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The influence of technological parameters of plasma cutting on the quality and surface roughness when cutting thick steel sheets

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Abstract:

The purpose of this study was to analyze the effect of selected parameters on the quality of plasma cutting. The main parameter studied was the cutting speed and how it affects the roughness of the cut surface. The second parameter analyzed was the current intensity adjusted depending on the thickness of the material being cut, which also has a significant effect on the surface quality of the metal being cut. The evaluation of the quality of the cut surface was carried out on 8, 20, 30 and 35 mm thick sheets of S235JR grade steel. Several samples were selected from each thickness for measurement and testing. The samples were cut with a MAGNUM CUT 160 plasma cutter. The results show that the current intensity and the speed of the torch pass have a significant effect on the quality of the cut surface.

Keywords: plasma cutting, surface quality, roughness, S235JR steel, MAGNUM CUT 160 cutter

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1. Introduction

Cutting is one of the basic technologies for manufacturing parts. Depending on the choice of the cutting method, a certain quality of the product can be obtained. One of the most advanced methods of cutting through material is thermal cutting. Currently, the most common methods of thermal cutting include plasma cutting, laser cutting and oxy-gas cutting [1–5].

Plasma cutting is a modification of the tungsten inert gas (TIG) plasma welding process, which involves permanently joining metals using a non-fusible electrode. The processes differ in the design of the gas nozzle, which must produce a rapid increase in gas pressure. The process is typically used for cutting electrically conductive materials such as aluminum, corrosion-resistant steel or structural steel [2–4].

The plasma cutting method is distinguished from the others mainly by the low price of the process. Plasma equipment compared with laser equipment is much cheaper and can produce very similar results. Plasma machines, with the development of technology, are being equipped with increasingly advanced CNC control systems. This method is most commonly found in the engineering, metal, automotive, aerospace, and automotive industries. The course of the cutting process is influenced by many factors, which are mainly technological cutting parameters. Of these, the most noteworthy are the current intensity and the speed of torch pass.

One of the most important parameters for assessing surface quality is surface roughness. Achieving low surface roughness during plasma cutting or plasma machining is a major challenge, considering the complex interrelationships between various cutting parameters, such as speed, gas intensity, and flow rate [6–8].

Currently, it is possible to perform both separating and qualitative cutting of sheets with a thickness of 40–50 mm using air as the plasma gas, whereas a little more than ten years ago, the maximum thickness was typically around 25 mm [2–4, 9]. The following step is a more detailed analysis of the state of the art in the field of plasma arc cutting (PAC).

Gostimirović et al. [10] examined various parameters in the context of the machining quality of low carbon low alloy steel in PAC and their effects on kerf geometry, surface roughness, and heat-affected zone (HAZ) microstructure, underlining challenges in achieving final machining quality due to metallurgical variations in the HAZ. Moreover, Hang et al. [11] explored the impact of various parameters on cutting surface quality in CNC plasma cutting, emphasizing the crucial role of cutting current, air pressure, and torch standoff distance. They concluded that air pressure significantly affects slag formation, and surface roughness is primarily influenced by standoff distance and air pressure, with cutting speed and cutting current having less significant effects.

Loktionov et al. [12] optimized processing modes to minimize deviation from perpendicularity and established relationships between cutting speed, cut width, and material thickness. Kim, S. I. and Kim, M. H. [13] identified optimal cutting speeds and current levels to improve cut quality and straightness for thick steel ship plates, while also revealing challenges in quality for plates 30 mm or thicker, attributed to observations of molten metal flow and HAZ depth. Hema and Ganesan [6] analyzed the impact of PAC parameters on SS 304 alloy, identifying optimal conditions for improved surface roughness and material removal rate.

Koura et al. [14] studied the influence of plasma arc cutting conditions on the surface texture of Hardox400 parts, highlighting cutting speed as the most influential parameter, with results showing surface roughness ranging from 5 to 5.5 µm. Aldazabal et al. [15] investigated the effect of plasma cutting processes on the mechanical behaviour of steel plate edges, concluding that the resulting cut heat-affected zones (CHAZ) are narrow and homogeneous.

