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ABRASIVE MATERIAL FOR ABRASIVE WATER JET CUTTING AND THEIR INFLUENCE ON CUT SURFACE QUALITY

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Abstract: *The problem of cutting difficult-to-machine materials used in the aerospace industry, aircraft industry and automobile industry, led to the development and application of today the most attractive technology for contour cutting - Abrasive Water Jet Cutting.*
The use of the abrasive water jet cutting is based on the principle of erosion of the material uppon which the jet hits. Each of two components of the jet, i.e. the water and the abrasive material has a specific purpose. It is the primary purpose of the abrasive material within the jet stream to provide the erosive forces. It is the primary purpose of the water jet to deliver the abrasive material to the workpiece for the purpose of erosion. However the water jet also accelerates the abrasive material to a speed such that the impact and change in momentum of the abrasive material can perform its function.
Materials used for abrasives are generally characterized by high hardness, and moderate to high fracture toughness. This Paper presents types and properties of abrasive materials used in abrasive water jet cutting, as well the influence of abrasive mass flow rate on the cut surface quality.

Keywords: *Abrasive Materials, Abrasive Water Jet Cutting, Cut Surface Quality.*

1. INTRODUCTION

Each day reveals new materials that could be applied in different areas of mechanical engineering. In most of these materials processing by conventional methods is a major problem due to breakage and tool wear, uneconomical or even impossibility of processing, while the non-traditional manufacturing processes are applied without the usual restrictions on the mechanical properties and machinability of materials.

Advances in the automobile industry, material science, and space technology in 70's and 80's demanded and stimulated the outgrowth of new ideas and novel technologies in manufacturing. The first commercial water jet cutting system was built to cut laminated paper tubes in 1971. Since then, water jet technology has experienced a steady growth. In the early 80's, the idea of entraining abrasive into water jet was promoted by Hashish (1982) and commercial abrasive water jet (AWJ) systems became available in 1983.

The technology of water jet cutting uses either pure water or a mix of water and a fine abrasive material to form an abrasive water jet for use on harder workpieces. The list of materials that can be cut using a pure water jet includes Styrofoam, fiberglass, PVC, nylon, rubber and food products such as fish, meat, bread and cakes. With abrasive added to the water jet, virtually any material can be cut, including metals such as aluminum, carbon steel and stainless steel, high-nickel alloys and brittle materials such as marble, reinforced composites and honeycomb and sandwiched materials.

Modern machine shops now use abrasive water jet machines side by side with other traditional or non-traditional machine tools to cut 2D parts out of all kinds of materials and profit from the use because of their productivity, quick turn-around time, and relative low cost [1].

The aim of the Paper is to provide an overview to the influence of abrasive material, and especially abrasive mass flow rate on the cut surface quality by abrasive water jet cutting.

2. ABRASIVE WATER JET CUTTING TECHNOLOGY

According to a report from a market research company, abrasive water jet cutting is the fastest growing segment of the machine tool industry. So far there are more than 10,000 units of water jet machine tools in operation across the world, with the annual increase rate of more than 20% in the last few years.

Abrasive water jet machining is appropriate and cost effect for a number of procedures and materials and is applied in nearly all areas of modern industry. In the area of manufacturing, the water jet technique is used for: cutting of difficult-to-machine materials, milling and 3-D-shaping, turning, piercing and drilling.

At its basic, water flows from a pump, through plumbing, and out of a cutting head (Figure 1). The energy required for cutting materials is obtained by pressurizing water to high pressures and then forming a high-intensity cutting stream by focusing this water through a small orifice [2].

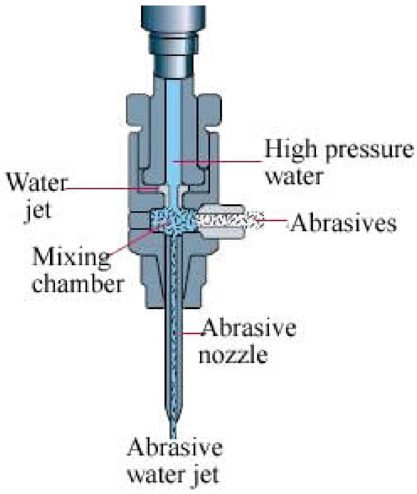

Figure 1. Abrasive water jet cutting head

Typical abrasive water jet cutting system provides an abrasive unit consisting primarily of an abrasive hopper, an abrasive feeder system, a pneumatically controlled on/off valve, and the specialized mixing chamber. The abrasive is first stored in the pressurized hopper and travels to a metering assembly, which controls the amount of particles fed to the nozzle (Figure 2). The abrasive is then introduced into the cutting stream in a special mixing chamber within the abrasive cutting head. After the cut, residual energy from the cutting stream is dissipated in a catcher tank, which stores the kerf material and spent abrasive [3].

