Nonconventional Technologies Review
Romania, September, 2013

RESEARCH ON THE INFLUENCE OF WORKING PARAMETERS ON CUTTING WATER JET

Popa Liliana[1], Ispas Andreea[2]
[1] University POLITEHNICA of Bucharest, lilipopa@yahoo.com
[2] S.C. Etanşări GRAFEX S.R.L., andreea.ispas @grafex.ro

ABSTRACT: This paper aims to highlight the influence of working regime parameters (flow of a water-abrasive cutting speed, grain size abrasive) on the surface quality obtained waterjet cutting and abrasive. It also highlights how theoretical research practice validated by cutting through the proposed method. The experimental program introduces a local Abrasive can reduce the cost of processing and which establishes the optimal processing regime. Depending on the analyzed parameters are calculated and the cost of processing with the use of two grades of abrasive: garnet and quartz sand.

KEY WORDS: cutting, water jet, abrasive water flow, flow of abrasive

1. INTRODUCTION

News domain approach is confirmed by the present work developing various scientific topics from around the world. Areas of research concerns the problem of generating jets basic research and development equipment, material interaction - running water (with or without abrasive) and the creation of industrial production database on optimum processing schemes for different types of materials, as well as the efficiency of the process.

Water jet machining (hydrodynamic) is a process for the removal of the material based on the mechanical effect of a erosive water jet or a liquid spray based on water and containing additives, with a high pressure and speed. The dimensional processing used 2 versions: water jet machining (WJM water-jet machining) or water jet machining abrasive (abrasive water-jet machining AWJM).

Schematic diagram of waterjet processing is shown in Figure 1.

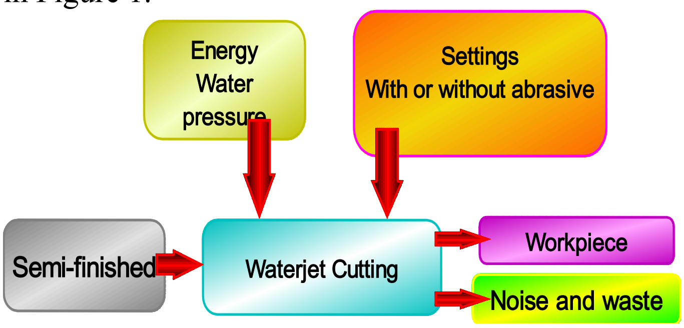


Figure 1. The principle scheme of AWJM

Machined surface quality depends on several parameters:

- parameters of the material: the material part, the nozzle material, the nature and properties of the fluid;
- cutting parameters: the distance of positioning, the nozzle inclination, the movement speed, number of passes;
- the parameters of the hydraulic: pressure in the nozzle flow speed, the flow of water, the diameter of the nozzle orifice and the power flow (which depends on the pressure in the nozzle and the nozzle hole diameter).

2. MECHANICAL AND PHYSICAL PHENOMENON AT ABRASIVES WATERJET CUTTING

After the formation of the water jet charged with abrasive mixture thus obtained is powered at a speed of about 400 m / s at the work piece surface where particles are removed by abrasion. Mechanical abrasion is characterized by the superposition of two ways:

- the removal of material by cutting (or erosion). It appears for low impact angles. If during the impact, the vertical component of the particle velocity is sufficient, the material deforms plastically, and component of the horizontal speed causes a shear stress on an area equal to the vertical section of the particle has penetrated the material. If the stress in this section is greater than the shear stress on the material, the material is damaged. This amounts to generate a chip, like a micro-cutting tool. This mode material removal appears to predominantly ductile materials. This is illustrated by the following diagram, Figure 2;
- removing material by plastic deformation occurs at high angles of impact. On the impact of abrasive particles, often likened to a sphere on a flat surface, the maximum voltage in the mass of material is obtained for a depth equal to twice the radius of the contact surface.

