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Investigation of the effect of cutting speed on surface quality in abrasive water jet cutting of 316L stainless steel

Piotr Löschner[a], Krzysztof Jarosz[a], Piotr Niesłony[a,] *

[a]Opole University of Technology, Opole 45-758, Prószkowska str 78, Poland*

Abstract

This study presents the effect of cutting speed on surface roughness in abrasive water jet cutting of 10mm thick stainless steel samples. Photographs of cut surfaces were taken and roughness parameters were measured in different locations across depth of cut. Differences between obtained surface geometric structures and measured roughness parameter values were presented and discussed. The research has shown a considerable effect of cutting speed on surface roughness, surface quality and presence of machining marks. This effect was especially noticeable in lower parts of examined cut surfaces.

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*Keywords:*stainless steel; abrasive water jet; cutting; machining marks; surface roughness

1. Introduction

Presently, abrasive water jet cutting is amongst the most rapidly developing and intensely researched methods of material cutting. It belongs to the spectrum of non-conventional manufacturing methods and is widely used for cutting a wide array of construction materials, including metals, fiberglass, rubber, stone and plastics. Other advantages include small cutting forces and low cutting zone temperatures [1, 2]. Surface roughness is one of the main ways of evaluating quality of cut surfaces obtained with AWJ cutting. It is also one of the most often specified end user requirements [1]. Process parameters such as traverse speed, material grade and thickness, abrasive flow rate and abrasive size directly affect surface roughness [3, 4].Numerous experimental studies examining the effect of process parameters such as abrasive mass flow, material thickness, traverse speed, standoff distance and water pressure on surface quality have been conducted [2, 5, 6,7]. Experimental measurements of vibrations and acoustic emissions accompanying AWJ cutting were conducted and their results investigated in-depth by Hloch et al. [8, 9] to provide a practical method of monitoring the process and predicting surface roughness. Researches on technological quality of elements machined with the use of AWJ cutting depending on their shape were also made [10]. Vast studies on AWJ have been concentrated on the extensive investigations in which empirical and numerical models have been published [11–13] and several authors studies [14-16] have been concentrated on the relationship of material properties and surface quality in AWJ process. The aim of this study was to examine the effect of cutting speed on surface roughness across the cut surface in AWJ cutting of 316L austenitic stainless steel.

2. Methodology

2.1. Experimental procedure

Three cylindrical test samples of 10 mm thickness made of 316L austenitic chromium-nickel stainless steel were prepared for

* Corresponding author. Tel.: +48 77 449 8460; fax:+48 77 449 8460.
*E-mail address:*p.nieslony@po.opole.pl

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experimental tests. The workpiece material has an elevated corrosion resistance, particularly against acids and chlorides. Its tensile strength is 558MPa, yield strength is 290MPa and hardness is about 79HRB. Its typical uses include chemical equipment, jet engine parts, engine exhaust manifolds and machinery exposed to marine atmospheres [17]. Chemical composition of 316L stainless steel according to manufacturer's specifications is shown in Table 1.

Table 1. Chemical composition of 316L steel [18].

C, %	Mn, %	P , %	S, %	Si, %	Cr, %	Ni, %	Mo, %	N, %
≤0.03	≤2.00	≤0.045	≤0.03	≤0.075	16-÷18	10÷14	2÷3	≤0.10

Cutting operations were conducted on a KIMLA Water Jet 4020 AWJ cutting centre, using three different traverse speeds, corresponding with quality grades (mediocre, good, excellent) as specified by the cutting system's manufacturer. Values of remaining technological parameters were established as constant. Due to their small diameter, test samples were mounted in a specially designed holder shown in Fig.1. After the cutting process was finished, photographs depicting obtained cut surfaces were taken and surface roughness measurements were conducted.

2.2. Process technological parameters

For this study, the cutting speed was selected as a variable process parameter. Its diversification allowed for obtaining cut surfaces of three different quality grades, as presented in Table 2.

