production process. The method of cutting affects the quality of a surface subjected to cutting, leads to structural transformations and results in the hardening of the edge subjected to cutting. The most popular plasma cutting is responsible for the most significant changes in the material and leads to the partial melting of the surface, which, in turn, necessitates the performance of further treatment. In terms of laser cutting, the quality of the surface is affected by the shielding gas used in the process. Oxygen-shielded cutting results in lower hardening and surface roughness than nitrogen-shielded cutting. The obtained quality of the edge is comparable with the quality obtained after cutting with the abrasive waterjet, yet, because of

the lack of structural transformations, cutting with water does not lead to an increase in hardness. It is possible to decrease the hardness of the material and improve the quality of the surface through initial normalising.

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