

Maximum Depth of Cut and Other Performance Characteristics of the AWJ Oscillation Cutting Process of Ductile Materials

by

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Abstract

The nozzle oscillation technique has been shown to enhance the performance of abrasive waterjet (AWJ) cutting. However, the fundamental reasons behind these process improvements have not been well established. A visualisation, as well as a parametric study of the cutting process, was conducted in an effort to determine these reasons and provide a model for the process. A transparent material, plexiglass, was used for the conducted visualisation experiments, while ductile materials, mild steel and aluminium, were used for the parametric studies. The results of the parametric study showed that the best improvements are realised when the nozzle is oscillated at relatively small angles and high frequencies of oscillation. The visualisation study shows that the improvements are largely due to the reduction in the general impact angle at higher depth of cut and minimisation of the residence time of the jet with reduced energy at the bottom of the kerf.

1. Introduction

Abrasive water jet cutting is a rapidly developing technology that is used in industry as a comprehensive tool for various applications, including plate profile cutting and machining of a range of materials. The technology is superior to most other traditional and non-traditional cutting tools and techniques used in industry because of the absence of heat-affected zones in the materials processed, its cost effectiveness, and the significantly smaller harmful environmental impacts experienced. It is particularly indispensable for processing composites and other advanced materials where limiting heat flux into the workpiece is critical to the maintenance of structural integrity and other properties of the target material. However, the application of this technology has been limited by the persistent presence of surface irregularities such as striations and roughness on the cut-wall surface of materials processed.

The striations on the cut wall surface of products are common phenomena to all cutting techniques that use a high-energy concentrated beam to cut materials such as laser cutting or plasma arc cutting. However, the striations on the sidewall of materials cut using AWJ cutting exhibit a characteristic feature that is unique to this cutting process [1,2]. This characteristic feature is the cut surface topography that constitutes of a distinctly upper smooth zone and a striated or wavy lower zone as shown in Figure 1. In addition, the surfaces also exhibit roughness of a random nature that is superimposed on these wavy patterns.

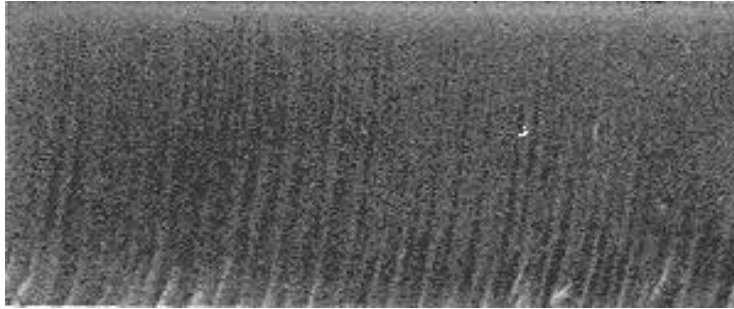


Figure 1 - Typical appearance of the upper smooth zone and the lower striated zone of a surface of product processed using Abrasive waterjet cutting.

The methods proposed for overcoming these problems include multipass cutting [3], angling the jet forward in the cutting plane [4,5] and cutting head oscillation [4,6]. Of these techniques, the cutting head or nozzle oscillation technique, which was introduced by Veltrup [7] and successfully used in AWJ cutting by Siores et al. [4] and Lemma et al. [6], has been found to be an effective way in increasing the performance of AWJ cutting. Although this technique has been used for cutting a number of materials including composites with good results, a continued development, including a predictive model for setting up machine process parameters, is indispensable to make the technology widely accepted in industry.

2. Industrial Implications

Improvements in abrasive waterjet cutting technology results in significant gain in productivity in industry and also make the process suitable for adaptation for new applications than is currently being used. To this end, some of the characteristics of the cutting process that have been identified to be barriers to its wider application are investigated. The most significant problems associated with the technology identified are the formation of striation on the cut-wall surface and the limited depth of cut that can be achieved with using the cutting process. Oscillation cutting have shown a significant promise in overcoming these difficulties associated with the use of AWJ technology as it stands currently. In oscillation technique, the cutting head is moved in an angular direction parallel to the cutting direction (in the cutting plane) at a given

angle and frequency of oscillation. It has been used for cutting a number of materials including composites with good results.

3. Brief Background Review

Hashish [8] proposed a general erosion process model in which the cutting process proceeds in a cyclic manner with steady material removal up to a critical depth h_c followed by the formation and removal of steps as the cutting depth increases. Below this critical depth, the material removal process is unsteady, resulting in the formation of striations or waviness on the wall of the cut surface. According to this model, the removal process for ductile materials is mainly due to micro cutting at the top of the workpiece and plastic deformation that takes place at the bottom of the kerf. Figure 2 shows the primary and secondary cutting zones where the wear cutting and deformation cutting modes respectively take place.