Table 2. Cutting speed values for test samples.

Cutting speed, mm/sec	3.21	2.46	2.02
Quality grade [18]	Mediocre	Good	Excellent

Values of constant process parameters are shown in Table 3.They were selected with regards to material type and thickness according to machining center manufacturer's recommendations.

Table 3.Technological parameters.

Technological parameter	Value
Sample thickness, mm	10
Water pressure, MPa	413.6
Abrasive type	mineral garnet
Abrasive mass flow, kg/min	0.68
Abrasive grain size	80 mesh
Nozzle diameter, mm	0.7620
Nozzle standoff, mm	1.5

Fig.1.Abrasive water jet cutting process with experimental sample mounted in the holder.

2.3. Scope of research

Photographs depicting surface geometrical structure of obtained cut surfaces were taken using LEICA MS5 stereoscopic microscope with the use of 9.5x zoom.

2D Surface roughness parameters were measured with the Hommel Tester T-1000 surface finish measuring system connected to a PC computer equipped with Turbo-Datawin NT software. Following roughness parameters were measured and compared: *Ra, Rz, Rt, Rq.* These parameters were selected in response to suggestions from the industry and due to their common use for evaluation of surface quality in both research and industrial applications.

Fig.2.Measurement procedure.

Measurements were taken in three places across the cut surface, as shown in Fig. 2:

- 1mm under the upper cut edge (IN);
- in the center of cut surface (MIDDLE);
- 1mm over the lower cut edge (OUT).

It follows that the distances from upper cut edge for IN, MIDDLE and OUT are 1 mm, 5 mm and 9 mm respectively. Measuring range of the profilometer was set to 80µm. Assessment length was 4.80mm with 0.80 mm cut off length. Every measurement was repeated four times and averaged. Standard deviation for averaged results was calculated.

3. Results and discussion

3.1. Visual evaluation of cut surface geometric structure

Photographs presented in Fig. 3 depict cut surfaces obtained with three different traverse speeds.

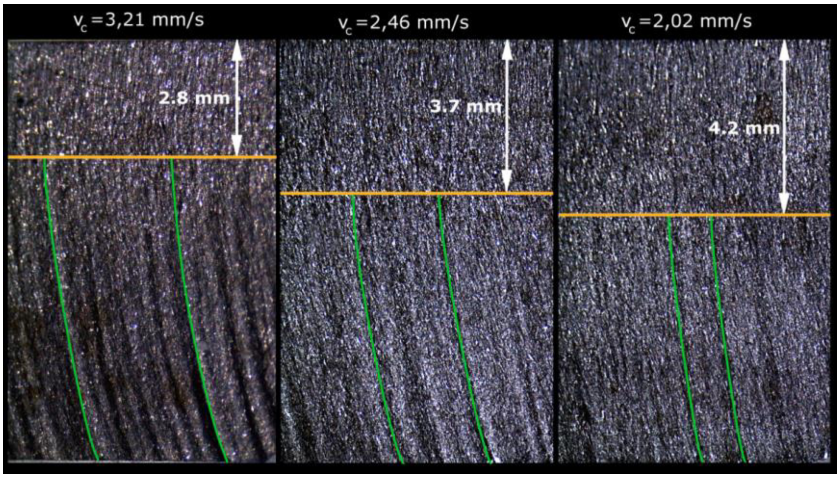

Fig.3.Photographs of obtained cut surfaces.

Obtained photographs were analyzed and edited with the use of image manipulation software. Cut surfaces were divided in two zones- upper zone with no visible presence of machining marks, and lower zone with visible machining marks. Lines outlining machining marks and showing their approximate curve angle was also added. For the surface cut with the highest speed, numerous grooves and elevations in the lower zone are clearly visible. With the decrease in cutting speed an improvement of surface quality in its lower part can be observed. For the lowest used cutting speed, machining marks are fewer and faintly visible- the last presented cut surface is of the best quality of all three research samples. It can be observed that width of the zone with visible machining marks and their curve angle increases with the growth in cutting speed. The presence of machining marks in the lower part of cut surfaces is linked to the decrease in kinetic energy of abrasive particles in abrasive water jet [19]. Therefore it can be inferred that with the increase in cutting speed, the kinetic energy of abrasive water jet drops.

