Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 34(2), ss. 1-8, Haziran 2019
*Çukurova University Journal of the Faculty of Engineering and Architecture, 34(2), pp. 1-8, June 2019*

# A Study on the Effect of Traverse Speed on Geometric Tolerances in Abrasive Waterjet Drilling of Aa7075 Aluminium Alloy

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*Geliş tarihi: 17.01.2019* *Kabul tarihi: 28.06.2019*

## Abstract

In this study, the effect of nozzle traverse speed on the geometric tolerances in the drilling of AA 7075 aluminum alloy by abrasive water jet was investigated. Holes were drilled with a diameter of 10 mm using 10 different nozzle traverse speeds (10, 16, 24, 34, 45, 55, 65, 75, 90 and 110 mm/min) and the other parameters were kept constant. Circularity and cylindricity deviation of the holes drilled using different nozzle traverse speeds was measured using a CMM. It was found that the increase in nozzle traverse speed results in increased deviation values from circularity and cylindricity. As a result, increased nozzle traverse speed reduces the amount of abrasive contacting the unit surface and the cutting process does not occur in accordance with the desired geometry.

**Keywords:** Abrasive water jet, Hole drilling, Cylindricity, Circularity

# AA 7705 Alüminyum Alaşımının Aşındırıcı Su Jeti ile Delinmesinde Traverse Hızının Geometrik Toleranslara Etkisinin Araştırılması

## Öz

Bu çalışmada, aşındırıcı su jeti ile AA7075 alüminyun alaşımının delinmesinde nozul travers hızının geometrik toleranslara etkisi araştırılmıştır. Delikler 10 farklı nozul travers hızı (10, 16, 24, 34, 45, 55, 65, 75, 90 ve 110 mm/dak) kullanılarak 10 mm çapında delinmiş ve diğer parametreler sabit tutulmuştur. Farklı nozul travers hızları kullanılarak açılan deliklerin dairesel ve silindiriklik sapması CMM kullanılarak ölçülmüştür. Nozul traverse hızı artışının silindiriklik ve dairesellikten sapma değerlerinin artışına neden olduğu tespit edilmiştir. Sonuç olarak, artan nozul traverse hızı birim yüzeye temas eden aşındırıcı miktarını azaltmakta ve istenilen geometri doğrultusunda kesme işlemi gerçekleşmemektedir.

**Anahtar Kelimeler:** Aşındırıcı su jeti, Delik delme, Silindiriklik, Dairesellik

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## 1. INTRODUCTION

Machines and mechanisms consist of several elements. It is of utmost importance for these elements to be of the size and geometry suggested in the engineering drawing of the machine or mechanism in question. Moreover, each one of these elements can be manufactured in a certain tolerance range. If not manufactured in accordance with the size and geometric tolerances noted in the engineering drawing, these elements would lead to issues in the assembly or in the proper functioning of a machine. Furthermore, these engineering issues are associated with shorter machine or mechanism life and increased cost if these parts are scrapped. Therefore, there is an ongoing interest of academia and manufacturers to seek the ideal production methods in order to minimize the costs and to create quality products. Abrasive water jet (AWJ) machining is one of these production methods which has recently found widespread use in the industry. AWJ machining is the number one choice for the machining of workpiece which requires total absence of heat deformation during this process. AWJ can be defined as cutting materials with the help of erosive effect of high-pressure water spray and micron-sized abrasive particles [1,2].

Abrasive water jet cutting involves machining of a workpiece using fine abrasive material mixed with water and sprayed on the workpiece at high pressures [3,4]. The fact that abrasive water jet cutting is a non-thermal cutting process, its high machining performance and surface integrity of the workpiece are significant features of this process [5,6]. Previous studies used abrasive water jet and abrasive air jet cutting and explored the properties of the micro holes drilled using these techniques. In general, these studies focused on the optimization of cutting parameters. Literature review showed that parameters such as traverse speed, standoff distance, abrasive mix ratio, depth of cutting, etc. affect the surface quality of the workpiece, i.e. kerf formation. Nevertheless, there was no study on the effects of these parameters on hole geometry. Literature reports on abrasive water jet technology suggested that increased abrasive particle hardness is an important parameter in terms of depth of cutting and that the use of coarse-grained abrasive material results in higher surface roughness. Moreover, it was found that the use of fine-grained abrasives results in better surface roughness when compared to coarse-grained abrasives [7,8]. In AWJ cutting, nozzle traverse speed and depth of cutting lead to deformation at the water drainage zones, while abrasive flow rate increases the material removal rate. Increased nozzle traverse speed and standoff distance results in increased surface roughness, and surface roughness improves with increased amount of abrasive used [9-11].

