Influence of abrasive material on abrasive waterjet cutting process

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1. Introduction

The abrasive materials used are silica, alumina, silicon, carbide or silicon nitride, composed of small particles (equivalent diameter between 0.08 - 0.1 mm).

These abrasive materials are introduced into the mixing chamber of the cutting tool (cutting head) and dispersed in the water jet. The water jet transfers the energy to the abrasive particles causing a rapid increase in their velocity.

The energy transfers between these components, water jet and abrasive is a complex process. First there is a reduction in the dynamic stability of the high pressure water jet, the effect being the coherent jet separation in fine droplets that increase the velocity of the abrasive solid particles, a process which is predominant in the mixing chamber.

Also, regarding the transfer of energy through the hydrodynamic forces imposed by water on the abrasive particles, it is found this to be a predominant situation at the level of the nozzle (of the cutting head).

As a result of the energy transfer, the abrasive particles provide about 90% of the energy required for the cutting process, and removal of the material in this case is due to erosion and micro abrasion processes, depending on the cut material.

Local erosion is the result of the variable stresses set at the impact between the jet and the work piece.

The actual cutting process causes a deformation of the cut surfaces and the angle of the striations is determined by the correlation between the cutting speed (speed of the cutting tool), the complexity of the cutting contour and the jet energy [1], [2].

2. Abrasive flow rate

As the cutting speed increases to a constant jet power (i.e., constant water jet pressure and constant abrasive flow rate), the tilting of the striations increases its value until no penetration occurs over the entire thickness of the material. The width of the cutting joint depends on the abrasive cutting version having values between 0.5 and 2.5 mm and the roughness of the cut surface having values between 0.1 and 0.6 mm.

Figure 1 shows trends in abrasive quantity (flow), cutting speed, and cost of effective cutting operations. It is noted that as the amount of abrasive introduced increases the cutting speed also increases and the cost of the cutting operation decreases to a limit where the cutting speed and cost reach optimum values (high cutting speed equal to a low cutting cost).

As far as the processing times are concerned, for the smallest values (imposed by the required productivity), the system needs to work at high capacities, using the maximum engine power value.

Following experimental programs, a conclusion was reached on the profitability of cutting operations that must be done at high speeds and with high abrasive input, independent of the quality of the cutting material and the power of the system.

As for the abrasive used in the water jet cutting operations, this is a hard sand, separated by particle size. The most commonly used abrasive in the market is the garnet.

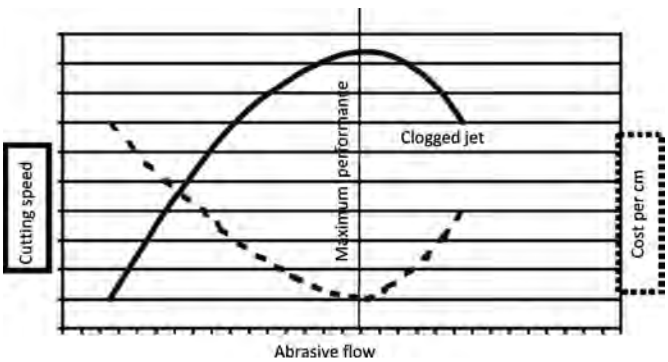

Figure 1. Performance chart of water jet according to parameters. For any given set of parameters (pressure, nozzle size, etc.) the cutting speed increases and cutting costs decrease as the abrasive flow increases resulting in a maximum performance.

It is a rough, durable and cost-effective abrasive. The current offer currently has the following qualities:

- Granulation 120 Mesh, produces a smooth surface;
- Granulation 80 Mesh, currently used for general use;
- Granulation 50 Mesh, used for cutting at high speed for rough cuts.

It is noted that the focusing tubes of the cutting heads have the role of accelerating and concentrating the abrasive materials.

The supply of abrasive nozzles (focusing tubes) on the market is varied ranging from different sizes and suitably different lifetimes.

Generally, the focusing tubes are 75 mm long and the outside diameter is ¼ "and the inside diameter is between 0.5 and 1.5 mm.