Tsiolikas et al. [16] demonstrated a balanced influence of all parameters on surface roughness during CNC plasma arc cutting, where optimal levels were discerned for cutting speed, torch standoff distance, and arc voltage, culminating in refined surface qualities, with further analysis revealing significant contributions of noise factors to variance. Suresh and Diwakar [17] aimed to optimize water–acetone

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plasma arc cutting for TWIP steel plates, utilizing design of experiments and response surface methodology to improve material removal rate, surface roughness, and cut time. Finally, Gani et al. [18] examined the feasibility of plasma machining for cutting parallel thin layers, emphasizing the importance of parameter optimization to minimize deformation and HAZs.

Most publications present information only about plasma arc cutting of thinner steel sheets, that is, 20 mm or less [8, 19], and that is why it is important to investigate the effect of PAC also on thicker steel sheets. This article contains the evaluation of the quality of the cut surface for 8, 20, 30 and 35 mm thick sheets of S235JR grade steel, which encompasses a broader thickness range, including sheets above 20 mm.

2. Materials and Methods

Sheets made of S235JR steel were used as the test material. It is a non-alloy structural steel with a variety of applications. One of its main applications is the creation of building load-bearing structures. This material is used to make long products such as steel profiles and plates, which are used to construct buildings, bridge structures, viaducts, or masts [20]. It is one of the most widely used materials in engineering, e.g., for the manufacture of construction machinery and equipment, and in the mining industry.

The main property of this material is high stiffness and good susceptibility to welding work. The chemical composition of the steel is shown in Table 1.

Table 1. Chemical composition of S235JR steel

C	Mn	P	S	Cu
		%		
≤ 0.17	≤ 1.4	≤ 0.035	≤ 0.035	≤ 0.55

The basic parameters of plasma cutting are [1, 11]:

- current intensity,
- arc voltage,
- cutting speed,
- type, pressure, and flow rate of plasma gas,
- type, pressure, and flow rate of shielding gas,
- type and construction of the electrode,
- diameter of the constricting nozzle,
- position of the torch relative to the object being cut.

Parameters that can be controlled by the operator in the plasma cutting process are:

- current intensity,
- plasma cutting speed,
- distance of the torch position relative to the material being cut.

Current intensity mainly determines the temperature and energy of the plasma arc. The higher the intensity, the greater the cutting speed, and with the given speed, it is possible to cut thicker materials. However, this leads to a decrease in electrode durability. Excessive intensity results in reduced cutting quality, increased kerf width, and rounding of the upper edges of the material. Conversely, too low intensity initially causes metal drooping, ultimately resulting in a lack of cut.

Cutting speed determines the quality of the cut, especially in the case of manual cutting. As cutting speed increases, its quality decreases, the kerf width decreases, and — similarly to current intensity — metal drooping begins to occur, ultimately resulting in a lack of cut. On the other hand, too low cutting speed leads to an increase in kerf width (material loss) and rounding of the upper edge, as well as the formation of metal drooping at the lower edge.

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The cutting process was carried out at the Research and Didactics Service Center in the Material Bonding Laboratory of the Faculty of Mechanical Engineering and Robotics of AGH University of Krakow, Poland. The device with which the cutting was performed was a MAGNUM CUT 160 plasma cutter (Fig.1.). It is designed for manual and machine air plasma cutting. These types of cutters are used in various industrial plants, but are also used in field conditions: on construction sites, when repairing machinery and equipment in the field, such as in open-pit mines and quarries. Technical data of the cutter can be found in Table 2.

Table 2. Technical specifications of the MAGNUM CUT 160 plasma cutter

Power supply	AC 400 [V], 50 [Hz]
Required safeguards	25/C
Cutting current	30 ÷ 160 [A]
Idle voltage	288 [V]
Approximate cutting thickness for structural steel	Separating max. 40 [mm] Qualitative max. 35 [mm]
Required air pressure	5 [bar]
Air consumption	210 [l/min]
Efficiency	60%
Product protection class	IP21S

Fig. 1. MAGNUM CUT 160 plasma cutter

For cutting, a basic LT-141 plasma torch was used-air-cooled, with a Euro-type connector, designed for handheld cutting machines, with a gas distributor integrated into the body.

The technical data of the torch can be found in Table 3.

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Table 3. Technical specifications of LT-141 plasma torch

Cooling	Air
Operation at 100 A	100%
Operation at 140 A	60%
Pressure	5 [bar]
Airflow rate	220 [l/min]
Max. cutting thickness at 120 A	45 [mm]
Max. cutting thickness at 140 A	55 [mm]
Connector length	6 [m]
Connection type	Euro

The plasma cutter device was equipped with an electric carriage, allowing the torch to move linearly at a set speed (Fig. 2). The speed of the carriage with the plasma torch was adjusted using a power supply and controlled by the voltage supplied to the carriage motor.