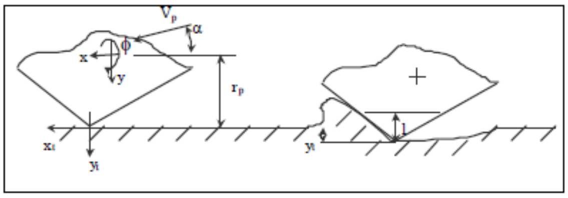


Figure 2. Removing material by erosion

The impact is considered to be elastic if the maximum stress at the impact does not exceed the elastic limit of the material. Otherwise, repeated impacts cause plastic deformation of the surface. This deformation affects the value of the limit elastic material, which increases to the value of tensile strength. The damaged area is then removed in pieces.

3. PHENOMENOLOGICAL ASPECT AT ABRASIVE WATER JET CUTTING

The best-known model is that of Hashish [2, 3] To which we have also proposed changes to the ENSAM with Latif [6] and Ferrendier. By introducing adaptive component of the particle size of the abrasive. Hashish model relies on the theory of Finnie [5], who made the first model of the mechanism of erosion of ductile materials by particle impact. This model was taken by Bitter, during work on the study of deterioration of industrial pipes. It has changed the model Finnie by integrating second user removing material: plastic deformation. His model takes into account the physical and geometrical characteristics of the abrasive in calculating the height of cut. Decomposition unit volume in the form of a penetration depth and a movement enables it to determine the depth of cut for each mode material removal (cutting h_c and deformation h_d), as shown in Figure 3.

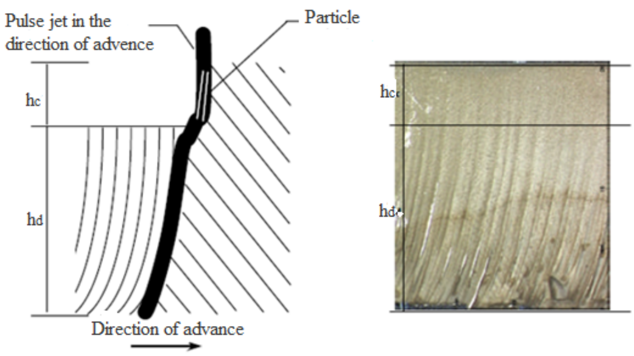


Figure 3. Erosion areas corresponding to models of cutting

The mode of erosion cut appears for low impact angles. It is a equilibrium status flow, the material removal rate is the rate of advance of the jet in the material. The trajectory of the jet is substantially vertical to cutting depth h_c. The cut faces does not have surface irregularities. The mode of erosion deformation appears at high angles of impact. This is an unstable state of the jet. The jet oscillates between a vertical and parallel to the surface part until a depth h_d. The rate of material removal decreases with penetration depth to be zero for h_d. The diameter of the jet varies, causing instabilities and promotes the appearance of streaks on cutting faces, features of this cutting method.

Evidence presented to allow the understanding of physical phenomena that occur during impact abrasive particles on the surface that are to be processed, particles put in motion and transported by a jet.

Hashish [4], describes the process of cutting that a process cycle of material removal. Its decomposition (Figure 4) is based on the observation of the cutting process in the transparent material (plexiglass, glass). Abrasive particles strike the surface at small angles of impact and shear material in the form of a cut. This action induces energy dissipation: the particles are slowed down and then diverted by the reaction forces of the material.