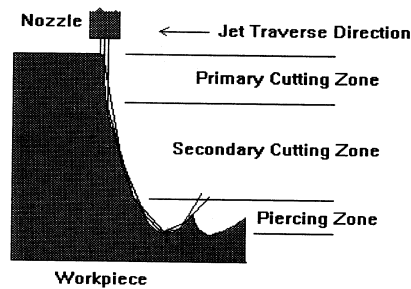


Figure 2 - The three zones recognized in abrasive waterjet cutting process [2].

In contrast, Arola and Ramulu [9] propose a material removal and striation formation model based on the existence of a critical kinetic energy of the high-speed slurry flow that has to undercut to produce the striations on the cutting surface. The jet with this lower energy will be deflected in angular direction at higher depth resulting in striations on the cut surface [9]. They also suggest that the material removal process, although it can be different for different materials, is independent of depth of cut for a given material.

The material removal process and striation formation mechanism proposed by Arola and Ramulu [9] is also supported by the research work [6] carried out in this project. In addition, oscillation cutting that is being investigated here have shown a promise for overcoming both these problems associated with the use of AWJ cutting.

4. Experimental Setup and Procedure

The experimental set-up consisted of a high pressure intensifier pump and a 6-degrees of freedom robot positioning the cutting head, a receiver and an abrasive feeding and mass flow monitoring system. The intensifier was capable of supplying water up to a maximum pressure of 55,000 psi (380 Mpa), while the robot was to position and move the nozzle to carry out the cutting. A high-speed video camera was used to record and view the cutting process on plexiglass samples

5. Results and Discussion

A regression analysis was applied on the experimental data obtained from both the Box-Wilson or Central Composite Design (CCD) matrix and on the additional data obtained from the one factor at a time (OFAT) experiments that was conducted for mild steel and aluminium samples to gauge the effects of the various levels of operating parameters used in oscillation cutting. The results of these analyses yield the following expressions:

$$D_{max} = 8.22 + 0.0569p - 7.43m - 0.002sd - 6.34S - 0.736\alpha + 0.715\xi \quad (1)$$

for mild steel samples and

$$D_{max} = 9.01 + 0.067p - 14.3m - 0.281sd - 2.82S - 0.050\alpha + 0.269\xi \quad (2)$$

for aluminium samples, where D_{max} is the maximum depth of cut in mm, p is pump pressure in MPa, m is mass flow rate in kg/min., sd is stand off distance in mm, S is jet traverse speed in mm/s, α and ξ are the oscillation angle in degrees and frequencies of oscillation in Hz, respectively. The adjusted R-squared values for these regressions were 81.6% and 85% for mild steel and aluminium samples respectively with a confidence interval of 95 percent.

The regression results indicate that a higher maximum depth of cut can be attained when the samples are processed with comparatively higher frequency and lower angle of oscillations as well as higher waterjet pressure and lower mass flow rates. Figure 3 and Figure 4 show the results of the experiments conducted using parameter settings that were on both sides of the regression prediction for the optimum performance. The depth of cut is comparatively small when the oscillation frequency is set below 6 Hz and angle of oscillation is set above 3 degrees.

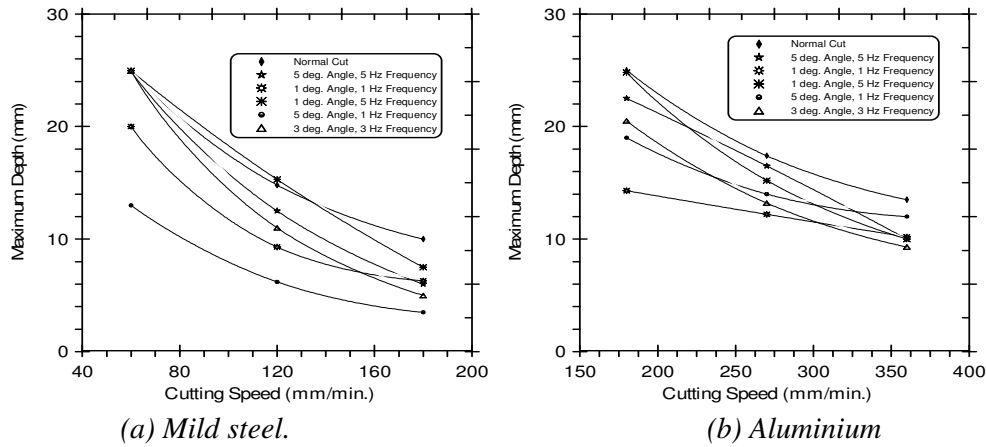


Figure 3 - Oscillation and normal cutting results without appropriate parameter settings (water pressure = 310 MPa, stand off distance = 2 mm, and mass flow rate = 0.272 kg/min).