From the point of view of the particle size of the abrasive, recent research quantifies the effect of particle size on the shape of the abrasive (radius of curvature, sphericity, etc., figure 2). For an identical shape factor, but of different dimensions, the depth of the cut increases, as the particle size of the abrasive decreases. On the other hand, the loss of impact energy at the exit of the nozzle for smaller abrasive particles is more efficient in terms of the depth of the cut (Figure 3).

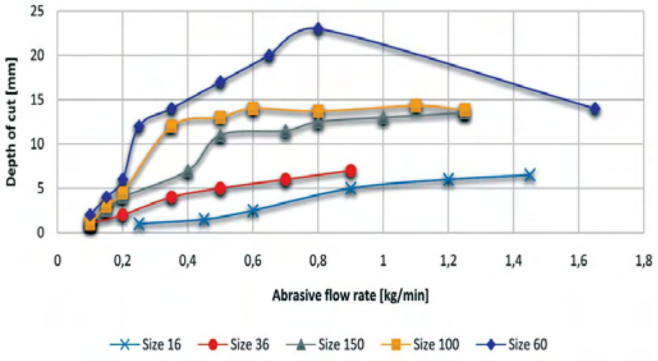

Figure 2. Influence of the dimensions of the abrasive particles on the thickness of the cut.

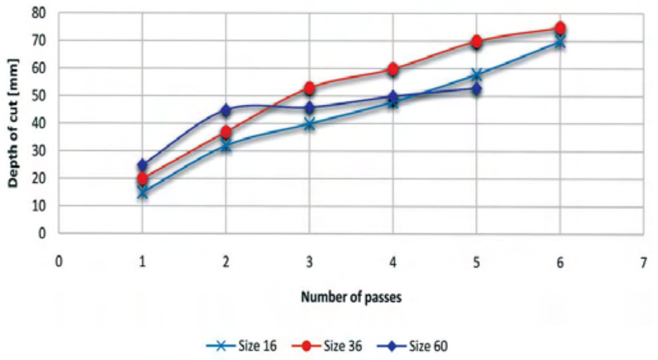

Figure 3. The influence of the number of passes on the thickness of the cut.

In the case of multiple cross-cutting, the large-sized abrasive material is more efficient in terms of cut thickness.

For cutting large thickness materials, multiple abrasive particles of different sizes can be used, so that for each thickness portion the optimum size of the abrasive size is used.

For the abrasive flow analysis, Figure 4 shows the influence of the abrasive flow rate on the thickness of the cut.

It is noted that by increasing the abrasive flow rate, the thickness of the cut has convenient values, up to a critical value, after which value further increase of the abrasive flow rate has a negative influence on the thickness of the cut material. [3].

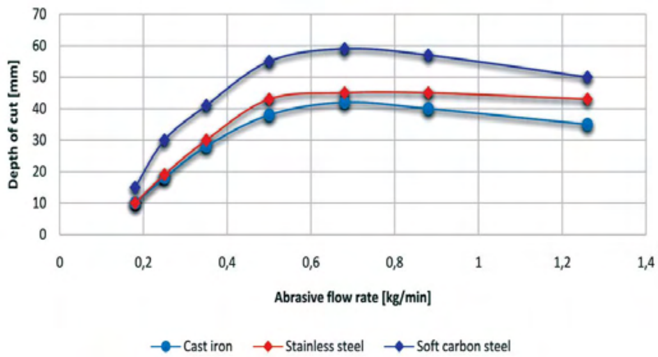

Figure 4. The influence of the abrasive flow rate on the thickness of the cut.

The impact between abrasive particles and material determines the water jet's ability to cut the material.

Since cutting is a cumulative process, the impact of the speed and frequency of abrasive particles are important. Particle speed determines the load on the material and potential energy transfer and implicitly the cutting depth.

