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THE WAVINESS OF AN ABRASIVE WATER JET GENERATED SURFACE

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Abstract: *Abrasive water jet generated surface has appearance that is characteristic for all machining procedures with the beam of high-energy density. On the surface machined with these procedures, characteristic lines, which are traces resulting from the passage of beam through the workpiece, can be observed. When machining with abrasive water jet, on the generated surface occurs trace lines and waviness. The appearance of waviness is more pronounced in the lower part of the machined surface. The aim of this study is to investigate the effect of traverse speed on the waviness appearance on machined surface and the regularity at which the waviness occurs. During investigation, it was observed that in the same period of time, at all traverse speeds and the thickness of material that has been processed, there is almost the same number of waves.*

Keywords: *waviness, trverse speed, abrasive water jet*

1. INTRODUCTION

Abrasive water jet machining is one of the latest non-conventional methods, which have recently been increasingly used in industry for cutting of various materials, from those with pronounced plastic properties, to very-brittle materials. The main advantage of this machining process is that there is no occurrence of heat affected zone.

Abrasive water jet machining is based on the process of erosion as the primary mechanism for the removal of material from the workpiece. Bitter [1] has defined erosion of material as damage, which occurs as a result of single impact of abrasive particle (which is located in a fluid and is moving at high speed). Hutchings [2] has defined erosion as abrasive wear in which abrasive particles (which are also located in a fluid and moving rapidly) hitting the surface several times and thus leads to erosion of the material. The traces on the surface machined with abrasive water jet, resulting from erosion of the workpiece material, are visible under a microscope. Their direction is changing with depth of cutting, and follows the direction of the cutting beam through the workpiece. On the abrasive water jet generated surface can be observed the curved lines that are characteristic for this type of machining. Also, machined surface has a pronounced waviness in the lower part, and it increases with increasing depth of cut. These irregularities on machined surface, and the taper of cut, significantly constrain the opportunities of application of abrasive waterjet machining.

2. ABRASIVE WATER JET MACHINING

Modern installations for abrasive water jet machining work with water pressure over 400MPa, while the water jet reaches speeds of up to 1000m/s. They consist of a driver and the executive and supporting components. The driver is a unit that creates high-pressure water, while an executive componenet is a cutting head. The system components of abrasive water jet cutting machine are shown in Figure 1.

The way of working is the following: Hydraulic oil under pressure of 5÷35 MPa enters the hydraulic cylinder and intensifier. Because of large difference in the diameters of the intensifier, water pressure reaches the value of 400 MPa or more. Intensifying system is the key of equipment. Pressure value in intensifier depends on the ratio of cross sections area of the cylinders. This ratio usually ranges between 1:10 and 1:25 and is a constant. To change the value of water pressure, it is necessary to change the oil pressure in the hydraulic system.

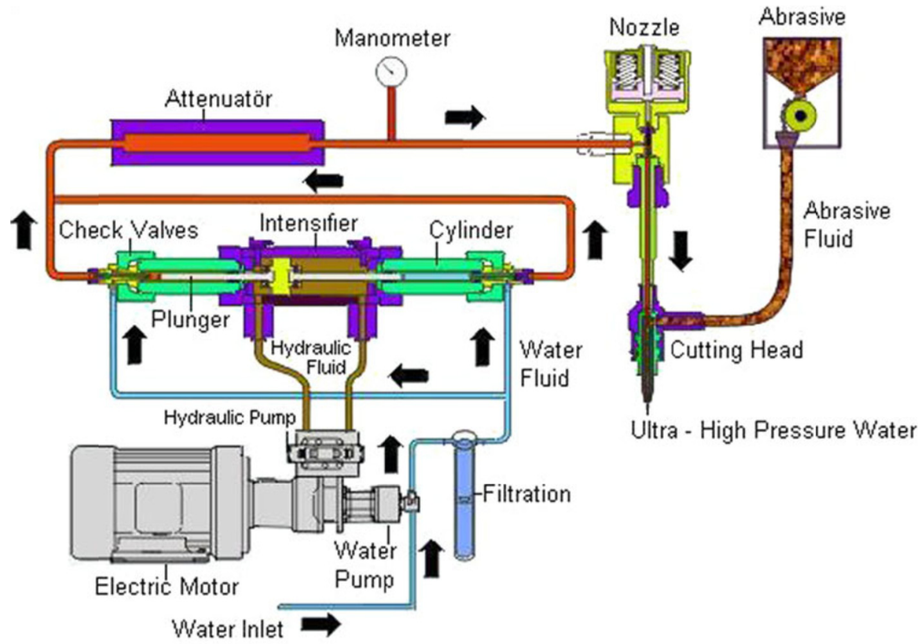


Figure 1. The system components of abrasive water jet cutting machine [3]

In order to get a jet of water, whose pressure is approximately constant, the most commonly duplex reciprocating pump- intensifier (DRP) is used. This is actually a complex cylinder which is double-acting pump, with two high pressure cylinders, joined with the back towards each other. When the first cylinder complete stroke, piston rod moves back and compresses the water in the second cylinder.