3.2. Surface roughness

Averaged results of measurements for each test sample are presented in Tables 4 ÷ 6.

Table 4.Results of roughness parameters for traverse speed v_c= 3.21 mm/s (mediocre quality grade).

Parameter, µm	IN		MIDDLE		OUT	
	value	standard deviation	value	standard deviation	value	standard deviation
Ra	3.21	0.39	5.15	0.22	7.34	0.85
Rz	20.3	2.46	27.91	2.01	36.42	3.72
Rt	26.93	5.02	37.44	3.08	52.10	4.36
Rq	4.11	0.50	6.44	0.25	9.33	0.86

Table 5. Results of roughness parameters for traverse speed v_c = 2.46 mm/s (good quality grade).

Parameter, µm	IN		MIDDLE		OUT	
	value	standard deviation	value	standard deviation	value	standard deviation
Ra	2.91	0.27	3.90	0.29	6.32	0.72
Rz	18.46	1.53	22.22	1.58	30.56	3.71
Rt	23.97	3.70	28.51	2.76	40.75	4.12
Rq	3.73	0.33	4.90	0.33	7.82	0.79

Table 6. Results of roughness parameters for traverse speed v_c= 2.02 mm/s (excellent quality grade).

Parameter, µm	IN		MIDDLE		OUT	
	value	standard deviation	value	standard deviation	value	standard deviation
Ra	2.69	0.20	3.41	0.17	5.16	0.63
Rz	17.53	1.25	20.1	1.44	27.44	3.04
Rt	24.13	3.79	26.16	2.55	36.7	1.88
Rq	3.47	0.32	4.36	0.28	6.46	0.72

Comparison of results with percentile differences between measured values of surface roughness parameters are presented in Figs. 4÷7.

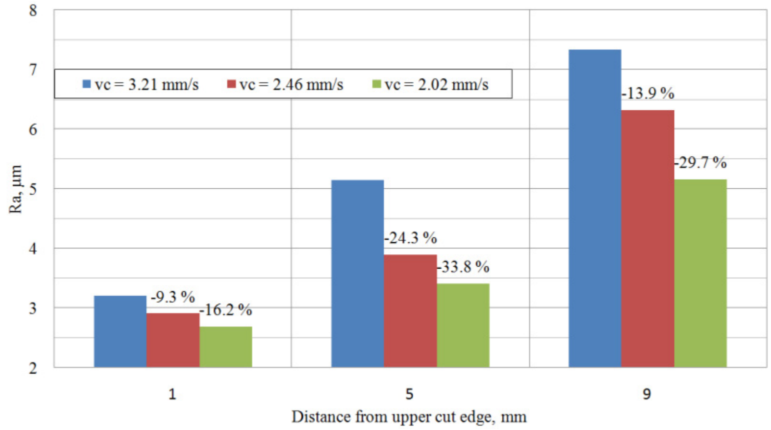

Fig.4.The effect of cutting speed on surface roughness parameter *Ra*.