The abrasive water jet differs from the pure water jet in just a few ways. In pure water jet, the supersonic stream erodes the material. In the abrasive water jet, the water jet stream accelerates abrasive particles and those particles, not the water, erode the material. The abrasive water jet is hundreds, if not thousands of times more powerful than a pure water jet. Both the water jet and the abrasive water jet have their place. Where the pure water jet cuts soft materials, the abrasive water jet cuts hard materials, such as metals, stone, composites and ceramics.

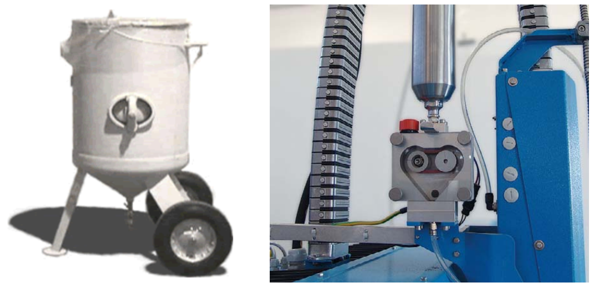

Figure 2. Abrasive hopper and feed-rate regulator

The abrasive water jet cutting process is characterized by a large number of process parameters [4] that determine efficiency, economy and quality. Typical parameter combinations used in abrasive water jet applications are give in Tab. 1.

Table 1. Typical process parameters of abrasive water jet cutting technology

Process parameter	*Value*
Workpiece material	any material up to about 250 mm
Operating pressure	240 - 410 MPa
Water jet nozzle diameter	0.25 - 0.46 mm
Abrasive water jet nozzle diameter	0.76 - 1.57 mm
Type of abrasive material	mineral garnet with # 60 - 120 mesh size
Abrasive flow rate	230 - 600 g/min
Water flow rate	1.9 - 3.8 l/min
Installation power	19 - 27 kW

Abrasive water jet cutting inherently is an environmentally friendly (green) process. Unlike traditional mechanical cutting systems, water jet cutting requires no cooling or lubricating oils, so there are no chemically contaminated chips to dispose of. Unlike thermal processes such as plasma or laser, water jet generates no noxious fumes during the cutting process [5].

3. CLASSIFICATION AND PROPERTIES OF ABRASIVE MATERIALS

Abrasives are those materials used in operations such as grinding, polishing, lapping, honing, pressure blasting or other similar process. Materials used for abrasives are generally characterized by high hardness, and moderate to high fracture toughness. Abrasives come in different particle or grit sizes depending on how much material needs to be removed.

The use of the abrasive materials with water jet for cutting is based on the principle of erosion of the material uppon which the jet hits [6]. Each hard abrasive particle acts like a single point cutting tool. Because of the size of the abrasive particles the impact on the workpiece of an individual particle is small but together the large total number of particles erode the material in significant volume.

Many different types of abrasive materials are used in the water jet cutting process, such as garnet, olivine, aluminium oxide, glass beads, copper slag and silica sand. Garnet, a hard, brittle crystalline mineral is the world standard abrasive for water jet cutting, with approximately 90% of all water jet cutting workshops using garnet.

The evaluation of an abrasive material for abrasive water-jet processes includes the following important parameters:

- *Material structure* - the chemical, physical and structural aspects of the abrasive material. Inclusions in the abrasive such as impurities have a tendency to be lighter and are usually ineffective for the cutting process, reducing the overall cutting ability of the abrasive.
- *Material hardness* - the hardness is decisive parameter for cutting efficiency. The hardness of an abrasive material is usually determined by Moh's hardness scratch test.
- *Mechanical behaviour* - the reaction of the abrasive grain on impact with the workpiece and the probability of the grain fracturing into smaller pieces.
- *Grain shape* - abrasive grain shapes can vary from near round and oval, to rectangular and triangular in shape. Abrasives with sharp, angular surfaces cut more effectively then other shapes.
- *Grain size distribution* - this is the range in the average size or diameter of the grain. It is important to have consistent grain size to maintain a uniform cutting action.

A markt report shows that most of the abrasive water jet workshops use garnet, followed by olivine mineral. In Table 2 are given mechanical properties and chemical composition of these two abrasive materials.