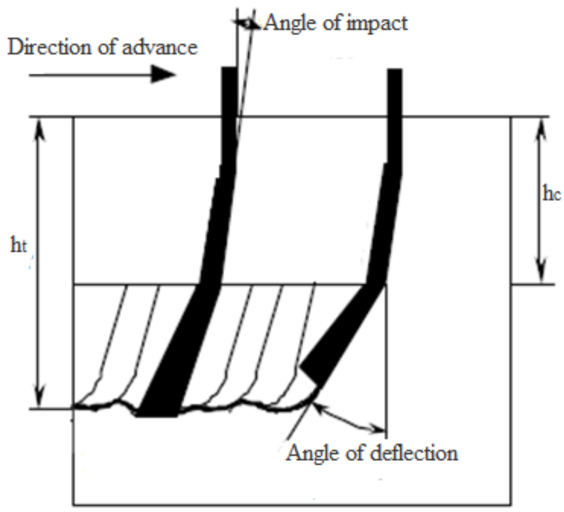


Figure 4. Description of the cutting process

There is a curvature of the flow, characterized by the angle of deflection. This curvature increases when the volume of material removed increases and becomes high (approx. 90 °) for final cutting height h_T.

Breaking of the material resulting from the abrasive grains located on the front curved flow, leads to a lower step. The flow above the step (HC) continues to move forward with moving the jet, while the bottom of the jet remains attached to the step.

Step advance, and the curvature of the bottom of the flow increases up to a limit of the step size of the jet is deflected to. With advances in material flow, start the process of forming the next step.

Advancing step and the curvature of the bottom of the jet increases, until a limit of the step size at which point the jet is diverted. With advances of flow in material, start the process of forming the next step. This change to the removal of material is characterized by the appearance of streaks on the groove cutting and the depth is related to the angle of deflection of the jet.

In Figure 4 are presented the different qualities of the surface obtained at waterjet cutting, depending on cutting speed, [1, 7]. This is the maximum for the sample Q1 and minimum for sample Q5. In the case of small thickness, in the first case, the speed can be up to three times higher than the latter, while for thicker speed used to obtain the quality of Q1 is 6 times higher than the quality of Q5.

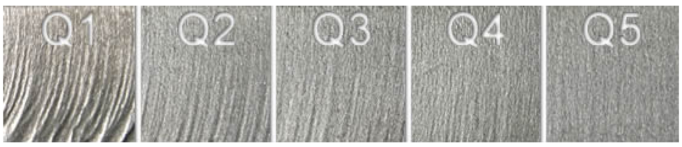


Figure 5. Different surface quality

Increasing the speed, increases and the angle between abrasive water jet and cutting front, which push back the water jet. Similar to the processes of heating cutting, also at water jet cutting can be found concepts which characterize the quality of the cut. These notions are cut-off, cut quality and cuts fine.

The cut-off cut into a workpiece a contour by applying the maximum possible cutting speed. The feed is adjusted so as to be surely cut. The cut has a V-shaped profile and at the bottom is formed striations (roughness).

To make a quality cut, water jet is driven with a lower speed. Cut profile is more steeply and smoother. Formation of striations (roughness) is not so obvious, we obtain a good quality of edges and corners. Feed rate is approx. 50% of the rate applied to separate the cut, Figure 5.

Figure 6. Simulation waterjet cutting at a cut-off (left), a quality cut (middle) and a fine cut (right)

At a fine cut are not formed than very few striation on cutting surfaces. The cutting cost greatly increase because of its slow advance, which is approx. 25% of the rate applied to the cut-off. In very severe requirements, these costs may be partially compensated by additional operations that could be removed, achieving savings.

Also, the cutting speed influences the geometry of the joint, in that the cut joint width decreases with increasing feed rate. This occurs because less advance speed, the cutting power available per unit length of cutting becomes smaller, which extends section abrasive jet of water, which is easily adaptable to the circumstances.

The flanks of cutting joint are not usually parallels. At an great advance, the opening is larger at the joint faces to the cutting head - typically above than the bottom. With the decrease in the feed speed, the point of the bottom is opened more than the above, so that at the very low feed rates, the lower opening is larger than the above. The phenomenon is explained by the energy loss suffered by the particles in water jet, on the one hand due to reduced speed, and on the other hand due to the effect of mechanical work applied to counteract the friction occurred during cutting material when jet cuts through metal.

The distance between the nozzle and the work piece may be up to 5 mm. A distance in this domain has a minimal influence on the quality of the cut.