In addition, visual examinations show that the products processed by superimposing nozzle oscillation exhibit a better surface finish compared to those processed using normal AWJ cutting. Figure 5 shows automatic traces of the jet/particle interface profile for normal and oscillation cutting taken at a cutting speed of 102 mm/min. The figure shows the slopes of the successive traces of the jet/particle interfaces for the head oscillation cutting technique are much more steeper than that of normal AWJ cutting. This is because, unlike normal AWJ cutting, nozzle oscillation reduces jet/particle interface trailing at higher depth of cut by allowing fresh abrasive waterjet to come into contact with these surfaces, thus increasing the rate of erosion.

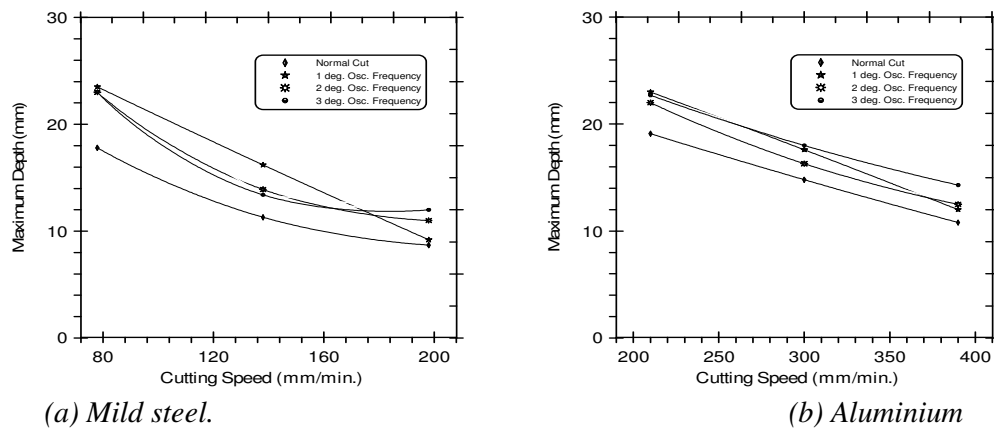


Figure 4 - Results of oscillation and normal cutting with optimised parameter settings (water pressure = 345 MPa, mass flow rate = 0.136 kg/min, stand off distance = 2 mm, frequency = 10 Hz).

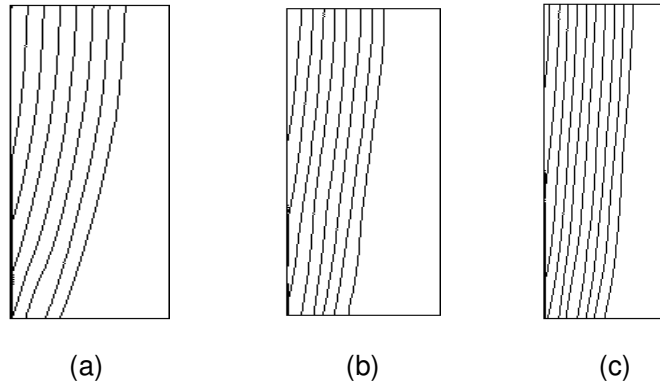


Figure 5 - Traces of the jet/particle interface in (a) straight cutting, (b) oscillation cutting with 2° and 5 Hz of oscillation, and (c) oscillation cutting with 2° and 8 Hz of oscillation. (traverse speed = 102 mm/min).

These successive traces of solid/abrasive jet which were collected from the images of the cutting process taken with a high speed digital camera as well as the maximum depth of cut achieved with a set of machine and operating parameters that were found from the parametric experiments on ductile materials, mild steel and aluminium, will now be used for constructing a mathematical model. The construction of the model is currently under progress which, when completed, will furnish a more complete understanding of the cutting process and its underlying material removal mechanisms as well as a tool for setting up machine and process parameters that can be used in industry.

6. Conclusions

The study indicates that improvements in the cutting performance can be achieved by using oscillation cutting by correctly selecting the process and oscillation parameters. The results also indicate that:

- Higher depth of cut and surface quality can be achieved when cutting with comparatively higher frequency of oscillation and lower angle of oscillations.
- The optimum angle of oscillation is in the range 1 to 3 degrees while the highest frequency of oscillation that can be used effectively is limited to 10 Hz.
- The results found here assist in the development of a general model for the cutting process

7. Acknowledgements

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8. References

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