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The research of the influence of traverse speed and depth of cut on surface roughness in abrasive water jet machining

Jelena Baralić[1*], Anđelija Mitrović[1], Marko Popović[1]

[1] University of Kragujevac, Faculty of Technical Sciences, Čačak, Serbia

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* **Correspondence:** Jelena.baralic@ftn.kg.ac.rs

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ABSTRACT

The main goal in today's production is to make as many products as possible in the shortest possible time. When machining with an abrasive water jet, this means that it is necessary to cut with the highest possible traverse speeds. Machining with a high traverse speed results in an increase in the surface roughness parameters of the surface machined with an abrasive water jet. With the increase in the thickness of the machined material, i.e. the depth of the cut, this is more and more pronounced. The aim of this work is to determine the influence of traverse speed on the roughness of the machined surface, R_a. Also, the influence of the thickness of the samples on the roughness of the processed surface, R_a, was investigated. The material of the samples was AlMg3 of different thicknesses (6, 8, 10 and 12 mm). The samples were cut with traverse speed of 200, 400, 600, 800, 1000 and 1200 mm/min. The roughness parameter of the machined surface, R_a, was measured at different depths, h and at several places along the samples. Based on the measured values of R_a, it was concluded that with the increase in traverse speed, the roughness of the machined surface increases. It was observed that the roughness parameter R_a at the same depth of measurement, h, has approximately the same values. The mathematical model, that describes the influence of traverse speed on the roughness of the machined surface was developed. This model showed satisfactory agreement with the measured values.

KEYWORDS

Abrasive water jet, Surface roughness, Traverse speed, Depth of cut

1. INTRODUCTION

Abrasive water jet machining is common in production today because it offers numerous advantages such as no heat affected zone, almost all kinds of materials can be machined, and high clamping forces are not needed [1]. In addition to the advantages it provides, there are also disadvantages such as uneven roughness of the machined surface by the depth of the cut, appearance of striations, kerf taper, etc. Also, it is very difficult to manage some process parameters such as hydraulic, abrasive, mixing and cutting parameters and keep them constant, i.e. manage them. The influence of dynamic parameters such as operating pressure, abrasive mass flow rate, traverse speed and standoff distance remarkably affect the quality of the abrasive water jet machining process. Most often, the quality of the machining process is evaluated by monitoring the maximum depth of the cut, kerf geometry and roughness of the machined surface. Figure 1 shows the abrasive water jet machining process parameters that affect the machining quality.

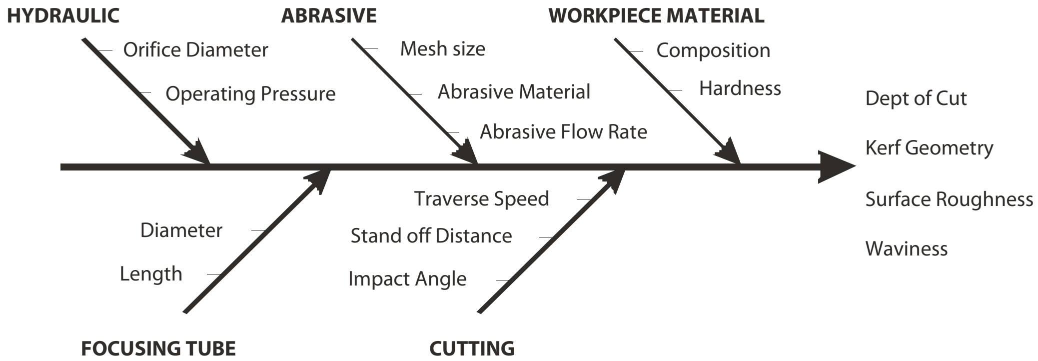


Figure 1: Parameters of the abrasive water jet process that affect the quality of machining

2. ABRASIVE WATER JET MACHINING

Modern abrasive water jet machines work with water pressure over 600 MPa (6000 bar), with the water jet reaching speeds of up to 1000 m/s. They consist of a drive part, an executive part and auxiliary components. The driving part is the unit in which water under high pressure is created, while the executive part is the cutting head. Auxiliary components include a water preparation system, a high-pressure installation, an abrasive magazine with an abrasive supply system, and a coordinate work table with an absorber of unused abrasive water jet energy.