Regarding abrasive material, most often used in industrial cutting operations is garnet. Other abrasive materials, such as aluminum oxide, silicon carbide, silica sand is also used, in particular for cutting processing or cleaning. The rate of erosion of the workpiece, and as a result, cutting efficiency is highly dependent on the material used. The size of the abrasive particles and abrasive flow rate greatly affect the quality of the cut surface and the cutting efficiency. Grain size most commonly used in industrial applications is between 50-120 (particle size between 125-300 microns) and abrasive flow from 3.8 to 11.4 g/s.

Striations resulting on the cutting surface has a typical structure as shown in Figure 6.

Figure 7. Striations structure

The striations are curved in the direction opposite to the direction of cutting, and the curvature for different materials and thicknesses vary depending on the pressure of the water jet and cutting speed. While the top is smooth , the bottom is rough and corrugated. The striations of surface is characterized by different parameters.

Possible causes of formation striations found in the literature are:

- vibration during the cutting process;
- the undulatory distribution of the kinetic energy of the abrasive particles inside the jet;
- decrease of kinetic energy of the jet with the depth of cut.

4. EXPERIMENTAL STUDY

4.1 Equipment used

Cutting machine with abrasive waterjet Flow Mach 2b (Figure 7), combines a cutting bench in the console with abrasive jet PASER ECL Plus, an ultra high pressure pump and a controller computerized Flowmaster. These components create a machine tool with a quick and simple programming. Using FlowPATH and FlowCUT generates the machine movements based on a standard file DXF (CAD).

Figure 8. Cutting machine with abrasive waterjet Flow Mach 2b

The varied feature of these products are listed below:

- Core components include flow's paser abrasive cutting system, pump technology, and flow master software
- 3-sided easy access to your work piece
- Large diameter ball screw drive system
- Unique auto lube system
- Rigid construction for structural integrity
- Roll-around control
- Multiple pump configurations
- Heavy duty material support
- Solid steel casting construction

4.2 Abrasives used

As shown above, was generalized garnet for practical use as abrasive in cutting process by water jet.

The main providers of garnet for this application are found in India, Australia and China. In terms of chemical composition, mineralogy and grain shape, virtually does not exist differences between garnet from these sources. In specific erosion process, some abrasive grains are broken generating an levigable component, Figure 8. In the basin of the cutting deck they mix with the other products of erosion cutting material. The resulting mixture is in the form of a slurry. By the process of washing, drying and sorting can recover a percentage of more than 60% of the initially abrasive introduced the cutting system.

Figure 9. The structure of the abrasive material during the processing

An essential step in recovery process is the sorting of abrasive such as to obtain a size distribution identical to that of garnet unused. Figure 9 shows the garnet grain size distribution of 80 Mesh, coming from Australia. The particularity of the technical system to transport abrasive, specific machines manufactured by Flow requires that abrasive components do not have components under size of 0.125 mm (not to be "dusty") and also granulometric composition must be relatively constant.

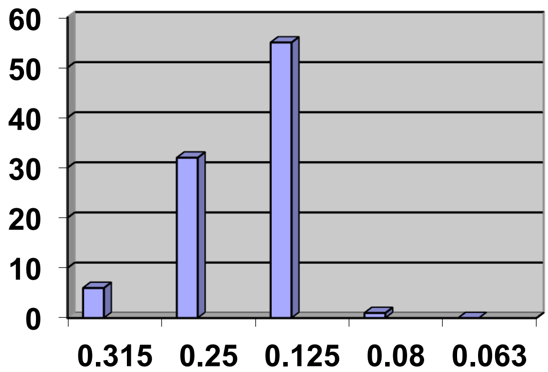


Figure 10. Particle size distribution of garnet

Cost of abrasive waterjet cutting is directly determined by the price of abrasive, that is on average 0.5 EUR / kg. Garnet consumption is generally optimized by the companies that produce these machines and materializes in software supplied with the equipment.