The particle flow rate of the abrasive partially determines the frequency of the impact particles and partly their velocity. The higher the abrasive flow rate, the greater the number of particles that must divide the kinetic energy of the water jet. At low abrasive flow rates, it is assumed that the particles do not collide with each other, so they hit the cutting material with a maximum kinetic speed and energy. As the abrasive flow increases, there is a likelihood that the abrasive particles will hit each other, so they will lose out of the kinetic energy, resulting in a lower impact velocity upon contact with the material.

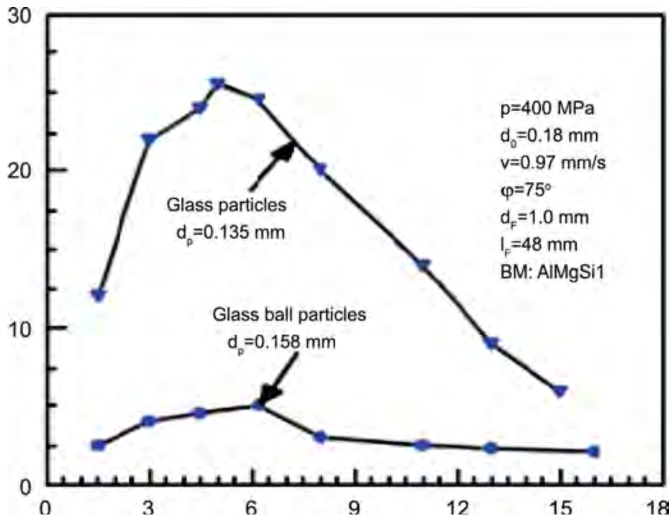

Figure 5. The relationship between abrasive geometry and cutting depth.

As can be seen, there is an exchange between a higher impact frequency and a decrease in kinetic energy of the particles. This shift is highlighted in Figure 5, which is a graph of the cutting depth according to the abrasive flow rate.

From the analysis shown in Figure 5 it results that at low abrasive flows, the collisions between the particles are fewer and they hit the cutting material with the maximum possible kinetic velocity and energy. However, at high abrasive rates, the impact between particles is more and more often due to increased density and even if more particles hit the material, many of them have a reduced kinetic energy and therefore a low speed. At high abrasive flows, water-solid films are also formed between the particles that hit the material and the material, which more dampen the impact of the particles with the material. Large abrasive flows also involve a larger jet of water for uniform dispersion of kinetic energy, therefore the cutting depth decreases.

Abrasive flow is dependent on many parameters such as pump pressure, focusing tube diameter, focusing tube length, and water flow. Figure 6, a) ÷ d) shows the dependence of the optimum abrasive flow rate on these parameters.

3. Cutting rate

Figure 7 shows the ratio between the cutting rate and the abrasive flow rate, i.e. the way the abrasive flow rate determines the cutting rate. The variation of the cutting rate is observed to a maximum, then decreases, even if the abrasive flow increases.

Of great importance in the abrasive analysis is the diameter of the abrasive particles. In Figure 8 a), b) are presented the dependence of the cutting depth on the particle diameter of the abrasive material.

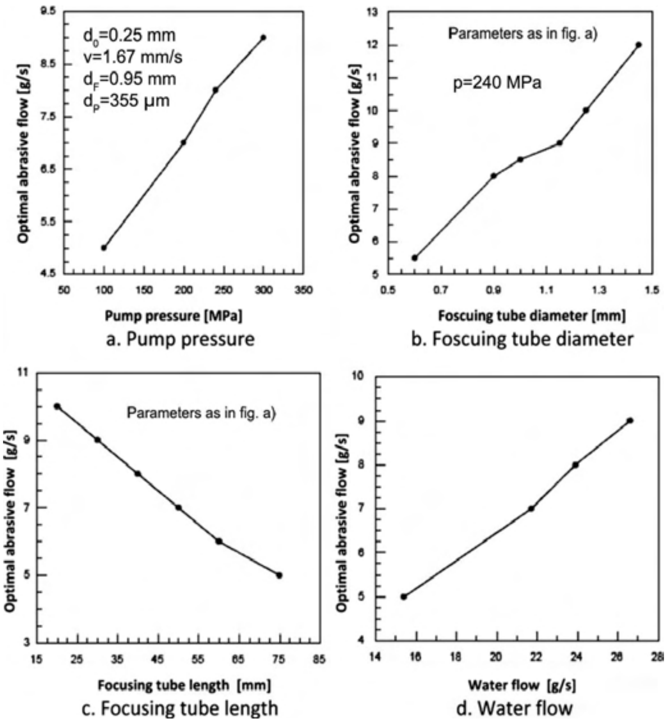

Figure 6. Influence of parameters on the optimal flow rate of abrasive.