Hole drilling process is performed with a stationary nozzle when the diameter of the hole being drilled is smaller than that of the nozzle while the standoff distance is reduced during the process when the diameter of the hole being drilled is larger than that of the nozzle. Abrasive water pressure is a significant parameter of hole drilling process [12]. For blind holes drilled using abrasive air jet (AAJ), air jet pressure and abrasive flow rate play an important role in the formation of convex, flat, and concave hole surfaces. Larger nozzle nipple diameter, standoff distance and air pressure are important for ideal kerf formation in the holes [13,15]. With increasing workpiece thickness, water jet pressure decreases which leads to poor surface quality and increased machining time. It was found that water jet orbit curve formation increases in the kerf when traverse speed is increased and the angle between the axis of nozzle and abrasive water orbit increases. This angle is further increased with increasing material thickness and material hardness [16].

Increased abrasive ratio leads to increases in the depth of micro holes along with their diameter; and the entry kerf is decreased with the increasing traverse speed. Increase in standoff distance and material flow rate, on the other hand, results in a wider entry kerf. In addition, increased depth of drilling is associated with reduced particle kinetic energy which in turn results in reduced hole diameter, while the hole diameter grows with increased standoff distance [17-21]. Previous studies reported that parameters such as traverse speed, standoff distance, material thickness, material hardness, abrasive particle hardness, abrasive flow rate, abrasive particle size, and abrasive water jet pressure affect the results produced in hole drilling with AWJ cutting. This study aims to explore the effect of the changes in traverse speed on the circularity and cylindricity of the generated hole when the diameter of the hole being drilled with AWJ is larger than that of the nozzle. Using AWJ, 10 mm diameter holes were drilled on workpiece prepared of AA7075 aluminium alloy and it was aimed to find the ideal nozzle traverse speed.

## 2. MATERIAL AND METHOD

In this study, 10 mm diameter holes were drilled on material made of AA 7075 aluminium alloy with 20 mm thickness and 60 HRC hardness using a USEL INTERJET CNC WJ 2040 abrasive water jet (Figure 6).

This AWJ machine comes with a KMT VI STREAMLINE including a 4,000 bar pump (3,800 bar in practice) and a work area of 2,000 x 4,000 mm. 10 different cutting speeds were used based on the recommendations of FAGOR, a software company which manufacture the automated abrasive transfer system and the CNC control unit of the AWJ machine. Sand rate (%50), cutting height (2 mm), nozzle diameter (1.02 mm), orifice diameter (0.27 mm) parameters were held constant and only the traverse speed was changed in the tests (Table 1).

Garnet powder with an average size of 80 mesh was used in the experiments as a material commonly used in the industry. As powder size is not exactly the same in every batch, a new batch was used to fill the powder container of AWJ for each cutting cycle. Workpiece was fixed on the machine's work area using a gauge in order to ensure the nozzle is perpendicular to the workpiece surface (AA7075). In hole formation, nozzle started from the center of the hole and formed the hole. A total number of four holes were drilled for each cutting speed using the same cutting parameters.

HEXAGON DEA Coordinate Measuring Machine (CMM) was used to measure circularity and cylindricity values of these four holes for each parameter set. Circularity and cylindricity measurements were performed at depths of 2 mm, 10 mm, and 19 mm from the upper surface of each hole. Arithmetic means of these four measurements were taken for each nozzle traverse speed. Additionally, images of the entry and exit holes were taken using AMCAP-Direct Show Video Capture Sample v. 9.016. Using these images, deviations from circularity were found (Figure 2).

The graphics were produced for the deviations from circularity using the (CMM) coordinate measuring machine.