The water that comes into the cutting head is usually under a pressure of up to 600 MPa and passes through a jewel water nozzle. The diameter of the water nozzle ranges from 0.08 ÷ 0.4 mm. Due to such a small diameter of the nozzle, the water jet reaches very high speeds, even up to 1000 m/s. This jet further reaches the mixing chamber. In this chamber, abrasive particles are added to the water jet and their mixing is carried out. The water jet accelerates the abrasive particles and together with them passes through a long cylindrical tube for focusing the jet. The mixture of water and abrasive particles as an abrasive water jet comes out of the focusing tube as a coherent jet and performs machining. It is very important that the water nozzle and focusing tube are well centered, because the appearance of the abrasive water jet depends on it, and therefore the quality of machining.

2.1. Machined Surface Quality

When machining with an abrasive water jet, the qualities of the machined surfaces are classified into five characteristic groups, Figure 2. The quality of the machined surface Q1, occurs when the workpiece material is cut with high traverse speeds. It is characteristic for rough cutting and additional force is required to separate the cut parts, because they are not completely separated. The machined surface must be further machined.

Figure 2: Five characteristic qualities of the machined surface [2]

The quality of the machined surface Q2 is characteristic for cutting of the material with high traverse speed, but there is a complete separation of the parts. Most often further machining is required. The surface machined with an abrasive water jet in quality Q3 is more demanding than the previous two. In order to obtain this quality of the machined surface, it is necessary to choose properly the machining process parameters such as operating pressure, traverse speed and the abrasive mass flow rate. With such machining modes, some stationary parts can be made, that is, depending on the purpose, their further machining is not necessary. The quality of the machined surface Q4 is better than the quality of the machined surface Q3. In this quality, many parts can be produced without additional machining. Q5 quality of the machined surface is very high and demanding. It is achieved when cutting with very low traverse speeds. The main criterion for the selection of the machining mode, at this case is not the machining time, but the machined surface quality. The kerf taper is negligible over the entire height of the machined part.

Defining the quality of the machined surface is usually a compromise between the least amount of time spent and the best achieved machined quality.

2.2. Traverse speed influence on the machined surface roughness

The roughness of the machined surface, obtained either by conventional or non-conventional machining methods, are characteristic of the machined surface, and they are standardized. Those characteristics are standardized and described with over thirty parameters. The aim of this research is to define influence of traverse speed on the roughness of the machined surface. R_a was selected as the basic parameter for evaluating the roughness of the machined surface.

The quality of the surface machined with an abrasive water jet is affected by system process parameters such as operating pressure, abrasive mass flow rate, depth of cut, standoff distance, impact angle of abrasive water jet and traverse speed [3]. The level of influence of each parameter of machining process on roughness of machined surface is different. Most authors agree that traverse speed, operating pressure and abrasive mass flow rate are the most influential. Traverse speed has a important influence on the machined surface quality and material removal rate [4]. It is the machining process parameter that is easiest to change when cutting the material Therefore, identifying the relationship between the quality of the machined surface and the traverse speed has great significance.

Figure 3 shows a change in machined surface roughness, depending on the traverse speed. Parameter of the machined surface roughness, R_a, increases remarkably with increase in traverse speed values. This diagram refers to tests performed on aluminum [5]. From the diagram, we can see that at low traverse speed values, there is no significant discrepancy in the values of the machined surface roughness parameter R_a with the upgrowth of the thickness of machined material, but, when machining with higher traverse speed values this discrepancy becomes obvious.