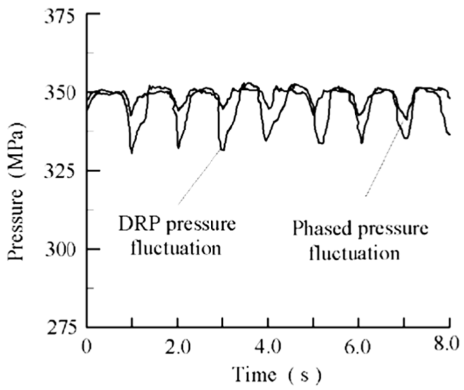


Figure 2. Fluctuations of pressure during machining with abrasive water jet [4]

These cycles are repeated successively. Because the water can be compressed 12% under the pressure of 400 MPa, the initial stage of the piston travel is used to compress the water [4]. Water is not delivered into the system until the water pressure reaches the set value. Therefore, the actions of draining water and absorbing water are discontinuous, and the pressure is fluctuant. To neutralize the pressure fluctuations, it is necessary to install an accumulator behind the intensifier.

Figure 2 is a diagram which shows the pressure fluctuations in a conventional intensifier and the phase-shifted intensifier cylinders.

3. ABRASIVE WATER JET GENERATED SURFACE

Abrasive water jet generated surface has a characteristic appearance and is shown in Figure 3. Curved lines, showing the movement of abrasive water jet through the workpiece material, can be observed in the Figure 3. The topography of the machined surface and the appearance of curved lines are the most important macroscopic properties of the surface machined with abrasive water jet. Based on the analysis of these two characteristics can result in significant information about the machining process.

Roughness of the surface machined with abrasive water jet increases with increasing depth of cut [5]. Surfaces machined with abrasive water jet are divided into two areas, fine machining zone (the upper zone) and rough zone (the lower zone). Irregularities that occur in the upper zone of the machined surface are considered as microscopic irregularities and are in the domain of roughness. Irregularities that occur in the lower zone of the machined surface have macroscopic dimensions. These irregularities are in the domain of waviness in conventional machining.

Figure 3. Appearance of the surface machined with abrasive water jet

Waviness of the machined surface is also an important phenomenon in the machining with abrasive water jet, Figure 4. It was found that there is a primary and secondary waviness on the surface machined with abrasive water jet [6]. Primary waviness is a waviness with higher step values, while the secondary waviness has less step value. For all cutting parameters, if the primary wavelength of the profile at the rough cutting zone is smaller, the surface is smoother. Guo [7] found that there is a dependence of the waviness step and focusing tube diameter, while Kovacevic [8] found a correlation between waviness step and a diameter of abrasive particles and the focusing tube diameter.

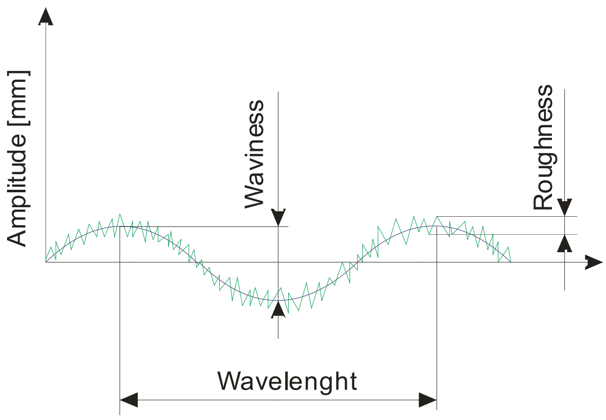


Figure 4. Waviness and surface roughness

The quality of the surface machined with abrasive water jet is influenced with system operational process parameters such as traverse speed, waterjet pressure, abrasive flow rate, standoff distance, depth of cut and angle of cutting [9].

Level of influence of certain parameters is different. The largest number of authors agrees that the most influential are traverse speed, operating pressure and the abrasive flow rate. Traverse speed of the jet has a strong influence on the surface finish of the workpiece and material removal rate [11]. Figure 5 shows the influence of traverse speed and abrasive mass flow on the waviness.

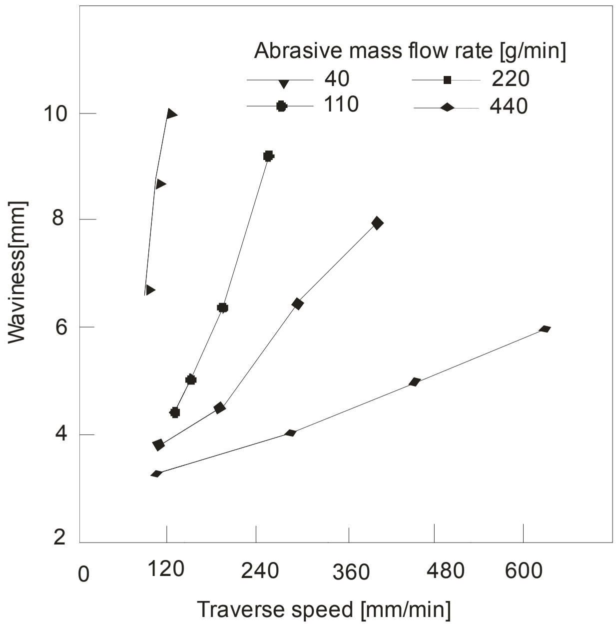


Figure 5. Parameter influence on the waviness [10]