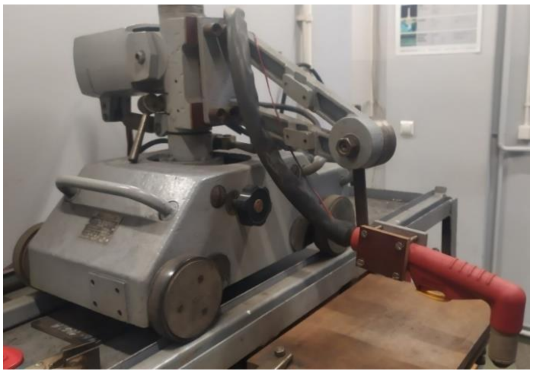

Fig. 2. Carriage with the torch

The research was conducted on a total of 10 samples: three with a thickness of 8 mm, three with a thickness of 20 mm, two with a thickness of 30 mm, and two with a thickness of 35 mm. For samples of the same thickness, the same current intensity was used, selected according to the device instructions and previous cutting trials with the plasma cutter used for the tests.

During the tests, only the cutting speed was changed within the range of 4 to 13 mm/s. A speed of 13 mm/s was applied to sheets with a thickness of 8 mm, and only a speed of 10 mm/s was used for sheets with thicknesses of 8 and 20 mm. These speeds were not used for the thickest sheets because of the inability to cut them at such speeds. The standoff distance of the torch remained unchanged throughout the experiment. The thicknesses of the samples and their corresponding parameters selected for the tests are collectively presented in Table 4.

Table 4. Set technological parameters during plasma cutting

Sample No.	Thickness	Current intensity	Cutting speed		Current to the carriage	Torch standoff distance	Gas type
	[mm]	[A]	[mm/s]	[m/min]	[V]	[mm]	[—]
1.1	8	60	7	0.42	8.53	5	Air
1.2			10	0.6	11.68		
1.3			13	0.78	14.83		
2.1	20	100	4	0.24	5.38		
2.2			7	0.42	8.53		
2.3			10	0.6	11.68		
3.1	30	130	7	0.42	8.53		
3.2			4	0.24	5.38		
4.1	35	150	4	0.24	5.38		
4.2			7	0.42	8.53		

3. Results

In Figure 3, photos of one of the samples (1.1) are shown after cutting and before and after the removal of the resulting drooping. The drooping is easily removable owing to the use of an oxidizing plasma gas, namely air.

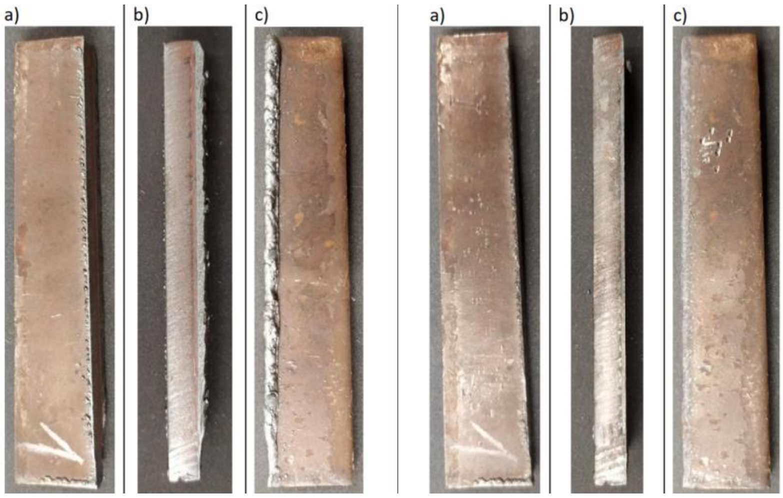

Fig. 3. Sample 1.1 after plasma cutting before and after removal of the droop: a) top view, b) cutting surface, c) bottom view

The roughness measurement was carried out using the Hommel Tester T1000E profilometer. The device was equipped with the Hommel Tester LV 15 measuring head. The measuring head was applied to the cutting surface in such a way that the measuring stylus moved in the direction of cutting. Measurements were taken at two locations: at 1/3 and 2/3 of the sheet thickness, as shown in Figure 4.

