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Advancement in Abrasive Water Jet Machining - A Study

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Abstract—The abrasive water-jet machining is an unconventional and eco-friendly technology used for hard and brittle material in industrial purpose. As the only cold high-energy beam machining technology, abrasive water-jet (AWJ) is one of the most rapidly developed techniques in material manufacturing industry and can be applied for wide variety of materials. Energy transformation is used to get pressurized jet and to have plastic deformation and fracture, results wear ratio is infinite. The study is focused on abrasive water jet lag info and recharging of abrasives and process parameter such as Influence of pressure, traverse rate, and abrasive flow rate, depth of cut and surface roughness and size and shape of abrasive particles and effectiveness of process to get higher surface finish. Advantageous and comparison will also be part of the concern study.AWJM technique has suitable for precise machining such as polishing, drilling, turning and milling. This technique has sought the benefits of combining with other material removal methods to further expand its applications.

Keywords*-AWJM; Abrasive; Jet lag; Process parameters*

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I. Introduction

Abrasive water jet (AWJ) cutting process is a powerful cutting tool, which main advantages are the absence of thermal influence and the ability to cut materials with high thicken [1]. Compared with other cutting processes, AWJ makes possible to cut a wider variety of materials, such as ornamental rocks, polymers, composites, wood, glass, etc. [2]. The use of AWJ cutting process has been increasing in several industry sectors, mainly because it is a technology which allows processing different types of materials and it has low thermal influence while performing the cut. The gemstone industry is increasingly using the AWJ process in artifact manufacturing because its flexibility allows obtaining a great variety of trimmed shapes, with an optimized use of the material than in conventional machining process. However, one of the main obstacles to the use of AWJ in the gemstone industry is it increases the final cost of the product, which in some cases makes it impossible to trade the artifacts manufactured by means of this process. In this context, this article presents a study regarding the influence of traverse speed and abrasive mass flow rate used for cutting gemstone by AWJ, as well as the surface finish resulting from changing these parameters in different thicknesses of material. AWJM cutting process as shown in figure 1.

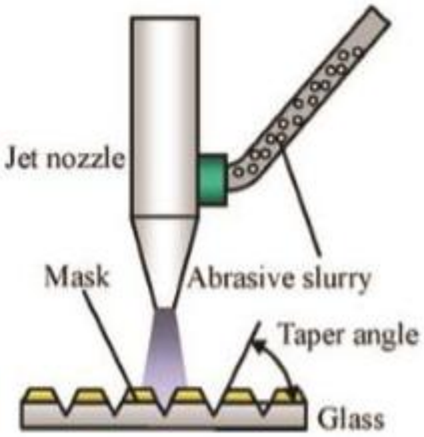

Fig. 1 Principal of AWJM

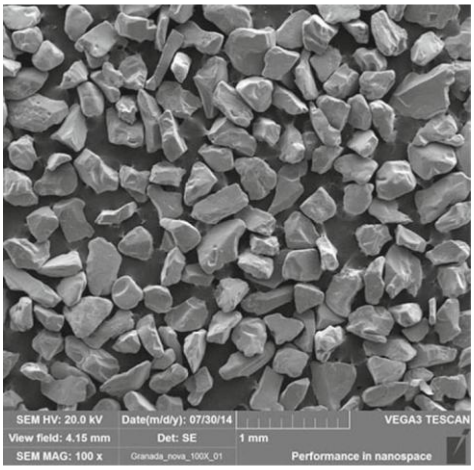

Fig.2 Abrasive used in the experiment: garnet with no. 80 mesh. Image obtained by SEM with ×100 magnifications

II. SURFACE FINISH MACHINED BY AWJ

Momber and Kovacevic [3] stated that there are several parameters which contribute to characterize the geometry, topography, and integrity of the AWJ-machined surface. The main features that will be analyzed in this work are surface roughness and striation marks since those parameters have an important impact on quality control of the machined pieces. As can be seen, the surface machined by AWJ has two distinct regions: a smooth surface (close to the jet entrance surface) and a rough surface (deep scars on the surface). Furthermore, it is possible to observe that the striation marks do not have a fixed angle but a curvature which increases as the jet moves away from the input surface. In general, the surface finish deteriorates with low values of abrasive mass. SEM image for abrasive use is shown in figure 2.

III. ABRASIVE WATER JET APPLIED ON ROCKS

The AWJ process is widely used to cut rocks, mainly because there is no overheat on the work piece. Thus, several studies are found in the literature about the application of AWJ on rocks. Engin [4] conducted tests with 42 different types of

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22 - 25

rocks, in most cases granite and marble derivatives. In this work, different process parameters were changed, in order to determine the cutting depth for a combination of parameters. The authors used the multiple linear and nonlinear regression methods to relate the cutting depth with process parameters and material properties. They concluded that the cutting depth decreases with the increase in the traverse speed and increases with increasing cutting pressure and abrasive mass flow rate. Moreover, the authors emphasize that the material properties that most affect the cutting depth are hardness, density, and abrasion resistance.