Considering these issues through experimental research aimed to establish the practical possibilities of using abrasive recovered and finding a solution to use an abrasive cheap and easily accessible.

On such abrasive is quartz sand used in construction or for obtaining training mixtures in ferrous foundries or the blasting material. A recognized source of quartz sand is Vălenii de Munte, Prahova county that delivers quartz sand washed and dried, the average particle size of 80 mesh, with a chemical composition of 97% silicon dioxide. The essential problem in using this abrasive on cutting machine described above is the grain uniformity. Bringing the a particle size distribution of the type shown in Figure 9, the sorting leads to the removal of about 25% of the abrasive purchased from the supplier. However, the economic effects of the possible use of this abrasive can be significant because of its price – about 20 times lower than garnet.

4.3 The processed material

The material used for experimental measurements is 1.2343 54 HRC (equivalent X38CrMoV5-1, according to EN ISO 10027).

4.4 Working parameters

For experimental measurements performed were are kept constant the parameters:

- Nozzle diameter = 0.33 mm
- Mixing tube diameter = 1.02 mm;
- Cutting pressure = 55,000 psi = 3850 bar;
- Abrasive used: garnet, sand.

4.5 The experimental program and results

Ishikawa diagram is a method used for problem solving to determine all potential or actual causes (inputs) to produce an effect (or output). It is used in the quality management to illustrate the relationship between a quality characteristic and factors affecting the characteristic. In Figure 10 is shown the Ishikawa diagram for water jet cutting abrasive.

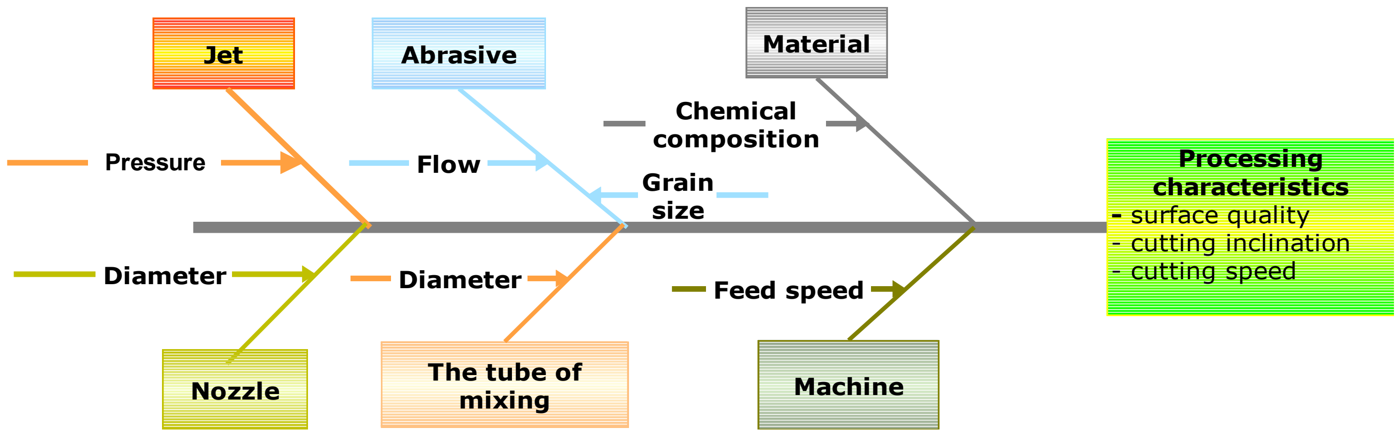


Figure 11. Ishikawa diagram for water jet cutting abrasive

For each of the two types of abrasive described above were made two measurements.

The first determination was maintained constant abrasive flow ($Q_{abrasive}$ = 625 g / min) and vary the speed, and in the two was kept constant cutting speed (v = 30.54 mm / min) and vary the flow of abrasive. The values of these parameters are presented in Table 1 and Table 2.

Was monitored cut quality in the two conditions.