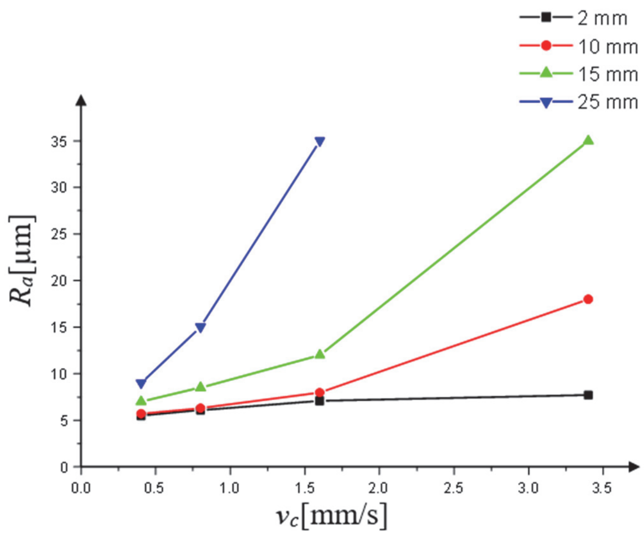


Figure 3: Traverse speed influence on the the machined surface roughness[5]

3. EXPERIMENTAL RESEARCH

In this work, traverse speed and depth of cut influence on R_a, roughness parameter of machined surface was analyzed. Experimental tests were realized in real, industrial conditions on the PTV-3.8/60 machine. Technical characteristics of the hydraulic part of the abrasive water jet cutting machine are shown in table 1.

Table 1: Technical characteristics of the machine PTV-3.8/60

Characteristic	Value
Maximum operating pressure	413 MPa
Water pressure at the entrance to the system	3.5 ÷ 6 bar
Maximum water consumption	3.8 l/min
Maximum power	39.2 kW
Maximum oil pressure	215 bar
Dimensions	1900 x 1250 x 1575 mm

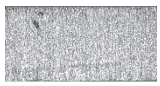
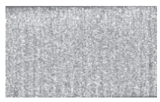
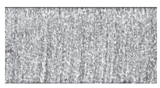
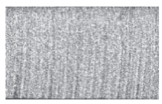
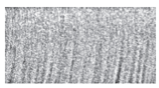
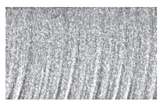
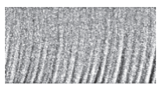
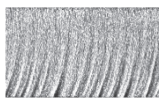
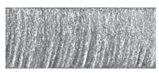
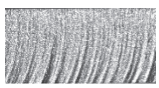
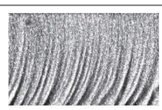
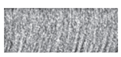
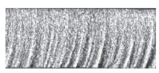
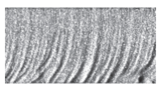
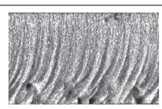
Figure 4 shows the machine, i.e. its executive part - the cutting head during sample cutting.

Figure 4: Cutting head of the PTV-3.8/60 machine during sample cutting

The roughness of the machined surface was measured 1mm from the upper surface of the sample - measuring point 1, i.e. the entrance of the abrasive water jet into the material, and then in the middle of each sample - measuring point 2 and 1 mm from the lower surface - measuring point 3, , i.e. the exit of the abrasive water jet from the material. For samples 12 mm thick, the roughness was also measured every 2 mm, starting from the upper surface of the sample. Also, for all samples, the roughness was measured at five places along the machined surface of the sample, and the mean value of the roughness was determined.

The material on which the tests were performed was AlMg3, of different thicknesses. Table 2 shows the appearance of machined surfaces created by machining AlMg3 of different thicknesses with different traverse speeds. The values of the other abrasive water jet cutting process parameters were constant during the cutting of the samples: p = 413 MPa, m_a = 350 g/min, x_0 = 3 mm, d_w = 0.3 mm, d_f = 1.02 mm.