IV. ABRASIVE MATERIAL

According to Momber and Kovacevic [3], the main materials used as abrasives in AWJ process are the garnet and olivine minerals. shows a scanning electron microscope (SEM) image of the abrasive used in experiments (garnet, no. 80 mesh), where it is possible to observe the irregular shape of the grains. As reported by Olsen [5], the abrasive is the element responsible for the major cost in AWJ process, accounting for 30 to 36 % of the total cost of the process. This value is highly variable depending on transportation costs and disposal. According to Babu and Chetty [6], the cost of the abrasive can reach up to 75 % of the operative expenses related to the AWJ process or may become even higher when added to the cost of the material disposal. In the region where this study was performed (Rio Grande do Sul, Brazil), the cost of the AWJ process is around BRL 150 to BRL 200 per hour, while the price of the abrasive (garnet, no. 80 mesh) is around BRL 2000 per ton. The AWJ is a good alternative to traditional machines and technologies for processing natural stone, but the cost of the abrasive material has restricted its use. However, depending on the type of processed mineral, 66 to 92 % of the used abrasive is still able to be re-used.

V. ABRASIVE MATERIAL

In water jet-guided laser process (Fig. 3a, 3b), the laser beam can be totally reflected on the wall of water jet and guided in the work-piece without taking the focus length into consideration. Thus, the working range is expanded dramatically; in the experimental research of Porter et al. [7], regardless of the variety of laser parameters, jet pressure, and nozzle diameter, the value of 50 mm was found to be a fairly reliable upper limit to the cutting distance for both normal and inclined surfaces [7]. Hence, the control of Z axis is unnecessary, and V-grooving default can be eliminated by changing the distribution of heat fundamentally. Thus, work-

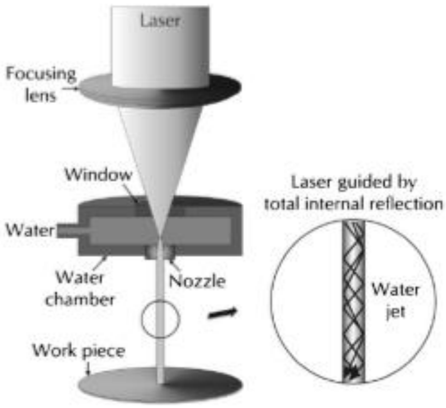

Fig. 3aWater jet guided laser machining

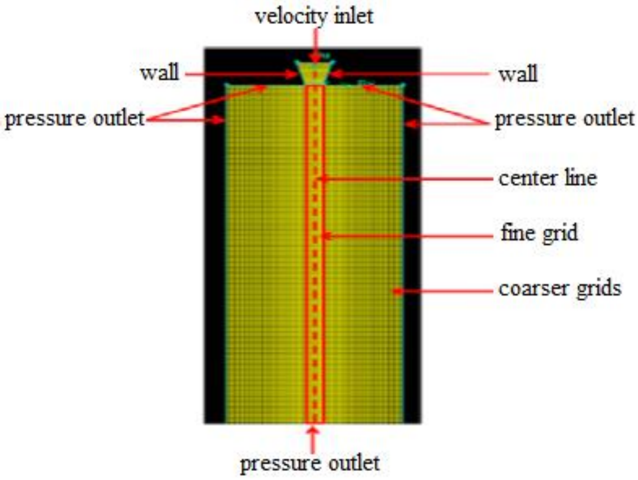

Fig. 3bWater jet guided laser machining with water jet

pieces could be machined with high dimensional accuracy and surface quality, especially in processing a thin and sensitive material [8–10].If the critical Reynolds number of a 30-μm-diameter nozzle jet is around 900 in room temperature, it is easier to obtain stable jet in a laminar flow than turbulence flow in atmosphere. Moreover, the longest stable length in laminar flow (obtained around a jet exit velocity of 6 m/s) is more than two. The stable length curve of laminar flow and turbulence flows are shown in figure 4a and 4b.

