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THE INFLUENCE OF MIXING WATER AND ABRASIVES ON THE QUALITY OF MACHINED SURFACE

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This paper shows the impact of mixing water and abrasives in water jet cutting process on the quality of the machined surface. The tests were done with polymer material SIPAS, where the influence of cutting parameters was researched (cutting pressure, cutting feed and abrasive mass flow). The surface roughness was measured on several zones, regarding the depth of materials, because the roughness is increased with the material thickness.

Key words: mixing, abrasives, nozzle, water jet

INTRODUCTION

Abrasive water jet (AWJ) cutting process differs from the pure water jet cutting because abrasive particles erode the cutted material in the kerf zone. AWJ is much faster than pure water jet and hard materials such as steel, metal, glass, stone, etc. can be cut more efficiently.

The abrasives are added to the jet after the creation of pure water jet. The most commonly used abrasive in abrasive water jet is sand, which is of different grain size. Garnet is the most widely used abrasive.

Characteristics of AWJ process are:
- extremely versatile process
- no heat affected zone
- no mechanical stresses
- easy to program
- thin stream
- detailed geometry
- less material loss
- simply to fixture
- low cutting forces
- reduced secondary operations
- little or no burr

ABRASIVES

Therefore, different types of abrasives can be used; some of them cheapen the machines value. For example, if it is cut lot of aluminum it can be used softer abrasives, thus slowing down wear in nozzle hose of mixing tube.

The most commonly used abrasive in the water jet industry is red garnet. Garnet is pretty tough and when it breaks, it creates sharp edges; these characteristics are advantageous in water jet cutting. They are chemically inactive and will not react with the material that one needs to cut.

However, one must never use abrasives that contain silicon, such as beach sand because the dust created by silicon abrasives may cause silicosis, a very painful and deadly disease.

The abrasive characteristics that are required are: twice sifted, sharpness (sharper abrasives cut better), purity (impure abrasives influence cutting), and the price.

CUTTING HEAD

The cutting head in water jet cutting mainly consists of two parts, Venturous chamber and mixing tube. The compressed water goes from tube into the opening (orifice). This specially designed and made, opening is used to turn water into a highly compressed accelerated water stream. Therefore, depending on different applications of diameters it can be from 0,2 mm to 0,35 mm.

Three most commonly used types of materials for making opening are sapphire, ruby and diamond.

Abrasive particles are fed into the cutting head where they come into contact with the water spray inside the Venturi chamber (Figure 1). Like a bullet in the rifle, abrasive particles are accelerated down the mixing tube and they go to the cutting point.

MIXING OF WATER AND ABRASIVE

In the water jet cutting, water jet accelerates abrasive particles that erode the materials [2]. Abrasive water-jet is formed in the mixing chamber . Water, at high pressure, is injected through the jet head. The diameter of the mixing chamber is usually from 0,2 to 0,4 mm.

The water jet, at high speeds, creates a vacuum that pulls abrasive particles into the mixing chamber along with air. Jet accelerates abrasive particles and air in the

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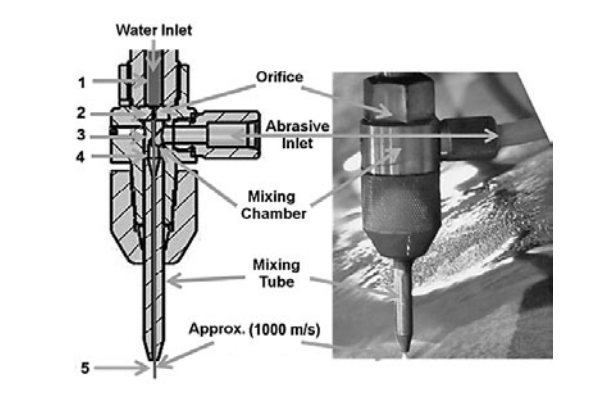

Figure 1 Cuting head with all parts.
1 - Pressurized Water, 2 - The water is forced through an oriĀce, 3 - The high velocity of the jet creates a Venturi effect, 4 - The abrasive is fully mixed in nozzle, 5 - The abrasive waterjet stream [1]

mixing tube. The cutting width depends on the diameter of the mixing tube and the distance from the work piece. If the mixing tube of 1 mm in diameter and the distance from the work piece is 3 to 5 mm, the cutting width is about 1,2 mm [3].

The water jet that is coming out of the mixing tube consists of three elements: the abrasive particles, air and water. The ability of material removal for each jet formed in a given nozzle depends on the pressure pump, type and abrasive mass flow. Generally, with the higher pump pressure the material removal ability increases.

When the flow of abrasive jet is of relatively small capacity the removing material increases with the abrasive mass flow. Because, when the abrasive mass flow rate is increased there are more abrasive particles involved in the cutting process. Also, if the cutting head has a lot of abrasive particles, kinetic energy of one particle is degraded due to limited kinetic energy of the water jet cutting. Therefore, there is an optimum mass flow of abrasive particles. If the mass flow is uneven it can cause pulsing jet, which is causing damage to the work piece.