Table 2: The appearance of machined surfaces

Traverse speed v_c [mm/min]	**Sample thicknesses** *s* [mm]			
	6	8	10	12
200				
400				
600				
800				
1000				
1200				

As can be seen from the pictures, when machining with a traverse speed of 200 mm/min, there is no significant difference in the quality of the machined surface. There is no appearance of waviness and striations. When machining with higher traverse speeds, the difference in the quality of the machined surfaces, is increasingly noticeable depending on the depth of cut, i.e. the thickness of the samples, striation and waviness are increasingly pronounced. Striation and increased roughness are also significantly pronounced in samples with a thickness of 6 mm, when they are machined with a traverse speed of 1000 mm/min and more.

The values of measured surface roughness-R_a are shown in Table 3.

Table 3: Measured values of surface roughness

Roughness of machined surface R_a [μm]				
Measuring point 1				
Sample thicknessess s [mm] / v_c [mm/min]	6	8	10	12
200	4.728	6.547	6.324	6.397
400	5.102	6.884	6.042	5.843
600	6.576	7.692	6.626	7.209
800	6.679	8.449	6.925	8.957
1000	7.196	8.786	8.734	8.84
1200	8.557	10.57	11.37	10.627
Measuring point 2				
Sample thicknesses s [mm] / v_c [mm/min]	6	8	10	12
200	5.726	7.042	8.733	8.843
400	6.629	7.238	8.9	9.277
600	7.229	8.948	9.697	9.628
800	7.461	9.95		10.84
1000	7.983	9.471		
1200	8.683			
Measuring point 3				
Sample thicknesses s [mm] / v_c [mm/min]	6	8	10	12
200	6.57	7.238	7.56	8.657
400	6.435	8.736	7.577	9.746
600	8.668	9.835	9.904	
800	9.038	9.987		
1000	9.147			
1200	10.1			

Figures 5, 6 and 7 show diagrams of the influence of sample thickness and traverse speed on the roughness of the machined surface at different measurement points.

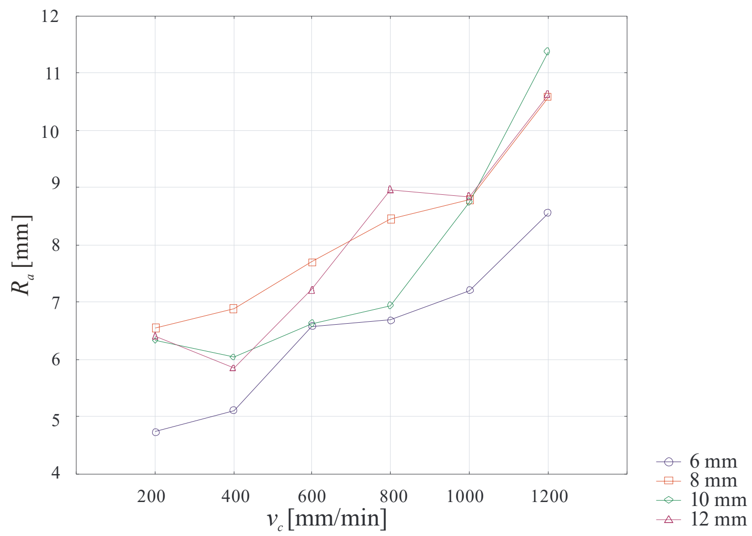


Figure 5: Influence of sample thickness and traverse speed on the roughness of the machined surface at measuring point 1

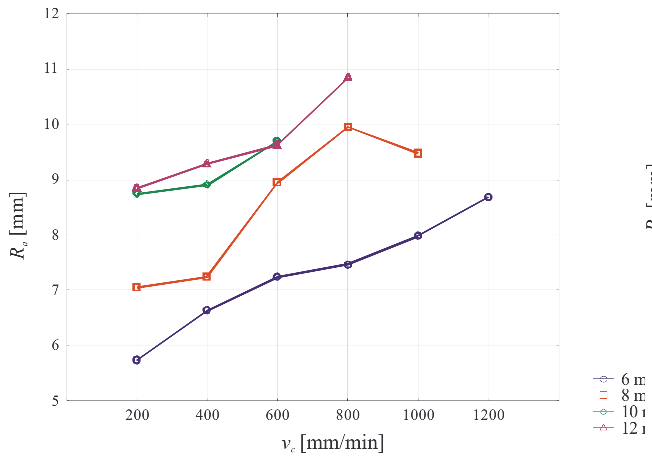


Figure 6: Influence of sample thickness and traverse speed on the roughness of the machined surface at measuring point 2