Table 1. The values of work parametres

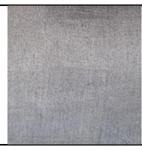
Abrasive	Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Garnet	Abrasive flow rate, Q [g/min]	625	625	625	625	625
	Cutting speed, v [mm/min]	15,28	22,91	30,54	38,17	45,82
	Appearance of the cut					
Quartz sand	Abrasive flow rate, Q [g/min]	625	625	625	625	625
	Cutting speed, v [mm/min]	15,28	22,91	30,54	38,17	45,82
	Appearance of the cut					

Table 2. The values of work parametres

Abrasive	Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Garnet	Abrasive flow rate, Q [g/min]	30,54	30,54	30,54	30,54	30,54
	Cutting speed, v [mm/min]	453,6	521,6	625	784,4	884,5
	Appearance of the cut					
Quartz sand	Abrasive flow rate, Q [g/min]	30,54	30,54	30,54	30,54	30,54
	Cutting speed, v [mm/min]	453,6	521,6	625	784,4	884,5
	Appearance of the cut					

Experimental results have validated the theoretical considerations presented in the previous sections. The appearance of the cut at various feed rates reveal the factors of influence such as the vibrations during the cutting process, the kinetic energy of the wave distribution of the abrasive particles within the jet, and the jet kinetic energy decrease with depth of cut.

Measurements were performed to determine the angle of the cut. The values obtained are shown in Table 3. Also were given ratings from very bad to very good surface quality achieved by the presence and size of striations (Table 4). Is observed that in the case of the speed variation with the increase of the cutting speed increases and inclination of the cut, while in the case of abrasive flow variation is observed the existence of an optimal value which the surface quality is very good. From this value the quality of the surface decreases as the increase in the flow of abrasive and for its reduction.

Table 3. Cutting inclination

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Variation of cutting speed					
Q = ct. = 625 [g/min]					
V [mm/min]	15,28	22,91	30,54	38,17	45,82
Quartz sand (NV)	0,07	0,01	0,2	0,12	0,14
Garnet (GR)	0,02	0,18	0,22	0,25	0,2
Variation of abrasive flow rate					
V = ct. = 30,54 [mm/min]					
Q [g/min]	453,6	521,6	625	784,4	884,5
Quartz sand (NV)	0,14	0,12	0,2	0,01	0,07
Garnet (GR)	There were no variations				

Table 4. Surface quality

Abrasive	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Variation of cutting speed – SAMPLE A					
Quartz sand (NV)	Very good (10)	Good (8)	Satisfactory (6)	Bad (3)	Very bad (1)
Garnet (GR)	Foarte bună (10)	Very good (10)	Good (8)	Good (8)	Satisfactory (6)
Abrasive flow rate variation – SAMPLE B					
Quartz sand (NV)	Bad (3)	Satisfactory (6)	Good (8)	Satisfactory (6)	Bad (3)
Garnet (GR)	Very good (10)	Very good (10)	Very good (10)	Very good (10)	Very good (10)

For the varying values and qualitative assessments presented in the previous tables, graphs were drawn in Figure 11-14.

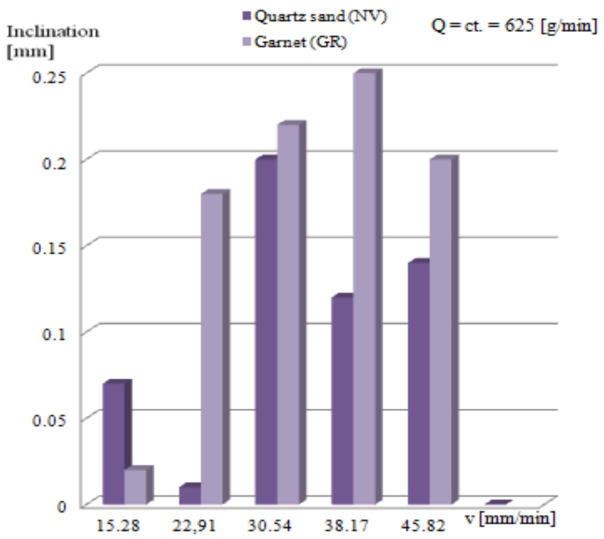


Figure 12. Variation of the surface inclination depending on the speed of advance

