Potential studies on Abrasive Water Jet Turning Studies

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Abstract: Abrasive Water-jet Technology (AWJT), due to its flexibility in cutting materials with almost any material properties is widely used in various manufacturing operations. The main advantages of AWJT will provide elimination of thermal effects during the process, and minimal stresses. Since it is a cold working process, AWJT is widely preferred when heat-affected zones are to be avoided. AWJT also serves as a replacement for conventional cutter head of a turning test apparatus. In the material removal process, the work pieces are turned using a spindle testing apparatus by moving the nozzle to an axis with a particular distance from the work piece. The planar workpiece that is harder to machine (Turn) can conveniently be machined using AWJM. However literature on the machinability of planar workpieces and machinability of cylindrical materials are scarcely available. This study not only reviews on turning of the workpiece using abrasive water jet, but also recommends further research.

Keywords: Abrasive water-jet turning, Abrasives Machining, Advanced manufacturing technology.

I. INTRODUCTION

With the technological developments, manufacturing challenges are always increasing which leads to the development of high performance materials such as advanced ceramics, composites, etc. As a result, traditional machining techniques are becoming inadequate for these materials to be effectively machined. Researchers need to focus on their study of development in terms of the strength of industrial materials in order to meet the expectations of the modern world. Innovative and stronger materials produced for the industrial purposes have led to the need for machinability of these materials [1-4]. To meet these requirements, alternative machining methods were needed. The purpose of the non-traditional manufacturing methods are to have metal and non-metal material rendered in a specific profile and size using different energy forms [5-9]. In the recent years, for the requirements of the advanced material needs, miniaturized and hard-to-machine work pieces are needed to be processed that leads to traditional manufacturing methods to become insufficient [10-12]. Hence, non traditional machining methods are more convenient to process miniature and hard-to-machine materials.
AWJT cutting is a cold working process (involving no thermal effects), that does not cause heat to increase in the cutting area during the material removal process by employing the erosion property of the fluid on the work piece [13-18]. Thus, for the material removal process, there is no heat building in the cutting area is considered as an important factor which has significant consequences for the machining performance and the surface quality of the workpiece [19-22]. Advanced technology has required some innovative steps to be taken in the manufacturing sector for the advancements in several fields of the industry [23-29]. The AWJT has been commonly used in the metal cutting process [30-33]. AWJT cutting is based on the principle of abrasion (erosion), for cutting it is necessary to apply high-pressure water on the material [34-36]. This pressurized water has a high level of kinetic energy expressed in terms of the Bernoulli equation when it is influenced through a narrow container [37-41]. Due to this high level of kinetic energy, erosion and cutting of the material occurs that leads to high water flow speeds [42-46]. Several technologies and systemic advancements are due to this AWJT because of these advancements, AWJT is preferred in the metal industry in order to work on Hard-to-machine materials [47-49]. This design increases the performance has led to new areas of work thus increasing the industrial use of AWJ [50-54]. The material machining time has reduced by the usage of multiple cutting heads and efficiency is also increased [55-59]. AWJT has a wide range of use from soft and ductile materials of tough and brittle materials and also become the state of the art of

industry such as automotive and aeronautics which produced consumer products. [60-62]. These studies include AWJ machining are cutting long, but small-diameter work pieces and making grooves on the hard-to-machine materials such as ceramics, composites, glass, etc. [63].

In the AWJT process, the use of experimental turning testing apparatus becomes unavoidable. The literature study showed that there are several experimental studies which involve AWJT machining method. However, it was found that in these studies, all the turning testing apparatus used were similar and this experimental testing apparatus did not involve an enclosure for the spindle mostly. AWJT has been used for turning hard and brittle materials with any geometrical process. To rotate the work piece, there is a testing apparatus. A general principle of AWJT process is shown in Fig. 1.

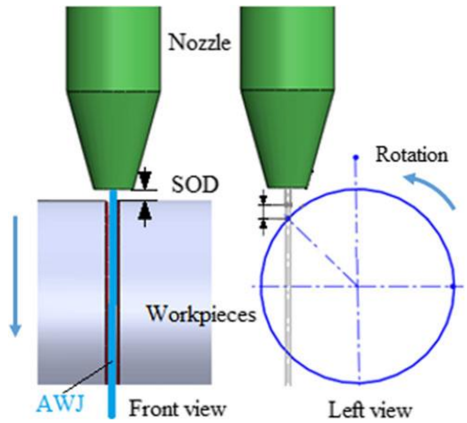

Fig 1. General principle of AWJT process

This study explored the literature scan and offers an evaluation in order to guide the further experimental studies which involve AWJT machining.