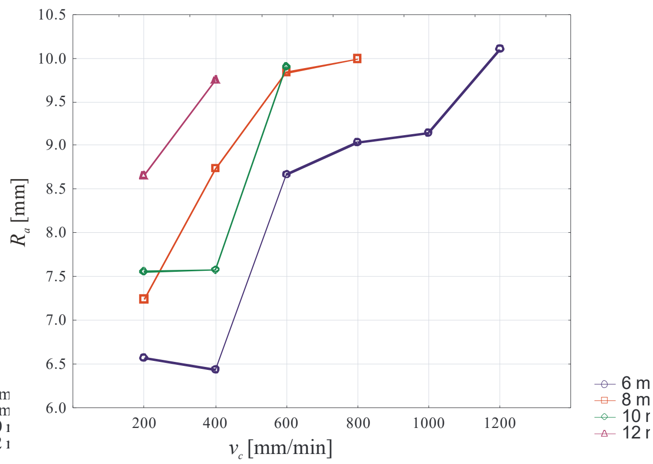


Figure 7: Influence of sample thickness and traverse speed on the roughness of the machined surface at measuring point 3

It can be seen from the pictures that when machining with a traverse speed of 200 mm/min, R_a at measuring point 1 is approximately the same for all samples. The difference between the lowest and highest values is about 2µm. The biggest difference occurs when machining with a traverse speed of 1200 mm/min, and is approximately 3µm. With the increase of traverse speed, there is a significant increase in the value of R_a at the same measuring points. Also, with an increase in the thickness of the samples, the values of R_a at measuring points 2 and 3 increase significantly. It was not possible to measure the values of the parameter R_a on some samples. On a 12mm thick sample, the roughness was measured every 2 mm. The results of these measurements are given in Table 4.

Table 4: Roughness of the machined surface for a sample with a thickness of 12 mm

Machined surface roughness R_a[µm]					
h [mm] / v_c [mm/min]	2	4	6	8	10
200	5.988	6.953	7.129	7.465	8.423
400	5.943	7.224	8.756	9.024	9.456
600	6.897	8.021	9.358	9.679	9.958
800	6.768	9.451	9.976	10.045	
1000	7.026	9.987			
1200	8.643				

Based on all the measured values, a diagram of the dependence of the machined surface roughness of the traverse speed and the depth of the cut is given, Figure 8.

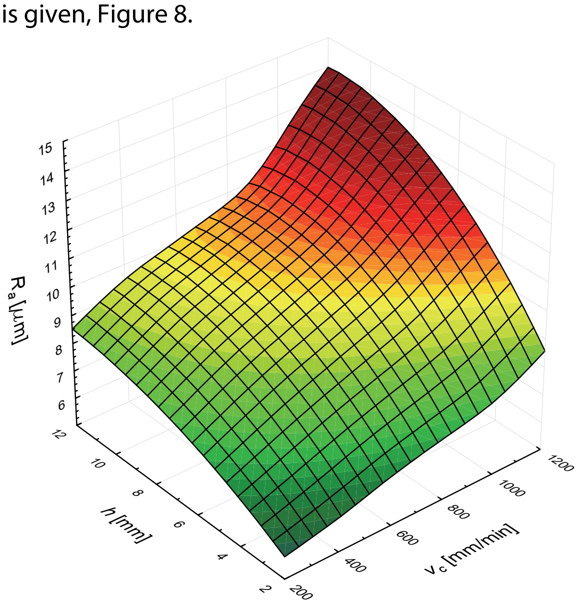


Figure 8: Diagram of changes in machined surface roughness depending on the traverse speed and depth of cut

Based on Figure 8, it can be concluded that the roughness of the machined surface-R_a increases with the increase in the value of traverse speed-v_c and depth of cut-h.