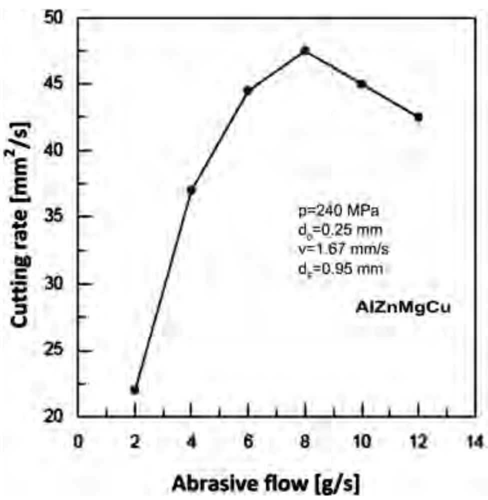

Figure 7. Cutting rate.

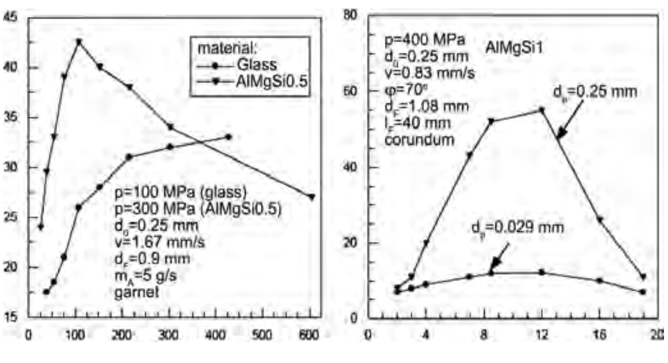

Figure 8. The relationship between abrasive particle diameter and cutting depth.

At the start, as the particle diameter increases, the cutting depth also increases. Once a certain optimum particle diameter is reached, the cutting depth begins to decrease. If this phenomenon is viewed from the point of view of the abrasive flow rate, it can be seen that an increase thereof results in an increase in the cutting depth, except for the large particle diameters [3], [4], [5].

4. Hardness of abrasive material

Analysing the phenomenon of abrasive water jet cutting, it was found that the cutting depth is dependent on the hardness of the abrasive particles, so that in any case, as the particle hardness increases relative to the hardness of the material, the cutting improves, as shown in Figure 9.

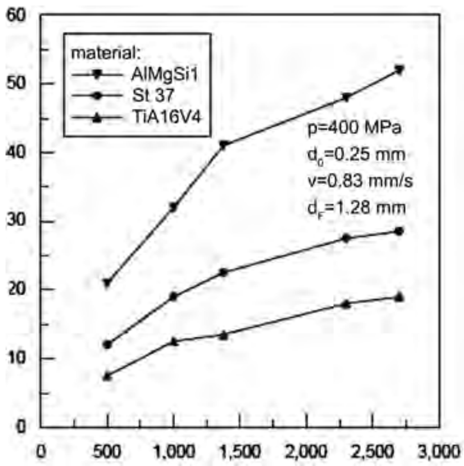

Figure 9. Influence of the hardness of the abrasive particles on the depth of the cut

The cutting depth is a function of the density ratio defined here:

$$hardnessratio = H_p/H_M \quad (1)$$

The structural abrasive water jet consists of three distinct parts: abrasive particles, water and air. At a greater distance from the exit of the nozzle, the volume of air will be higher and near the nozzle, the percentage will be decreased.

Figure 10 shows the flow diagram of the jet that exits through the nozzle.