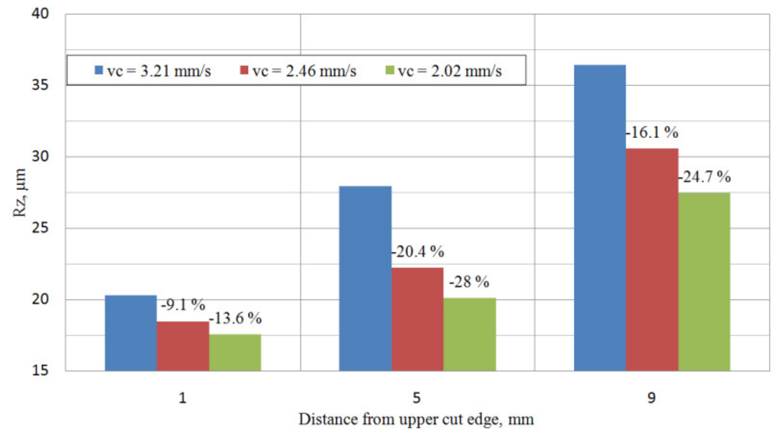

Fig.5.The effect of cutting speed on surface roughness parameter *Rz*.

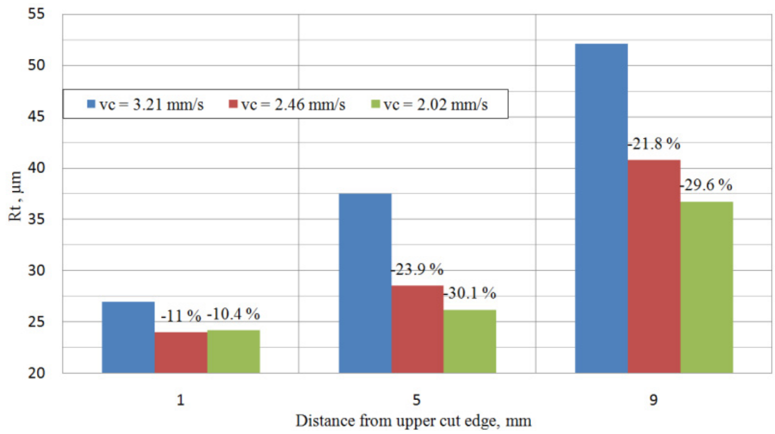

Fig.6.The effect of cutting speed on surface roughness parameter *Rt*.

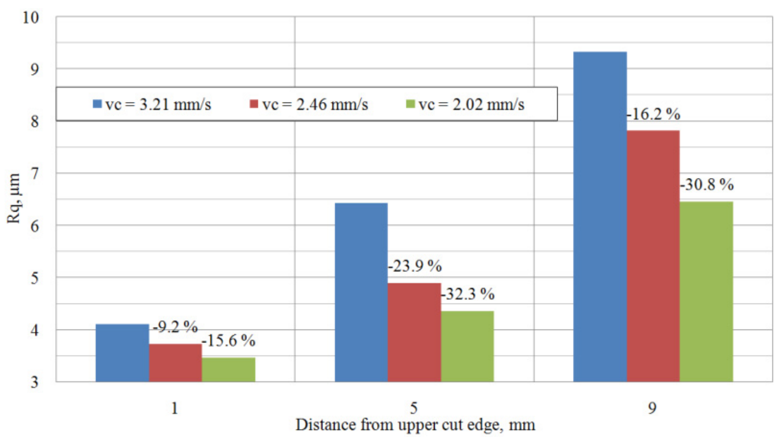

Fig.7.The effect of cutting speed on surface roughness parameter *Rq*.

Basing on the analysis of bar graphs presented in figures 4 ÷ 7 it can be stated that the cutting speed v_c has a significant influence on surface roughness of cut surfaces. Also, the distance from the upper cut surface edge directly affects surface quality and measurement results.

In the area where abrasive water jet enters the cut material, decrease in cutting speed by around 23% (from v_c=3.21 mm/s to 2.46 mm/s) results in drop of roughness parameter values by approximately 10%. Further decreasing the cutting speed from v_c = 3.21 mm/s to 2.02 mm/s (decrease by approximately 37% against the base value) results in roughness parameters dropping by 10÷15%.

A downward trend can also be seen when analyzing the results of measurements taken in the center of cut surfaces. However, this time the drop is more significant- respectively by 24% for the medium cutting speed and 30% for the lowest used cutting speed.