The mathematical model that describes the influence of the traverse speed and the depth of the cut on the machined surface roughness-R_a is represented by Eq. 1:

$$R_a = 1.626 \cdot v_c^{0.2} \cdot h^{0.23} \tag{1}$$

The model described with Eq. 1, has a good match with the measured values, as shown by the fact that the correlation coefficient is R = 0.95. Figure 9 shows the relationship between the measured values of machined surface roughness and those obtained based on the model given by Eq. 1.

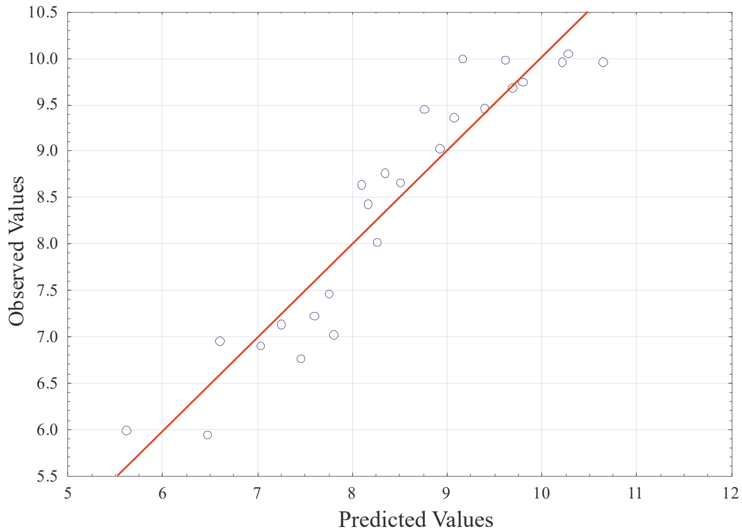


Figure 9: The relationship between the measured values of machined surface roughness and those obtained based on the model

Figure 10 shows a comparison of 6 mm, 8 mm, 10 mm and 12 mm thick samples obtained during machining with a traverse speed of 800 mm/min. The significant matching of striations at the same depth of cut, on all samples, regardless of their thickness can be observed.

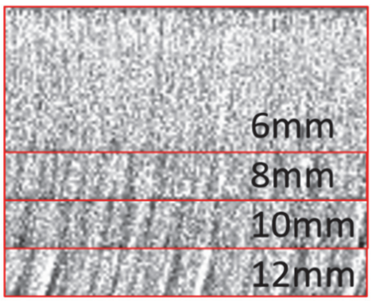


Figure 10: Comparison of machined surfaces of different thicknesses, cut with same traverse speed

Also, the increase of roughness at the exit of the abrasive jet from the workpiece is observed. Also, it increases with the growth of the cutting depth, i.e. the thickness of the sample.

4. CONCLUSION

The paper presents the results of an experimental investigation of the influence of the traverse speed and the depth of the cut on the roughness of the machined surface. Based on the results, obtained from experimental tests, it can be concluded that with an increase in the traverse speed, there is an increase in the roughness of the machined surface. Also, based on the results, it can be concluded that with an increase in the depth of the measurement, there is an increase in the roughness of the machined surface. Based on the measured values, a mathematical model was also given. The measured values of the machined surface roughness and those obtained on the basis of the mathematical model have a very good match.

By comparing samples of different thicknesses, obtained at the same traverse speeds, it can be observed that the shape of the striations, which are characteristic for machining with an abrasive water jet, are significantly matched on different samples machined with the same traverse speed. Based on this, it can be concluded that the thickness of the sample has no influence on the geometry of the striations-cut front geometry. Also, it was observed that roughness measured at approximately the same depths on the samples machined with same traverse speed, have approximately the same values regardless of the thickness of the machined sample.

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