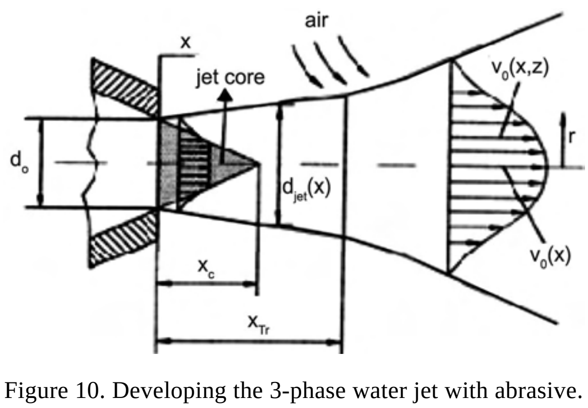

Figure 10. Developing the 3-phase water jet with abrasive.

The shape, size and composition of the jet changes in both axial and radial directions. It results in the need to characterize the phase distribution of the jet in both directions.

Figure 11 shows the abrasive mass flow rate in grams, depending on the radial direction from the centre line of the jet.

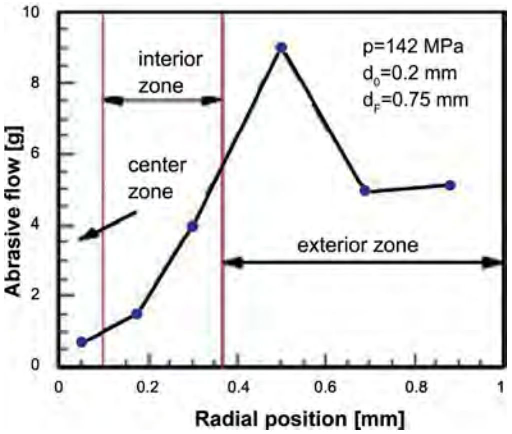

Figure 11. The relationship between the radial position of the jet and the distribution of the mass of abrasive particles.

It is noted that the amount of abrasive in the centre of the jet has a small value, but it increases at high speed, followed by a decrease and a stabilization in the outside of the jet.

There are three areas that are defined depending on the diameter of the jet and the focusing tube.

The central area is defined as the circular diameter equal to the diameter of the jet. The inner area is defined as the circular area between the diameter of the jet and the diameter of the focus tube and the outer area is the circular area extending further from the diameter of the focusing tube [5], [6], [7].

An increase in either abrasive flow or pump pressure can increase the amount of abrasive in the center area. This increase is shown in Figure 12.

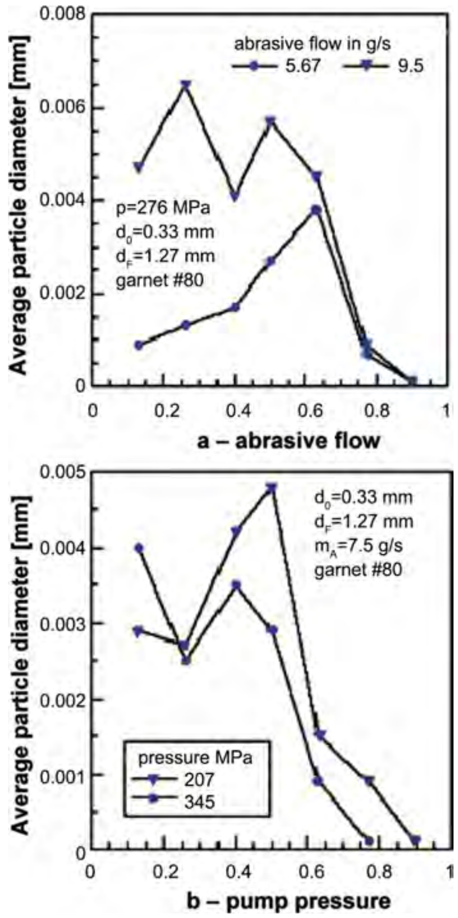

Figure 12. Influence of the parameters on the average diameter of the abrasive particles.

Figure 13. shows the variation of the percentage of abrasive in relation to the axial distance.