Fig. 4. Schematic of roughness measurement

The results are presented in Table 5. Results of measurements where errors occurred are highlighted in red. These errors were caused by excessive surface irregularities, leading to incorrect readings by the measuring device. Consequently, these results were not taken into account.

Table 5. Roughness measurement results

Parameter		Measurement location	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2
Ra	[μm]	1/3	4.49	6.09	5.08	11.67	8.16	7.54	8.23	7.66	7.65	8.53
		2/3	5.08	6.77	5.28	8.55	10.44	8.1	13.4	7.98	11.17	10.13
Rt		1/3	25.14	50.38	32.48	67.68	52.96	56.16	61.52	63.5	56.86	64.22
		2/3	29.06	59.06	45.24	61.38	52.88	48.08	81.88	63.1	81.88	63.7
Rm		1/3	24.58	38.76	29.16	63.46	52.2	52.6	54.32	55.1	55.8	52.2
		2/3	29.06	41.66	41.42	55.84	48.92	44.68	80.12	54.08	67.36	63.7
Rz		1/3	23.91	41.32	28.69	64.52	49.59	50.2	55.5	59.39	53.64	57.7
		2/3	28.21	33.36	38.56	54.92	49.37	43.98	76.48	54.49	74.2	56.7

For a more illustrative representation of the data, graphs were made for the more interesting roughness parameters, for *Ra*, *Rt* and *Rz*, respectively. They can be seen in Figures 5–9.