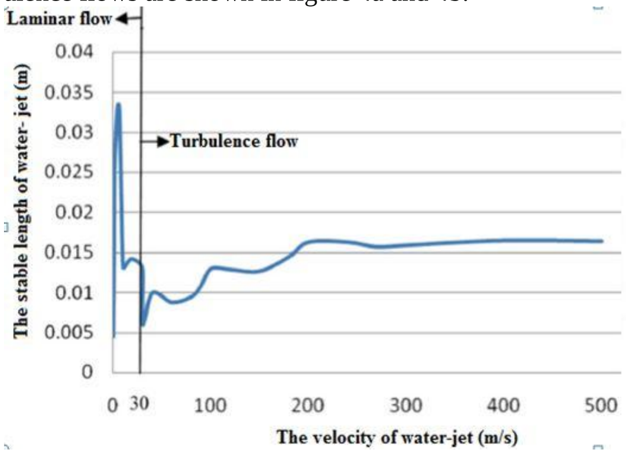

Fig. 4aStable length curve and velocity of water jet

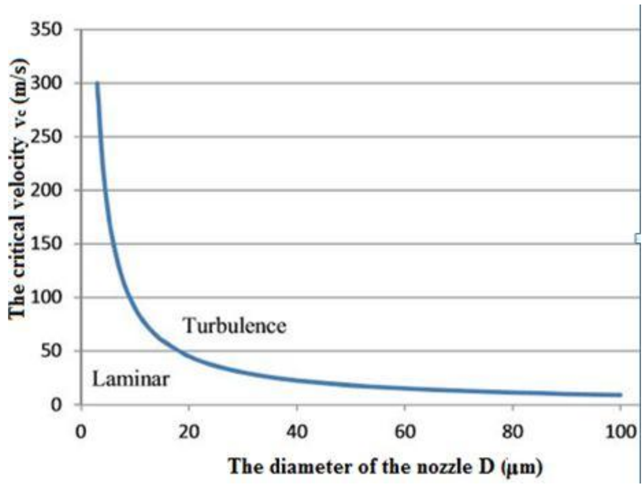

Fig. 3b Velocity and diameter of nozzle for laminar/ turbulence flows

VI. IMPROVEMENT OF ABRASIVE WATER JET MACHINING ACCURACY FOR TITANIUM AND TINB ALLOY

Despite its excellent physical and mechanical properties, titanium is very difficult to be machined. It has a very low thermal conductivity, which increases the temperature on the borderline during machining processes and so it decreases lifetime of the used tools. By these reasons, AWJ is increasingly applied for titanium and titanium alloy machining. Therefore, the importance of a proper modeling of the machining process and its control increases rapidly [11–13]. However, a satisfactory description of the interaction between AWJ and titanium alloys has not been completed yet. Nevertheless, AWJ can be used for material cutting and also for turning, milling, grinding and polishing when applying suitable parameters. AWJ machining is commonly considered to be a process with no thermal influence on material, since the machining tool applied to break mechanical bonds in materials is only the high energy of water jet doped by abrasive particles. Moreover, the liquid carrying the abrasive particles acts simultaneously as an effective coolant. Another great advantage of AWJ technology is making the waste material recycling easier (no oil contamination of the removed material comparing with e.g. milling–shaping).

The values of declination angles on the striations generated during abrasive water jet cutting of titanium and titanium–niobium alloy were experimentally measured and theoretically calculated. The results showed a good correlation of both the analysed materials. However, the experimentally determined value of the striation declination angle exceeded the ideal theoretical value for lower traverse speeds. This effect can be explained by the fact that outer layers of the abrasive water jet contain bigger and slower particles. Due to their big size and the consequent relatively large inertia, these particles penetrate relatively deep into the material.

VII. ACCURACY LAVELIN JET LAG

As mentioned above, jet lag is a very important character of AWJ. Catching accurate jet lag information would expand AWJ's application greatly. This paper reviewed the research progress made in jet lag and cutting front in recent years. The cutting process was studied with a visualization experiment, and main geometry deficiencies caused by jet lag was discussed in detail. A new method for tracking the accuracy jet lag information in nontransparent material has been presented. In order to obtain jet lag information accurately, a series of actions have been taken, which include stopping cutting process when traverse speed is in a stable phase, controlling abrasive feeding process accurately, and measuring jet lag accurately. Based on those actions taken, obtaining accurate jet lag information is feasible. The measurement results showed that jet lag can be characterized by parabolic curves very well.

The investigation on various process parameters of AWJM shows that MRR increases with increase in water pressure, but the major drawback is that the surface roughness and sub-surface damage increases with increase in pressure. Types of abrasives and traverse speed also effects the various quality parameters of work part. A comparative analysis and a summary of results as shown in table 1.

TABLE I. EFFECT OF PROCESSING PARAMETERS ON PROCESS OUTPUTS IN AWJM

Process parameters	Quality parameters							
	Effects	Surface roughness	MRR	Kerf width	Top width of cut	Bottom width of cut Taper	Taper of cut	Width of cut
Pressure	Increases	↑	↑	↑	↑	↑ Less extent	↓	↑
	Decreases							
Traverse speed	Increases	↑						
	Decreases							
Stand-off distance	Increases		↑ Less extent		↑	↑ Less extent	↑	↑
	Decreases							
Abrasive flow rate	Increases	↓						
	Decreases							
Work feed rate	Increases						↑	↓
	Decreases							

VIII. CONCLUSIONS

The main conclusions observed in this study are as follows:

- The increase in the depth of the jet entrance surface is the most significant factor for the measured parameters.
- The traverse speed is more significant than the abrasive mass flow rate in both output parameters measured in this experiment (striation marks and surface roughness). The abrasive mass flow rate showed less influence compared to the other parameters, and its influence becomes more significant only at greater depths from the jet entrance surface (>5 mm).
- The depth of cut increases significantly with up to 40% recharging and marginally thereafter, both with test sample and mesh size 80 sample. Hence, this level of recharging is recommended.

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