**Figure 1.** USEL INTERJET CNC WJ 2040 machine, abrasive sand and workpiece

**Table 1.** Machining parameters

| Material Al -7075 | Cutting Speed (mm/min) | Cutting Time (min:sec:ms) |
|---|---|---|
| 1st Test | 10 | 32:31:60 |
| 2nd Test | 16 | 20:24:52 |
| 3rd Test | 24 | 1:33:53 |
| 4th Test | 34 | 9:37:65 |
| 5th Test | 45 | 7:56:09 |
| 6th Test | 55 | 5:08:03 |
| 7th Test | 65 | 4:58:08 |
| 8th Test | 75 | 4:20:05 |
| 9th Test | 90 | 3:54:09 |
| 10th Test | 110 | 2:59:07 |

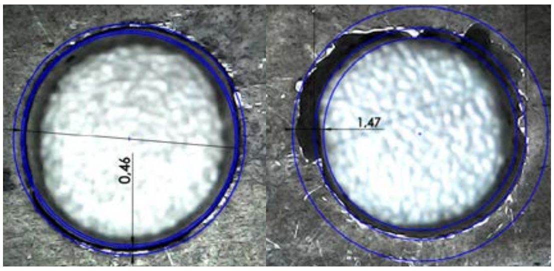


**Figure 2.** Circularity measurements of entry hole and exit hole

## 3. RESULTS AND DISCUSSION

In this study, holes were drilled on a workpiece prepared of AA7075 aluminium alloy with 10 different nozzle traverse speeds using abrasive water jet. Deviations in circularity and cylindricity of these holes were then measured using a CMM and these deviations are graphically shown in Figure 3.

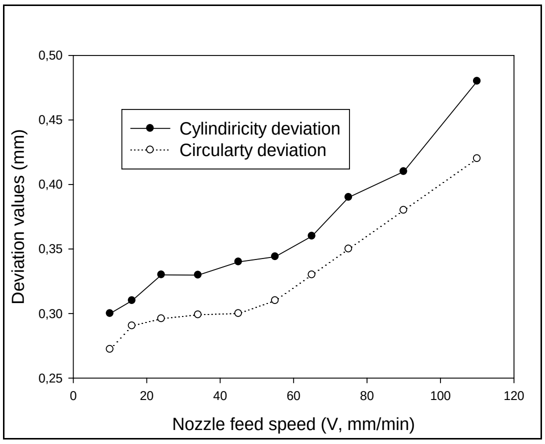


**Figure 3.** Comparison with CMM measurements

A closer look at the graphics in Figure 3 shows that deviations in circularity and cylindricity increases with the increased traverse speed. This can be accounted for by the circular motion precision of the nozzle when the diameter of the hole being drilled is larger than that of the nozzle and decreasing amount abrasive material per surface unit. Decrease in the amount of abrasive material per unit surface would make it harder for the AWJ to cut. As the decrease in the amount of abrasive material per unit surface leads to a faster decrease in the kinetic energy of the particle, abrasive water jet pressure drops [1-11].

At lower traverse speeds, the amount of abrasive material cutting the unit surface is higher than the amount of abrasive material cutting the unit surface at higher traverse speeds. Increased traverse speed means that the amount of abrasive material cutting the unit surface is lower, that it will be harder to cut the material, and the pressure of the water jet will drop between the entry and exit holes. This would make it harder for the nozzle to cut around the hole with respect to the desired geometry. As a result, deviation from circularity and cylindricity of the holes increases with increasing traverse speed. Diagrams in Figure 4 are further proof of this finding.

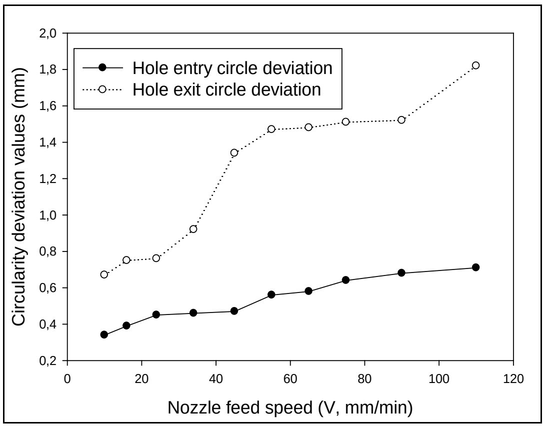


**Figure 4.** Comparison of deviations from circularity

A closer look at Figure 4 shows that the water jet pressure decreases between the entry hole and exit hole as deviation from circularity of the entry hole is lower than that of the exit hole. Moreover, the difference between the deviation from circularity of entry hole and exit hole from traverse speed of 10 mm/min to 24 mm/min only increases with further increase in traverse speed. This can be accounted for by further decrease in the water jet pressure at the exit hole as nozzle traverse speed increases. Decrease in the water jet pressure leads the particle to lose its kinetic energy and its hardness earlier which makes it harder to form the desired geometry. The images of entry hole and exit hole given in Figure 5 and Figure 6 are further proof of this mechanism.