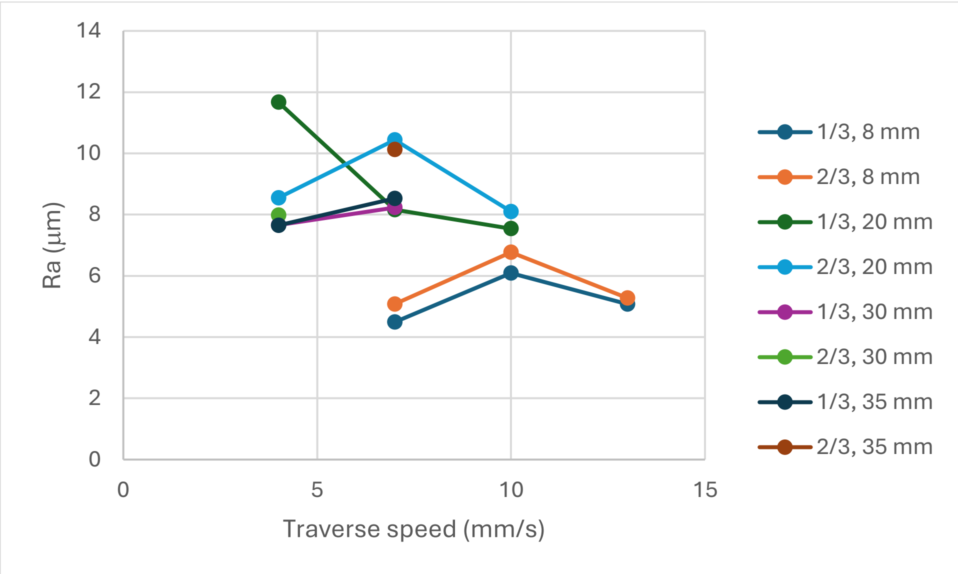

Fig. 5. The relationship between roughness *Ra* and cutting speed

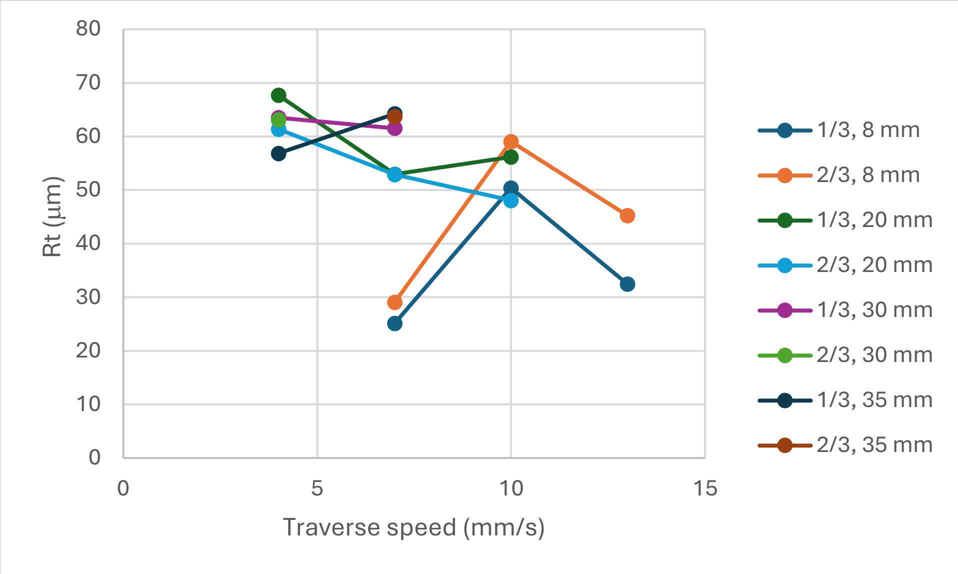

Fig. 6. The relationship between roughness *Rt* and cutting speed

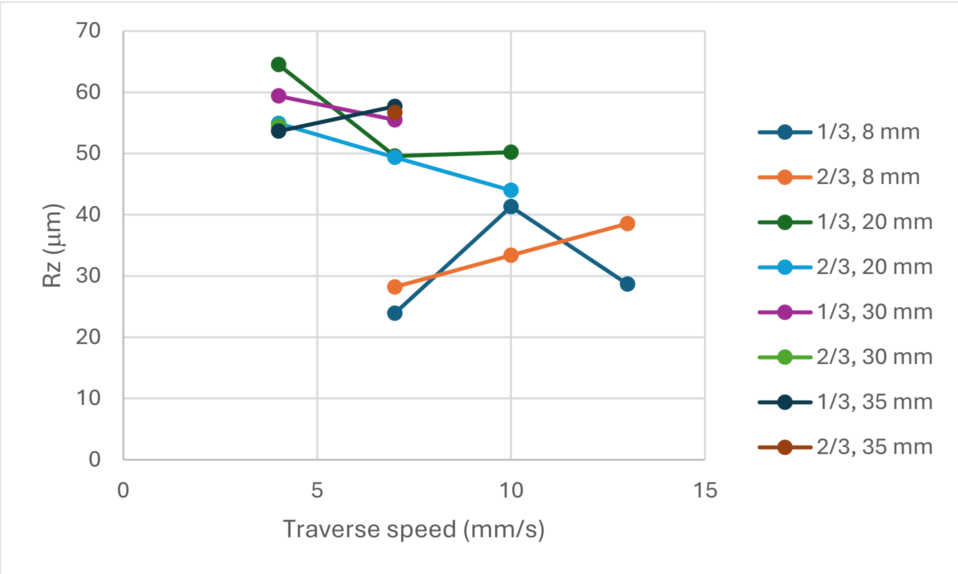

Fig. 7. The relationship between roughness *Rz* and cutting speed

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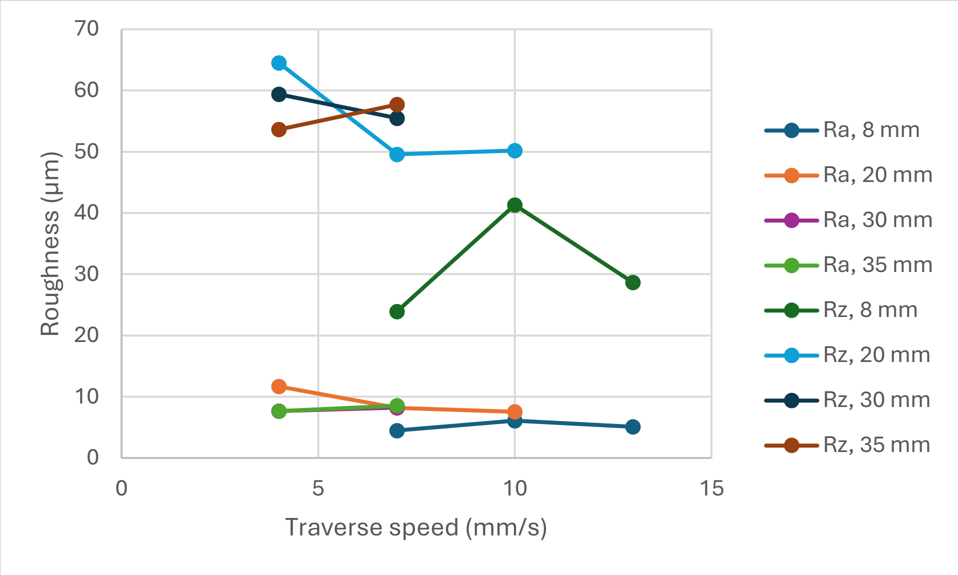