II. A LITERATURE SURVEY OF ABRASIVE WATER-JET TURNING

The studied on impact of AWJT parameters of the volume of material removed when machining the Al6061 alloy. This study involves some machining parameters such as different pump pressures, abrasive flow rate, and nozzle feed rate as variables while spindle speed and abrasive size as constant [21]. When the pump pressure and the abrasive flow rate were increased then the material removal rate is also increased.

The investigated the trails created on the machined surface by the AWJT process and macro characteristics of AWJ turned surfaces. While machining a 25-mm diameter aluminium sample, it was found that after the material removal process surface roughness were created for the work piece [64].

Macro image analysis of the longitudinal turning study of an aluminium sample taking standoff distance as constant with different nozzle feed rates is verified. The decrease of material removal rate and when the standoff distance from the work piece has increased the efficiency of the jet suffers and also reported that surface roughness increases with the increased nozzle feed rate. [65]

The newly developed experimental turning testing apparatus and experimented on a glass material was analyzed. This apparatus involves a direct connection from the electric motor to the spindle, and intermediary transfer elements were not used [66]. The spindle was insulated against pressure water and abrasive particles. 25 mm cylindrical glass samples were used in the experiments. The machining parameters were spindle speed, standoff distance, pump pressure, nozzle feed rate, and abrasive flow rate. It was reported that surface roughness and waviness increase with create at the center of the workpiece after the facing process [67] and the increased nozzle feed rate. The increased workpiece rotation speed is used to find the improvement in the surface quality. The lowest surface roughness value was obtained with low nozzle feed rate and high rotation speed. Standoff distance is increased so that it results in high surface roughness values. Finally, the report shows increased pump pressure leads to increased surface roughness and waviness [68].

The study was conducted by comparing the AWJ and traditional turning methods and exploring the preparation of a test sample. Researchers have developed the experimental testing apparatus for the AWJT. There is no thermal effect during the sample preparation process, and it was possible to machine several materials with different characteristics with reduced operating times and costs was reported [62]. Machined a titanium-aluminium alloy using both AWJ and traditional turning methods. During the AWJT process, six-axis AWJ testing apparatus was used [54]. For the AWJ machining, an experimental turning testing apparatus was developed. The schematic presentation of the AWJT process is shown in Fig. 2.

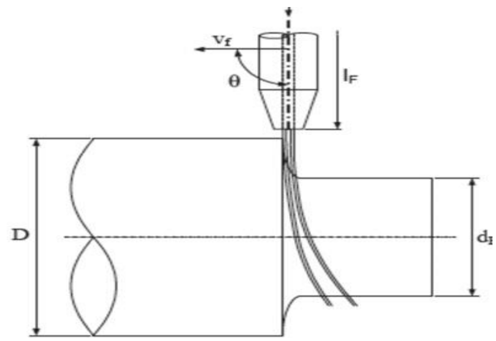

Fig 2 Schematic presentation of the AWJT process

There is an abrasive flow rate between 100 and 600 g min−1 which was taken to the study [28]. A garnet of 80 mesh was used as the abrasive material. The nozzle feed rate was 10 mm min−1, pump pressure was 550MPa, standoff distance was 50 mm, and nozzle angle was 30° as constant parameters. This study showed that traditional turning process leads to material accumulation on the cutter while causing thermal effects due to friction, and these results were documented. In terms of the volume of material removed, it was shown that AWJT was able to remove, the higher amount of material (13 cm^3). The Ra values obtained from the AWJ process were in a range between 5 and 20 µm. Furthermore, the Ra=5 µm gave a material removal rate (MRR) of 0.3 cm^3 min−1. Following a preliminary experiment which involved a final diameter of 4.98mm and a depth of cut of 3.3 mm resulted in the same surface quality with an MRR of 0.8 cm^3 min−1.