4. EXPERIMENTAL INVESTIGATIONS

The aim of this study was to investigate influence of traverse speed on the appearance of profile waviness on machined surface. The experiments were conducted using a Byjet 4022 abrasive water jet cutting machine (Bystronic AG, Switzerland). Aluminium alloy AA-ASTM 6060 (EN: AW-6060; ISO: AlMgSi) was used as a workpiece material. Aluminum and its alloys are characterized by high reflectivity and thermal conductivity. This makes them relatively difficult to cut with lasers. Therefore, the machining with abrasive water jet is much more acceptable for aluminium alloy.

Abrasive water jet cutting involves a large number of variables that affect the cutting results (kerf width, taper and surface roughness, waviness). In the present study, the influence of the following parameters was investigated: traverse speed (the speed at which the cutting head moves along workpiece during cutting operation) and material thickness. The other process parameters were kept constant using the standard machine configuration (d_0=0.3mm; d_A=1.02mm; p=380MPa; Q=350g/min).

The samples of aluminum alloy 6 and 10mm thick were cut with different traverse speeds V=(200, 300, 400, 500, 800 i 1000 mm/min). On such machined samples, length at which the ten waves were observed, was measured, Figure 6.

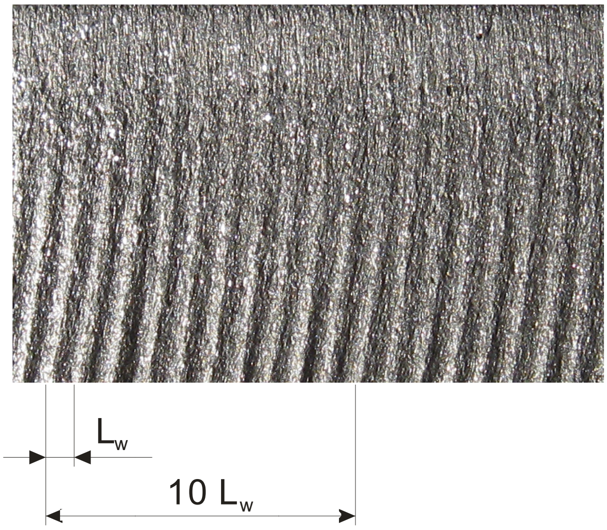


Figure 6. Measuring the length of ten waves

For this measured values ($10L_w$), based on Formula 1, the time needed to make ten waves (t_{10}) was calculated.

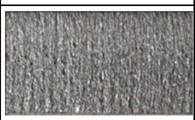
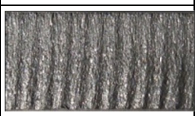
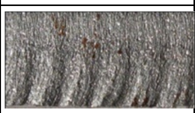
$$t_{10} = \frac{10L_w}{V} \cdot 60 \text{ [s]} \quad (1)$$

Based on these values, according to Formula 2, the number of waves that were made in one minute (N) was calculated.

$$t_{10} = \frac{10}{t_{10}} \cdot 60 \quad (2)$$

Table 1 shows the images of 6mm thick samples, obtained with different traverse speeds, and values for $10L_w$, t_{10} and N.

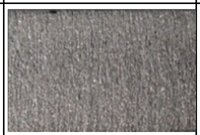
Table 1. 6mm thick samples

V [mm/min]	Images of samples	$10L_w$ [mm]	t_{10} [s]	N [1/min]
200		Waves are not clearly marked		
300		Waves are not clearly marked		
400		8.4	1.26	476.2
500		10.6	1.272	471.7
800		16.8	1.26	476.2
1000		21.1	1.266	473.9

5. CONCLUSION

By analyzing the results, it was observed that a change in traverse speed affects the wavelength and height on surface machined with abrasive water jet. As the traverse speed increases, the higher is the wavelength of profile waviness. Also, machining with higher traverse speed results in the increase of height of profile waviness. The most interesting is the fact that, regardless of the traverse speed and thickness of the workpiece, the number of waves in one minute is approximately the same. The frequency of the waves, and also the curved lines, is approximately constant and in this case ranges from 460 to 476 waves per minute. This fact can probably be explained with fluctuations in the value of the operating pressure of the abrasive water jet. In order to better explain the relationship between pressure oscillations and profile waviness frequency, more detailed examination are required.

Table 2. 10mm thick samples

V [mm/min]	Images of samples	$10L_w$ [mm]	t_{10} [s]	N [1/min]
200		Waves are not clearly marked		
300		Waves are not clearly marked		
400		8.4	1.26	476.2
500		10.6	1.272	471.7
800		16.8	1.26	476.2
1000		21.1	1.266	473.9

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