The mixing process is a gradual mixing of abrasive particles and water jet.

During the mixing process, abrasive particles are gradually accelerated because of the gradual torque transfer from the aqueous phase to abrasive phase.

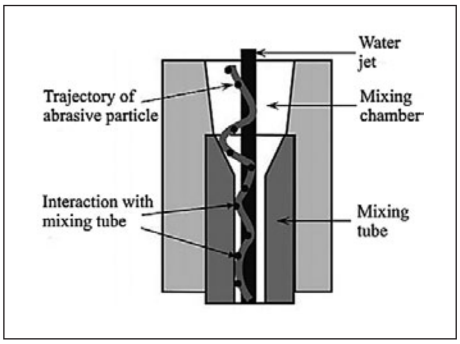

Figure 2 Schematic of mixing process [4]

Therefore, when exiting the mixing tube both phases have the same velocity (Figure 2).

Mixing tube is mainly made of tungsten carbide with an internal diameter of 0,8 mm to 1,6 mm and with a length of 50 to 80 mm. The tungsten carbide is used because of its resistance to abrasives.

The mixing process can be presented by mathematical models:

$$v_{wj} = \psi \sqrt{\frac{2 p_w}{\rho_w}} \quad (1)$$

Where is: v_{wy} = velocity of water jet, ψ = velocity coefficient of the opening (orifice). For example, if orifice diameter is 0,65 mm velocity coefficient is 1,01 [5], p_w = water pressure, ρ_w = density of water

Volume flow:

$$q_w = \phi * v_{wj} * A_{orifice} \quad (2)$$

$$q_w = \phi * v_{wj} * \frac{d_o^2 * \pi}{4} \quad (3)$$

$$q_w = \phi * \frac{d_o^2 * \pi}{4} * \psi \sqrt{\frac{2 p_w}{\rho_w}} \quad (4)$$

$$q_w = c_d * \frac{d_o^2 * \pi}{4} * \sqrt{\frac{2 p_w}{\rho_w}} \quad (5)$$

where is:

Φ = "vena-contracta" coefficient. The typical value may be taken as 0,64 for a sharp orifice. [6]

$A_{orifice}$ = surface size of orifice

d_o = diameter of orifice

c_d = the orifice coefficient discharge. [7]

The total power of the water jet can be given as:

$$P_{wj} = p_w * q_w \quad (6)$$

$$P_{wj} = p_w * c_d * \frac{d_o^2 * \pi}{4} * \sqrt{\frac{2 p_w}{\rho_w}} \quad (7)$$

$$P_{wj} = c_d * \frac{d_o^2 * \pi}{4} * \sqrt{\frac{2 p_w^3}{\rho_w}} \quad (8)$$

Energy and momentum do not remain constant due to losses during the mixing process. But, in the beginning, it can be assumed that there is no loss of jet momentum before and after the mixing [8].

Table 1 shows us achievable high differences at maximum cutting of depth. Generally, hard materials

Table 1 **Thickness of the cutting material**

Cutting material		Material thickness / mm
1	Stainless steel	70
2	Wood	150
3	Glass	50
4	Ceramics	30
5	Polymer	130
6	Stone	90
7	Copper	80
8	Aluminium	100
9	Steel	100

can be cut with smaller thicknesses, while cutting of softer materials can be done with larger thicknesses. For instance, wood can be cut with a thickness of 150 mm and the stone with a thickness of 90 mm.

EXPERIMENT

The tests in the experiment were made on polymer material SIPAS 60 with properties shown in Table 2.

Table 2 **Mechanical properties of the cutted material [9]**

Typical values at 23 °C	Values
Properties	
Abbreviated term	PA6
Density	1,14 / g/cm^3
Viscosity number	140 / ml/g
Processing	
Melting temperature	220 / °C
Mechanical properties	
Tensile modulus	3,9 / MPa
Yield stress	90 / MPa
Flexural modulus	2,9 / MPa
Flexural strength	95 / MPa
Ball indentation hardness	190 / MPa

SIPAS 60 is a material with excellent resistance to abrasion and impact load. It is used for making gears, coupling elements for eccentricity, sealing rings, screw elements, sliding elements and other elements exposed to impact loads.

The quality of the machined surface is determined by its roughness. Theoretical roughness depend primary on the geometry of the abrasive water -jet tools and applied process. One has to take into account that the real roughness exclusively depends on theoretical roughness, although higher or lower roughness depends on several factors. These factors make the surface as a trajectory of action in abrasive water-jet cutting. [10]

Limit values for the parameters were chosen as the marginal cases of the selected machine. The parameters were kept between minimal and maximal mass flow and water pressure that can be obtained in the machine (marginal cases). The cutting head velocity was chosen as a calculated value obtained from software "velocity calculator".

To measure the surface roughness, it was used Mitutoyo Surf test SJ301.