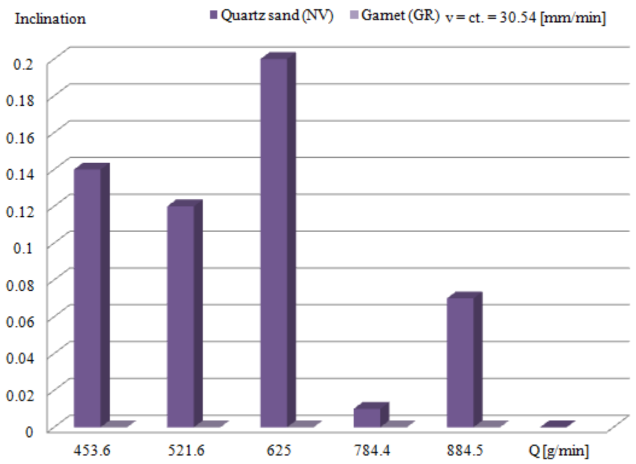


Figure 13. Variation of the surface inclination depending on the flow rate

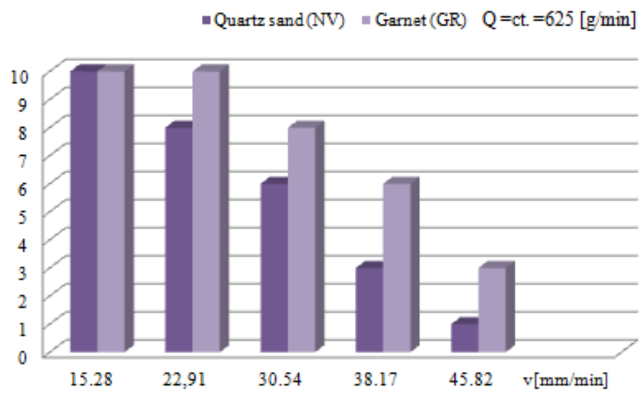


Figure 14. Variation of surface quality depending on the speed of advance

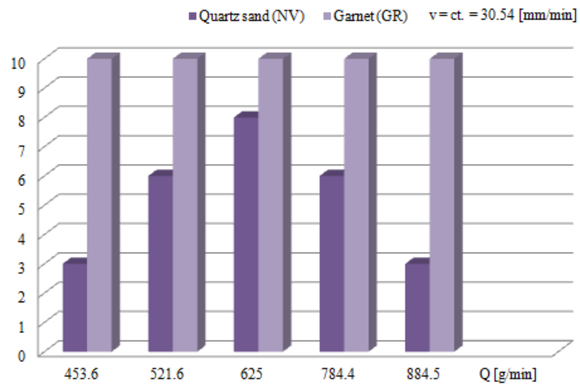


Figure 15. Variation of surface quality depending on the flow rate

5. CONCLUSIONS

Abrasive waterjet cutting is:

- a new process with many advantages to cutting metal materials (no heat affected zone);
- optimal method (single) for cutting composite materials;
- optimal method for fragile nonmetallic materials: glass, ceramics, thermosetting plastics, etc.

Processing costs are relatively high and are defined by:

a) abrasive consumption;

b) Cost of pump operation, cutting head, pressure pipes. These costs are given by replacing used components periodically: pump nozzle, mixing tube and pipe pressure replacement etc.

c) Consumption of water, electricity and salt (for water softener).