It was observed the effects of machining parameters of the AWJT process on the grinding disk. To perform the turning process, the authors have designed an experimental turning testing apparatus [32]. Researchers found AWJ is a new technique. However, convex and concave profile geometries were observed on the grinding disk and two different sizes of grinding disks were made up of aluminium oxide with 50- and 140-mm diameters were reported in this study. A five-axis KMT, 413-MPa ultra-high-pressure AWJ pump was used as the AWJ testing apparatus. The diameter of the orifice was 0.3 mm while the diameter of the nozzle was 1.1 mm. Among the machining parameters, spindle speed was 90–168 min−1, the nozzle feed rate on the z-axis was 1–120 mm min−1, standoff distance was 5–60 mm, pump pressure was 69–415 MPa, and the abrasive material was garnet of 80 mesh in size. This showed that when the nozzle feed rate was increased to 30 from 10 mm min−1, then the machining width was reduced from 3.6 to 2.6 mm, Due to increased standoff distance, the accuracy of the profile cross section of the grinding disk was corrupted because the accuracy depends on the diameter and focus of the jet, that better results will be obtained with scattered jet formation, and that the jet obtained with 285 g min−1 abrasive content results in linear and scattered jet formation [66].

A new model developed a mathematical model building based on the erosion model in order to develop an erosion model for AWJT [41]. By taking the impact angle of the abrasive and water delivered from the nozzle as a function of the decreased diameter, the model was developed. Their experimental study involved Al 6063 as the experimental sample. Researchers have designed the experimental turning testing apparatus for the AWJT [27].

Among the machining parameters were pump pressure(250 MPa), abrasive flow rate (5 g/s), abrasive size (80 meshgarnet), three different nozzle diameters (0.76, 1.2, and1.6 mm), four different spindle speeds (13, 25, 37, and50 min−1), 12 different nozzle feed rates (1, 1.5, 2, 2.5, 3, 4,5, 10, 20, 30, 40, 50 mm min−1), and five different standoff distances (11.7, 10.7, 9.7, 8.7, 7.7 mm). It was reported that the values obtained from the experiments were equal to the ones estimated by the mathematical model [21]. The developed a mathematical model to find the final diameter of the ductile material after the material removal process using AWJ. Researchers have conducted an experimental study using AWJ in order to be able to compare the accuracy of their theoretical findings with actual manufacturing process [28]. Researchers reported that the results of their theoretical model and results of the experiments were equal. Based on that results, nozzle feed rate (2mmmin−1), to investigate the effect of traverse speed and to check the efficiency of the propose model, the predicted diameters obtained by the proposed model and Manu model and the comparison with experimental data are shown graphically.

This study had developed a specially made experimental turning test apparatus for the machining of the cylindrical samples using AWJ. In their study, during the AWJ machining researchers have developed a safety cabinet for the driving motor and spindle which are affected by the abrasive and water. With this development, the unfavorable conditions occurring during the turning process were eliminated with the safety cabinet [45].

The studies on the impact of machining parameters on surface roughness for the turning of a copper alloy (Cu-Cr-Zr) using AWJ. Pump pressure of 350 MPa, abrasive type of garnet and size of 80 mesh, and nozzle diameter of 1.2 mm are kept constant throughout their experiments. A copper alloy of 30 and 240 mm in size was used during the experiments [39]. By using these four parameters nozzle feed rates (10, 15, 20, and 25 mm min−1), abrasive flow rate (50, 150, 250, and350 g min−1), spindle speed (25, 50, 75, and 100 min−1), and nozzle distance (2, 5, 8, and 11 mm), the sample was machined. Finally, the result shows that the nozzle feed rate and nozzle approach distance led to an increase in Ra, giving a Ra value of 2.5–5.5 µm.

This design processed low-density polyethylene material using AWJT processing parameters with L18 orthogonal array [19]. In their study, using a traditional turning setup, researchers have tested material removal work on a polyethylene work piece. Researchers have reported that the surface roughness of the polyethylene work piece was high and the material removed tends to stick to the finished surface and also AWJT process did not involve unfavourable conditions commonly encountered with the traditional turning process and that the machining area was not exposed to thermal deformation and therefore melting occurs when machining with AWJ.

In this study studied the impact of AWJ parameters like spindle speed, nozzle feed rate, abrasive flow rate, and standoff distance on both the material removal volume and the machining depth of AISI 1040 steel [56]. Authors had [42] have experimented with the titanium material of Ø 55mm for AWJT [33] Garnet of 60 meshes was used as the abrasive material. Among these constant machining parameters, pump pressure (400 MPa), spindle speed (60 min−1), standoff distance (10 mm), and abrasive flow rate (400 g min−1), five different nozzle feed rates (1.5,3, 4.5, 6, and 7.5 mm min−1) were variable.