Garnet is hard, tough and inexpensive. A very small number of garnets are pure and flawless enough to be cut as gemstones. The majority of garnet mining is for massive garnet that is crushed and used to make abrasives. Garnet ranges in particle size from 0,2 to 0,5 milimeters. Different mesh (grit) sizes are used for different jobs. For example: #120 mesh – produces smooth surface; #80 mesh – most common, general purpose and #50 Mesh – cuts a little faster than #80, with slightly rougher surface.

Table 2. Mechanical properties and chemical composition of most common abrasive materials

	Garnet	Olivine
Mechanical properties		
Hardness [Moh's scale]	7 - 8	5.5
Specific weight [g/cm^3]	4.1	3.3
Grain shape	Edged	Angular
Chemical composition		
Silica (SiO_2) [%]	35.0	42.0
Iron (Fe_2O_3) [%]	31.0	7.0
Aluminium (Al_2O_3) [%]	21.0	0.5
Magnesium (MgO) [%]	8.0	48.0
Manganese (MnO) [%]	0.5	0.1
Calcium (CaO) [%]	1.5	0.1

4. EXPERIMENTAL STUDY ON INFLUENCE OF ABRASIVE FLOW RATE ON CUT SURFACE ROUGHNESS

Effects of abrasive feed rate on the cut surface roughness were experimentally investigated. The aim of this study is to investigate experimentally the quality of machined surfaces in terms of abrasive flow rate in AWJ-machined aluminium alloy (EN AW-6060). A series of water jet cutting experiments were conducted using a Bystronic abrasive water jet cutting system. It is equipped with a dual intensifier high output pump and a five axis robot positioning system, to cut 50 mm long slots on 700×300 mm test specimens of s = 6 mm and s = 10 mm thick.

The main process parameters varied in the cutting operation are the abrasive flow rate and cutting head feed rate (nozzle traverse rate). In this initial study the feed rate and abrasive flow rate was varied. For each level of the abrasive flow rate (q = 300 and 400 g/min), six levels of feed rates (v = 200, 300, 400, 500, 800 and 1000 mm/min) were used at a single level of water pressures of p = 400 MPa and a single level of impact angle of α = 90°. The other parameters were kept constant using the system standard configuration, that is, the water orifice diameter was d_0 = 0.30 mm, the abrasive nozzle diameter was d_A = 1.02 mm, the length of abrasive nozzle was l_A = 80 mm, and stand-off distance of z = 2 mm. The abrasive used was garnet sand with a mesh number of 80.

Whilst surface roughness is a common phenomenon in all machining operations, striation or waviness is a special feature of cuts with beam cutting technology, such as AWJ cutting. It is formed when the ratio between the available energy of the beam and the required energy of the destruction becomes comparatively small [7].

Abrasive water jet cutting belongs among complicated dynamical and stochastic processes with incomplete information about mechanism and side effects character. In AWJ cutting, the final cut surface roughness and the dimensional accuracy depend on the process parameters including the water pressure, the abrasive mesh number, the abrasive mass flow rate, the feed rate, and the orifice and abrasive nozzle diameters [8-9].

The cut surfaces produced by abrasive water jet cutting typically exhibit a smooth upper zone followed by a lower striated zone. Figure 3 shows the cut surface appearance obtained by cutting aluminium alloy using following abrasive water jet cutting parameters: water pressure of p = 400 MPa, material thickness of s = 10 mm, abrasive mass flow of q = 400 g/min, feed rate of v = 400 mm/min [10].

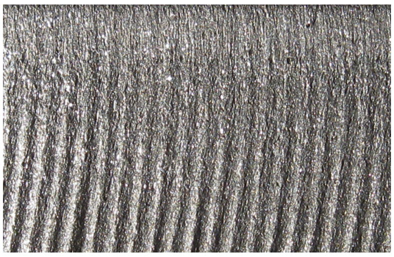

Figure 3. Cut surface generated in abrasive water jet cutting of aluminium alloy sample

In the present study, surface roughness as assessed by the centre-line average roughness Ra (according to standard ISO 4287:1997) was used in evaluating the cut quality. Surface roughness was measured at upper and lower region of the cut surface, and at the middle of the cut. These measurements were taken for each cut away from the ends of the slots to eliminate any effect of the cutting process at the jet entry and exit. The surface roughness was measured perpendicularly to the jet penetration axis, and parallel to the nozzle feed direction.

The cut surface has better quality at upper region (entrance area) of the jet. From the middle of the thickness downwards, the surface quality deterioration is observed. Surface quality deteriorates as the material thickness increase. As the penetration depth of abrasive water jet increases, the jet loses its energy due to the jet–material interaction, mutual particle impacts, etc. This situation results in rougher surface characteristics at the lower region of the cut surface. Figure 4 shows dependence of roughness average (Ra) at upper, middle and lower region of the cut surface of different feed rate values for material thickness of 10 mm.