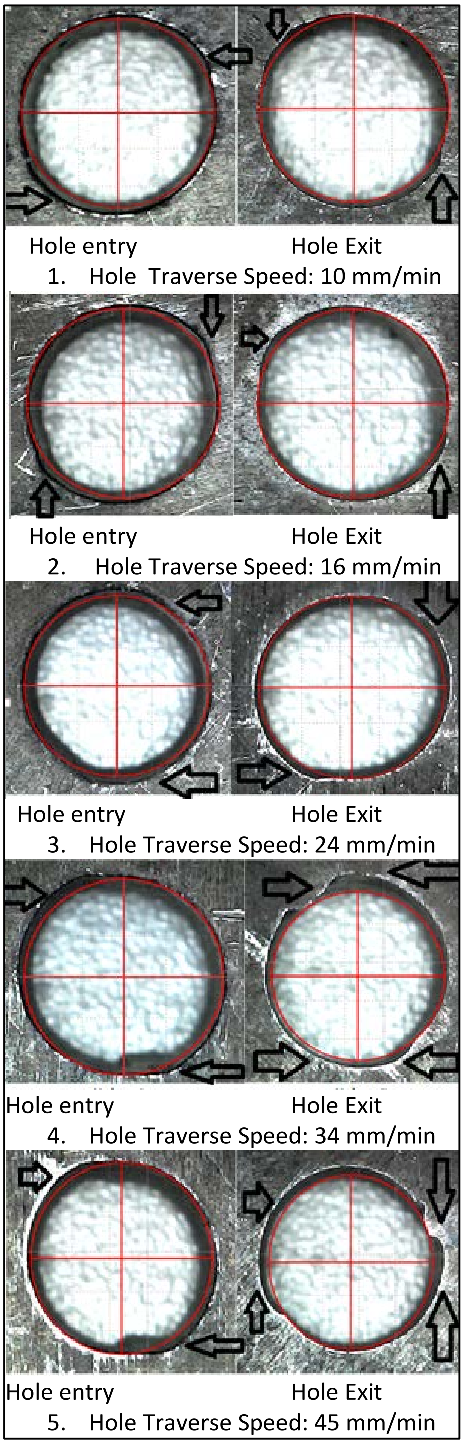


**Figure 5**. Images of the entry hole and exit hole with respect to traverse speed

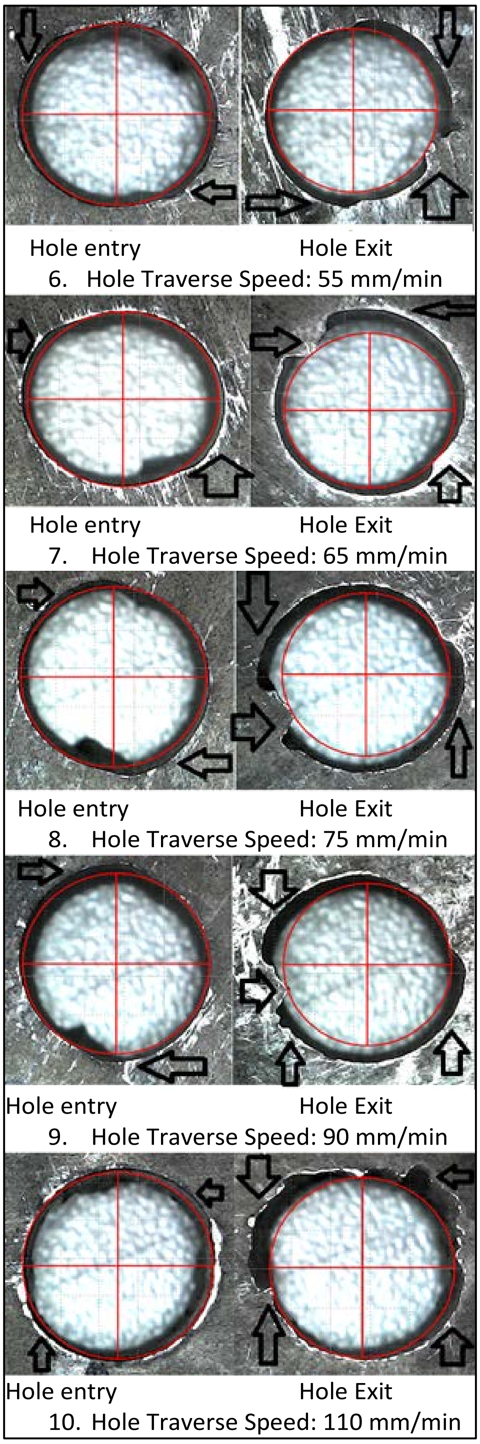


**Figure 6**. Images of the entry hole and exit hole with respect to traverse speed

A closer look at the images given in Figure 5 and Figure 6 shows that the increase in traverse speed led to deformations at the entry hole ring and exit hole ring. It was observed that the scale of the deviation from circularity was increased between traverse speeds of 10 mm/min and 16 mm/min. The deviation was further increased when the traverse speed was set to 24 mm/min.

This can be accounted for by the decreased amount of abrasive material eroding a unit surface at unit time when the traverse speed was increased and resulting decreased in water jet pressure and abrasive hardness around the exit hole surface. The fact that deviation from circularity was extremely high when the traverse speed was set to 110 mm/min is another proof of this mechanism. Cutting process involves the erosion caused by the speed of the nozzle parallel to the material surface (traverse speed) and the speed of the abrasive particle perpendicular to the workpiece surface. The speed of nozzle which is parallel to the material surface defines the amount of abrasive jet applied to the surface. Any increase in the nozzle traverse speed leads to an increase in the water jet cutting curves on the surface [16,17,23].

Accordingly, the amount of abrasive material performing the cutting of unit surface at unit time decreases when the traverse speed is increased from 10 mm/min to 16 mm/min. Moreover, in addition to the reduced amount of particles cutting a unit surface with increased traverse speed, the water jet pressure is reduced if the distance between entry hole and exit hole is longer. The reason behind this phenomenon is that the increased amount of jet curves with increased traverse speed requires abrasive particles to travel a longer distance. Thus, with the increased traverse speed, not only the amount of cutting particles is decreased but also the particles lose their hardness and kinetic energies due to the increased distance traveled which in turn increase the deviation from circularity.