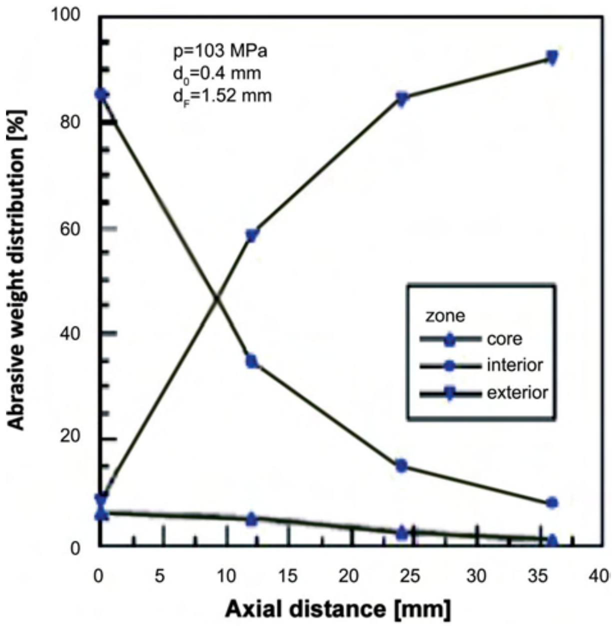

Figure 13. The relationship between particle spacing and the distribution of abrasive particles.

As can be seen, at the exit of the nozzle, about 85% of the abrasive is in the interior area and less than 10% in each of the other two areas. At about 10 mm from the nozzle, the percentage of abrasive in the outer area is equal to the one in the inner area, both of which are 45%. The percentage in the jet core area is approximately 10%. At a distance of 35 mm from the nozzle, most of the abrasive is in the outer area.

5. Conclusions

The water jet and abrasive cutting process consists in directing a high-pressure abrasive water jet (3000-6000 bar) and high speed (500-900 m/s) towards the cutting site. The high pressure of the abrasive water jet exerts compressive stresses on the material and due to local shear and erosion, removes the material and makes the cutting gap.

Approximately 90% of the energy required for the cutting process, and removal of the material in this case, is due to erosion and micro abrasion through wear, depending on the cut material.

Abrasive waterjet cutting operations must be done at high speeds and with a high abrasive supply, independent of the quality of the cutting material and the power of the system in order to obtain an ideal profitability.

For an identical shape factor, but of different dimensions, the depth of the cut increases, as the particle size of the abrasive decreases.

By increasing the abrasive mass flow, the cutting thickness has convenient values, up to a critical value, after which value, further increase of the abrasive mass flow has a negative influence on the thickness of the cut material.

Abrasive flow is dependent on many parameters such as pump pressure, focusing tube diameter, focusing tube length, and water flow.

The cutting depth is influenced by the hardness of the abrasive particles, so that in any case, as the particle hardness increases relative to the hardness of the material, the cutting capacity is improved.

References

[1]. Andreas W. Momber, Radovan Kovacevic: „Principles of Abrasive Water Jet Machining" e-ISBN -13:978-1-4471-1572-4

[2]. Wang, Jun: Abrasive Waterjet Machining of Engineering Materials, Trans Tech Pubn, 2003, Detroit, USA.

[3]. Miloş, L.: Tăierea termică, Ed. SEDONA 1996, Timişoara, Romania

[4]. Lesser, M.B. and Field, J.E.: «The geometric wave theory of liquid impact,»6th Conf. on Erosion by Liquid and Solid Impact, Cavendish Laboratory, 2006 University of Cambridge, England

[5]. Orbanic, H. et.a: Simulation of abrasive waterjet cutting process. Modelling simul. Mater. SCI. ENG., nr. 12, 2004, London, England;

[6]. D. Ionescu, I.S. Serban, I.A. Perianu: "Process for obtaining a mortar type construction material from abrasive material waste", *Patent no. 129363* from 30.12.2016.

[7]. D. Ionescu, I.S. Serban, I.A. Perianu: "Abrasive waste disposal device", *Patent no. 129441* from 30.10.2017.