Fig. 8. The relationship between roughness *Ra* and *Rz* and traverse speed for 1/3 of the depth

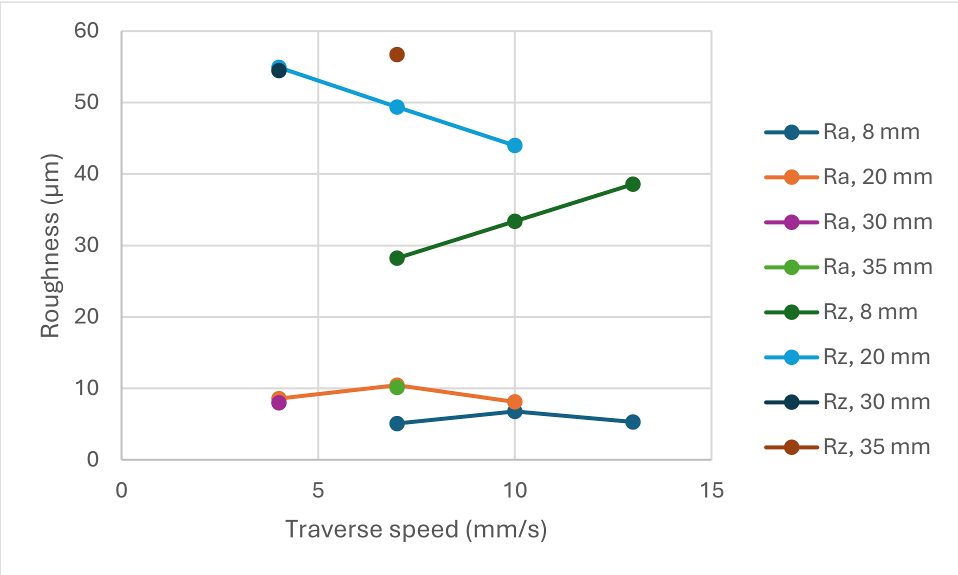

Fig. 9. The relationship between roughness *Ra* and *Rz* and traverse speed for 2/3 of the depth

From the charts, it is possible to determine at what speed, for a given thickness of sheet, the best quality of the cut surface can be achieved, as in the study, the same current intensity was set for each sample of the same thickness. The surface roughness of the cut surface is strongly dependent mainly on the cutting speed and the set current intensity.

Parameters that better illustrate the effect of parameters on surface quality in plasma cutting are the height parameters *Rz* and *Rt*, as they are much more illustrative of the change in surface roughness than the arithmetic mean parameter *Ra*, which is better suited to the study of machined surfaces owing to its widespread use in the industry. Using mean parameters such as *Ra* when measuring roughness after thermal cutting can suggest that the surface is better than even visual observation of the surface suggests—Figures 8–9.

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4. Conclusions

It can be noticed that speed has a significant impact on the quality of plasma cutting. Properly setting of the torch travel speed can improve the quality of the cut surface. At the same current intensity value, cutting speed becomes the most important technological parameter in the plasma cutting process. Therefore, during the process, close attention should be paid to the angle of molten metal ejection, as it is largely dependent on cutting speed-traces of machining after molten metal ejection are visible in Figure 3.

Analyzing the results for the sheets of different thicknesses, it can be concluded:

– For 8 mm, at a current equal to I = 60 A, the best surface quality is achieved at a speed of v = 7 mm/s.

– For 20 mm, at a current equal to I = 100 A, the best surface quality is achieved at a speed of v = 10 mm/s.

– For 30 mm, at a current equal to I = 130 A, the best surface quality is achieved at a speed of v = 4 mm/s.

– For 35 mm, at a current equal to I = 150 A, the best surface quality is achieved at a speed of v = 4 mm/s.

Depending on the intended use of the plasma-cut object, some cut materials with smaller thicknesses do not need to be further machined. However, objects made of thicker sheets require further machining processes, mainly because of high roughness, as well as the lack of perpendicularity of the surface.

Apart from the observations included above, it should also be noted that the additional value of the present research lies in the fact that there has been a scarcity of data in the subject literature for the material group here studied.

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