Comparison of the machining times given in Table 1 and entry hole and exit hole images given in Figure 5 brings insight to these findings. The deviation from circularity was 0.34 mm for the entry hole and 0.67 mm for the exit hole when the traverse speed was set to 10 mm/min. On the other hand, the deviation from circularity was increased to 0.39 mm for the entry hole and 0.75 mm for the exit hole when the traverse speed was set to 16 mm/min. And, the deviation from circularity was increased to 0.45 mm for the entry hole and 0.76 mm for the entry hole when the traverse speed was set to 24 mm/min. The increase in deviation from circularity at entry hole and exit hole was increased proportional to the increase in traverse speed. However, the deviation from circularity at entry hole was 0.47 mm when the traverse speed was set to 45 mm/min and a normal increase was observed. The deviation from circularity at entry hole, on the other hand, was 1.34 mm. Further increases in traverse speed resulted in similar increases. The deviation from circularity was 0.71 mm for the entry hole and 1.82 mm for the exit hole when the traverse speed was set to 110 mm/min. The deviation from circularity of entry hole found for the traverse speed of 10 mm/min was almost doubled for the traverse speed of 110 mm/min, while these increases were 3-fold for the exit hole. These findings suggest that the amount of abrasive particles cutting a unit surface and particle hardness decreases as traverse speed increases and that the water jet pressure decreases around the exit hole due to increased jet cutting curves on the surface. As a result, the desired hole geometry cannot be manufactured when traverse speed is increased.

## 4. CONCLUSION

A set of holes were drilled on a workpiece prepared of AA7075 aluminium alloy with 10 different nozzle traverse speeds using abrasive water jet and the deviation from circularity and cylindricity of these holes were analyzed based on the change in traverse speed.

- It was found that the increase in nozzle traverse speed has a significant impact on deviation from circularity and cylindricity.
- The lowest deviation from circularity and cylindricity was found using the lowest nozzle traverse speed, 10 mm/min, and the highest deviation from circularity and cylindricity was

found using the highest nozzle traverse speed, 110 mm/min.

• Moreover, it was observed that the deviation from circularity was increased more in exit holes when compared to entry holes.

• Deviation from circularity was negligible for traverse speeds of 10, 16 and 24 mm/min, however the deformation was visually observable with traverse speeds of 34, 45, 55, 65, 75, 90 and 110 mm/min. The geometry of the exit hole obtained with traverse speed of 110 mm/min was the sample with the highest deformation

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