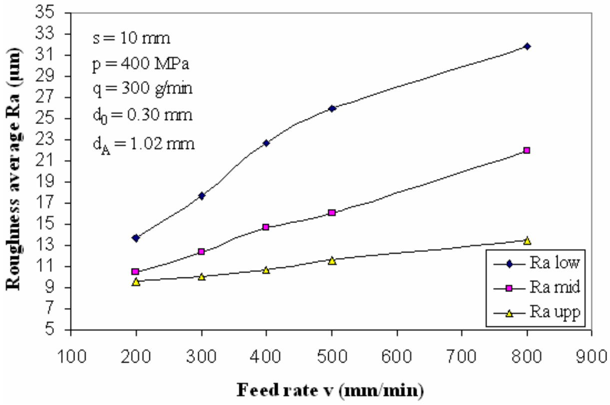

Figure 4. Roughness average Ra in dependence of feed rate when material thickness is 10 mm

The results of determining surface roughness at lower region of the cut surface with respect to the material thickness, feed rate and abrasive flow rate are graphically represented on Figure 5.

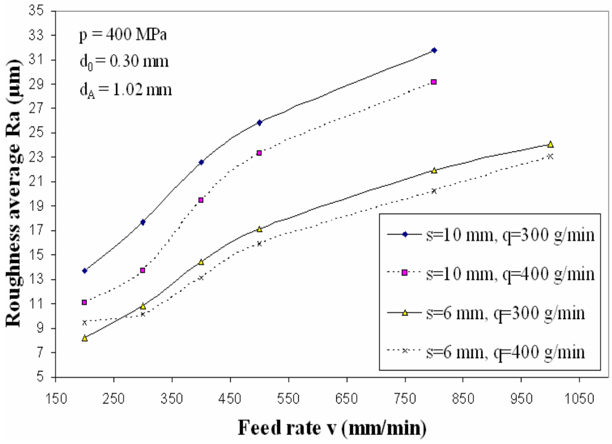

Figure 5. Roughness average Ra in dependence of material thickness, feed rate and abrasive flow rate

It can be noticed that the surface roughness significantly increases as the feed rate increase. This may be anticipated as increasing the feed rate allows less overlap machining action and fewer abrasive particles to impinge the surface, deteriorating surface quality [11].

The influence of abrasive flow rate is found to be less significant on surface roughness. The increase in the number of impacting particles contributes to the improved surface finish. A high number of abrasive particles involved in mixing increases the probability of particle collision that decreases the average diameter of the impacting particles, so the roughness decreases with an increase of the abrasive flow rate. These results are in accordance with the literature [12 - 14].

By literature review [15] the type of abrasive material, i.e. the hardness of the evaluated abrasives as a factor is not significant to average roughness by abrasive water jet cutting of aluminium (Fig. 6).

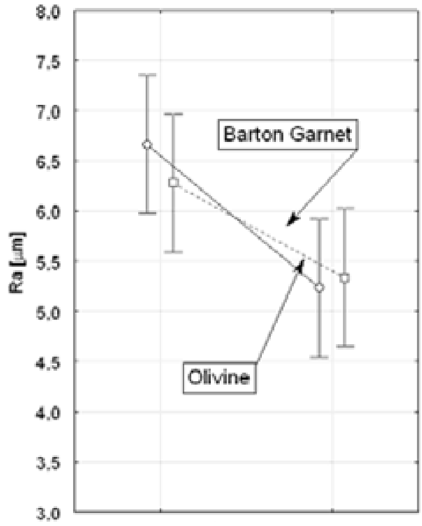

Figure 6. Plot of marginal means for abrasive flow rate of q = 300 g/min and q = 500 g/min, nozzle feed rate of v = 100 mm/min and two types of abrasive material

5. CONCLUSION

The flexibility and cool cutting characteristics of the abrasive water jet technique make it an important tool for cutting applications of new materials such as composites and sandwiched materials that are difficult to machine with traditional machining processes.

In abrasive water jet cutting the final cut surface roughness and the dimensional accuracy depend on the process parameters including the water pressure, the abrasive mesh number, the abrasive mass flow rate, the feed rate, and the orifice and abrasive nozzle diameters. Experimental study shows that, among others, the most important factors influencing the cut surface roughness of aluminium alloy are nozzle feed rate and abrasive mass flow rate.

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