In the lower part of studied cut surfaces the sharpest growth in values of measured parameters can be seen for the highest used cutting speed. For the lower cutting speeds, the increase in roughness is not as intense when related to values observed for the upper and middle parts of cut surfaces. This can be caused by the drop in kinetic energy of abrasive water jet being less intense for lower cutting speeds. In this part of the surface, biggest increases in surface quality can be achieved by using the lowest researched cutting speed(v_c = 2.02 mm/s).

In this study two groups of amplitude parameters were analyzed: *Rt,* (maximum profile height) *Rz* (ten-point height) and *Ra* (arithmetical average profile height), *Rq* (standard deviation of distribution in profile heights) [20]. It was observed that sensitivity of measured parameters is directly related to both cutting speed and distance from upper cut edge. With the increase in cutting speed v_c, a degradation of surface quality defined by analyzed parameters for MIDDLE and IN planes was observed (Fig. 8). For the MIDDLE plane the percentile increases in evaluated roughness parameters for cutting speeds v_c=2.02mm/s, v_c=2.46mm/s and v_c=3.21mm/s were respectively 8-27%, 19-34% and 56-60%. Percentile increases for the OUT plane took the values 52-92%, 65-117% and 80-128% of respectively. It is evident that the change of cutting speed significantly affects the values of measured parameters. Moreover, those changes are also affected by the distance from the upper cut edge. It was also observed that the sensitivity to changes in cutting speed and distance from upper cut edge differs between parameters *Rz* and *Rt* are less sensitive to those changes than *Ra, Rq* parameters. For example, for MIDDLE plane maximum changes in values of *Rz* and *Rt* depending on v_c vary by 8÷39%. In relation to this, values of *Ra* and *Rq* (which constitute averaged measurement results) vary by 25÷60%.

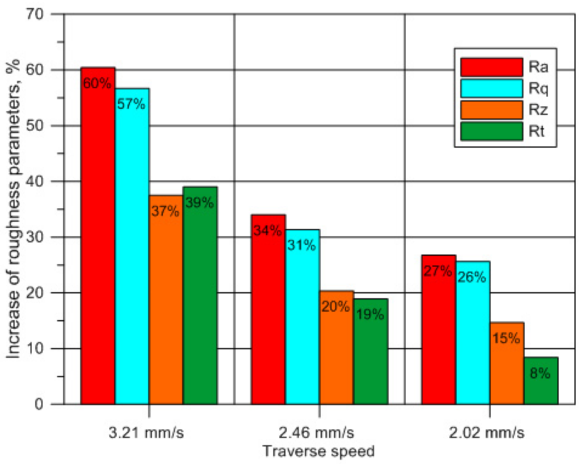

Fig.8 Percentile increase in roughness parameters between IN and MIDDLE measurement places.

4. Conclusions

Basing on conducted research work, following conclusions were drawn:

- With the decrease in cutting speed, cut surface quality visibly improves, which is most clearly noticeable for the lower part of examined cut surfaces. For example a difference in the measured value of Ra parameter is about 30% between the highest and lowest researched cutting speeds, in favor of the latter.
- Cut surfaces are characterized by the occurrence of two zones. In the first zone, there are no visible machining marks. In the second one, machining marks can be easily observed. The width of the second zones and visibility of machining marks is closely related to cutting speed. The width of the first zone increases by approximately 50% between the highest and lowest of used cutting speeds.

- Depending on the requirements towards surface quality, each of researched cutting speeds is applicable. However, if the cut surfaces are to undergo any further machining, it is not advisable to use the lower cutting speeds. Using the lowest cutting speed yields especially good results if there is a desire to obtain a finished product with the use of abrasive water jet cutting method.
- Results of this research can have a practical use in determining surface roughness parameters best suited to adequately evaluate cut surfaces of elements machined with the use of abrasive water jet made from stainless steels.

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