The worst result of surface roughness in Table 3, we obtained on the sample I3, because the sample has the smallest abrasive mass fl ow (0,4 kg/min), the lowest pressure (250 MPa) and a top speed of cutting head (160 mm/min). As for the materials with thickness of 19 mm, because of poor quality surface, roughness could not be measured (Figure 3). The cutting material has a thickness of 20 mm.

Table 3 **The Cutting Parameters**

Mass flow kg/min	Pressure / MPa	Velocity of cutting head / mm/min	
0,4	350	80	G1
		120	G2
		160	G3
	300	80	H1
		120	H2
		160	H3
	250	80	I1
		120	I2
		160	I3
2,8	350	80	J1
		120	J2
		160	J3
	300	80	K1
		120	K2
		160	K3
	250	80	L1
		120	L2
		160	L3

Table 4 **The measurement results**

Depth Num.	Roughness / µm					
	1 / mm		11 / mm		19 / mm	
	Ra	Rz	Ra	Rz	Ra	Rz
G1	8,1	47,7	8,9	52,8	10,5	58,4
G2	7,6	44,5	9,8	55,1	11	51,9
G3	7,8	41,7	8,2	49	11,5	62,8
H1	7,2	44,5	7,9	55,8	10,2	55,6
H2	7,9	51,6	10,7	52,3	16,1	83
H3	9,7	60	10,5	55,6	15,4	87,9
I1	8,2	47,9	11,7	67,9	9,4	57,1
I2	7,5	44,1	12	66,1	13,4	73,6
I3	7,2	45,5	12,6	68,3	/	/
J1	6,9	36,8	6,9	48,4	8,3	48,2
J2	6,7	43,7	9	47,3	8,6	49,3
J3	8	45,1	8,1	49,2	9,2	54,2
K1	6,1	40	7,5	42,9	7	44,3
K2	7,9	41,5	6,8	42	8,7	49,6
K3	8,1	47	8,6	47,3	9,4	58,6
L1	5,7	35,6	6,9	46,5	7,9	45,8
L2	6,2	36,1	6,9	45,1	8,8	48,3
L3	6,8	35,8	7,5	45,8	8,2	50,1

Figure 3 Surface of I3 specimen

CONCLUSION

Measurements of surface roughness were conducted on the cutted surface created by AWJ cutting while influence of cutting parameters were examined (increasing pressure and abrasive mass flow rate). The increase of the abrasives mass fl ow has a greater impact than increase the pressure of water.

If the results of roughness measurements in the lower reaches of the sample I3 and L3 are compared with the same parameters (water pressure and cutting head velocity) with a different mass flow it can be concluded that with the mass fl ow rate increased 7 times there is incomparably better quality of surface roughness. In sample I3 water and abrasives do not have a good interaction because there is not enough abrasives in the system. Therefore, all results of measurements are approximate. The cutting tool is only water with a small percent of abrasives. With increased water pressure from 250 MPa to 350 MPa with the same mass flow rate and the cutting head velocity (for samples L3 and J3), in the cutting lower zones there is 10 % better surface roughness. In the upper and middle zones the impact of changing parameters is 10 %.

Also, with the increased cutting head velocity from 80 mm/min to 160 mm/min (for samples K1 and K3) in the cutting lower zones there is 25 - 30 % better surface roughness. In the upper and middle zones the impact of changing parameters is 15 - 20 %. If there are materials with low density they can be cut with a low-speed cutting heads and low pressure, thus saving machine and increasing profits.

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REFERENCES

[1] http://www .wardjet.com/01-waterjet-cutting-characteristics.html (17.04.2013)

[2] P. Hreha, S. Hloch, J. Valíček, K. Monková, P. Monka, M. Harničárová, M. Fusek, P . Konjatić; Impact of abrasive mass flow rate when penetrating into a material on its vibration, Technical Gazette, 17(2010)4, 475-480

[3] http://cdn.intechopen.com/pdfs/15606/In Techtribology_in_water_jet_processes.pdf (13.12.2012.)

[4] http://nptel.iitm.ac.in/courses/Webcourse- contents IIT%20Kharagpur/Manuf%20Proc%20II/ pdf/LM-37.pdf (17.04.2013)

[5] J. H. Lienhard; Velocity Coeffi cients For Free Jets From Sharp-Edged Orifi ces; Journal of Fluids Engineering, 106(1984), 13-17

[6] http://content.alterra.wur.nl/Internet/webdocs/ilri-publicaties/publicaties/Pub20/pub20-h1.2.pdf (29.03.2013)

[7] http://www.engineeringtoolbox.com/ orifice-nozzle-venturi-d_590.html (29.03.2013)

[8] h ttp://nptel.iitm.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Manuf%20Proc%20II/pdf/LM-37.pdf (29.03.2013)

[9] http:/www.sipas-galdovo.hr/materijali.html (12.03.2012)

[10] A. Stoić, M. Duspara, B. Kosec, M. Stoić, I. Samardžić. The application of water jet in cutting polymer materials. Metalurgija 52(2012)2, 255-258

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