Abrasive consumption costs (point a) can be calculated using the equation:

$$C_a = C_{abr} \cdot D_{abr} \cdot \frac{L}{v_c} \ [€] \quad (1)$$

Where: C_{abr} - the abrasive purchase price [€/kg]; D_{abr} - abrasive flow rate [kg / min]; L - length of cut [mm]; v_c - cutting speed [mm / min].

Cost analysis of machine operation over 2 years has led to a value of the cost in points b) and c) 30 €/hour or computed using the equation below:

$$C_{b+c} = 0.5 \cdot \frac{L}{v_c} \ [€] \quad (2)$$

For cutting length L = 1m result total unit cost:

$$C_u = \frac{C_{abr} \cdot D_{abr} + 0.5}{v_c} \ [€/m] \quad (3)$$

Garnet abrasive has a medium purchase price of 0.5 €/kg and quartz sand from Vălenii de Munte 150 RON / ton.

Abrasive flow work parameter varied difficult because it is determined by the construction of the transmission system. This is optimized by the manufacturer of the machine depending on the diameter of the water nozzle and the mixing tube. For example, when use the quartz sand from Valenii de Munte, samples 4 and 5 of the sample B-NV, the surface quality results satisfactory, respectively as poor be cause the transport of abrasive was not possible.

For optimum abrasive flow rate 0.625 kg/min prescribed by the machine manufacturer to couple the nozzle/tube mixing, the variation of unit cost of cutting with the cutting speed is shown in Figure 15.

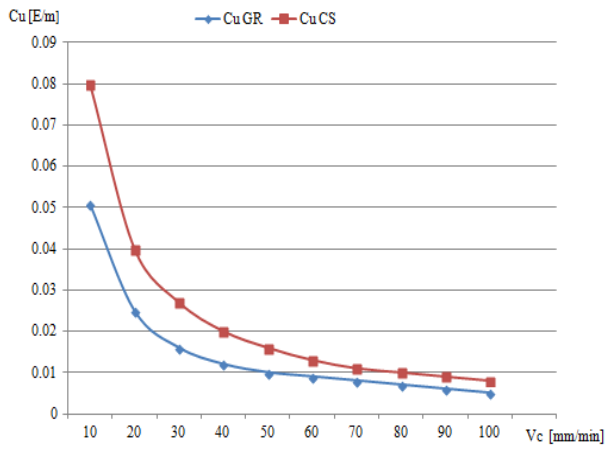


Figure 16. Variation depending on the unit cost of cutting speed cutting

From the point of combination between the quality of the cut surface and inclination of cut, optimum results are as follows: $C_u^{GR} = 0.053$ [€/m] and $C_u^{CS} = 0.023$ [€/m].

It follows, therefore, the possibility and the economic importance of replacement whenever possible in terms of technology, the garnet with quartz sand.

6. REFERENCES

1. Fekaier, A. - *Etude théorique et expérimentale d'un processus de découpe hydroabrasive*, Thèse de l'Université de Paris 6, France, (1995)
2. Hashish, M., *An improved Model of Erosion by Solid Particle Impact*, 7th Internationale Conference on Erosion by Liquid and Solid Impact, Cambridge, pp. 66, (1987)
3. Hashish, M., *A Model for Abrasive-waterjet Machining*, Transactions of the ASME-Journal of Engineering Materials and technology, Vol.111, pp.221-228, (1989)
4. Hashish, M., *Characteristics of surfaces machined with abrasive-waterjet,* Transactions of the ASME . Journal of Engineering Materials and Technology, vol. 113, pp. 334-362, (1991)
5. Finnie, I., *The mechanism of erosion of ductile metals*, Journal of Engineering Material and Technology, p. 527-532, (1958)
6. L. Latif, *Etude et modélisation de la découpe d'un matériau ductile par jet d'eau abrasif*, Thèse de l'ENSAM, Paris,(1998)
7. Cornier, A., *Developpement d'un modele d'enlevement de matiere par granulation utilisant la jet d'eau haute pression*, Thèse de L'Ecole Nationale Supérieure d'Arts et Métiers Paris, France, (2004)