It was stated that the work piece was attached to the experimental turning testing apparatus directly without any safety material and then it was machined. The results of the AWJT of the titanium material showed that the nozzle feed rate of 1.5mm min−1 given Ra of 6.984 µm, while the highest nozzle feed rate gives Ra of 8.308 µm. It was reported that when Ra was increased, the material removal rate was reduced by the increased nozzle feed rate. Nevertheless, it was stated that AWJT offers significant advantages when it comes to materials which are hard to machine using traditional turning methods [33].

In this study [34], the AWJ machining of the high strength AISI 4340 steel samples. Researchers investigated the impact of machining parameters of the AWJT on the Ra and the material removal rate of AISI 4340 steel [34]. The machining parameters nozzle feed rate (3, 6, 12, and24 mm min−1), pump pressure (200, 260, 320, and 380 MPa), abrasive flow rate (228, 333, 420, and 498 g min−1), nozzle angle (45°, 60°, 75°, and 90°) and spindle speed (97,194, 389,and 777 min−1). To estimate the Ra and material removal rates, researchers have developed a mathematical model building on the Bernoulli equation. The error rate between the mathematical model developed, and the results obtained from the experiments were 2 %. Researchers used the experimental turning testing apparatus for the AWJT.

The study concluded that, for optimal material removal the nozzle feed rate of 6 mm min−1, pump pressure of 380 MPa, abrasive flow rate of 498 g min−1, AWJ impact angle of 90°, and spindle speed 777 min−1 are required. They have found when the spindle speed is increased, machining depth also increases. Radial mode and offset mode were compared to identify which one is advantageous for the surface roughness and material removal rate. It was found that when compared to the offset mode, radial mode resulted in a rougher surface and it was stated that the offset mode must be preferred in order to obtain surfaces with reduced roughness [34].

In this study [27] investigated the impact of AWJT parameters on the material removal rate. Among the AWJT parameters, pump pressure (130, 200, 250, 300,and 370 MPa), abrasive flow rate (106, 230, 324, 422, and557 g min −1), nozzle feed rate (3, 5, 7, and 9.8mmmin−1), and spindle spin (160, 300, 400, 500, and 640 min−1), AA 2011-T4 aluminium alloy of Ø 30 mm was selected as the workpiece.

Researchers have used the experimental turning testing apparatus for the AWJT of the AA 2011-T4aluminum alloy. To define the impact of the machining parameters on the material removal rate, researchers have conducted variance analysis, response surface methodology (RSM), and multiple regression analyses. It was reported that any parameter other than the spindle speed had a statistically significant impact on the material removal rate then the nozzle feed rate is the most significant parameter among the others [62].

The developed machine to investigate the machinability of the AISI 1050 steel material using AWJT called as a custom experimental turning machine [36]. The machining parameters were nozzle diameter (0.7 and 1.3 mm) nozzle feed rate (5, 25, and 45 mm min−1), abrasive flow rate (50,200, and 350 g min−1), spindle speed (500, 1500, and2500 min−1), and standoff distance (2, 10, and 18 mm). Experiment design followed Taguchi L18 and was conducted accordingly. The impact on the machining depth of the AWJ parameters was explored using the variance analysis. A linear regression model was presented by utilizing the interaction between factors found to affect machining depth in this study. The study concluded that without production defects, high levels of material removal are possible in a single pass. The most significant effects on the machining depth were observed with the nozzle feed rate, abrasive flow rate, and spindle speed, respectively. According to the variance impact percentages, Nozzle feed rate and the abrasive flow rate had an impact on the machining depth by 75 and14 %, respectively. Using the factors affecting the machining depth, a linear regression model was proposed and the data obtained from that regression model was compared with the data obtained from the experiments [16].

III. DISCUSSIONS AND THE FUTURE STATUS OF AWJT

From several studies, it was stated that many experimental attempts were made in the AWJT machining, design, and applications. Researchers have been contributing to the development of this technology yet this field is open to research on many different levels due to its complex structure. AWJT offers a suitable option for the needs of today's applications. To receive growing attention in many engineering applications, several experiments were conducted on the materials such as modern composites, glass, and ceramics. AWJT is replaced with traditional machining methods such as ultrasonic machining, laser beam machining, and electro-discharge machining which is used for hard-to-machine and firm materials for it offers a faster process which does not damage the surface integrity of the material. To expand the application and machining characteristics of AWJT, the options for combined use of other material removal methods with AWJT was studied. One of the main focuses of the AWJT research is the optimization of the process variables. Researchers have excluded several important factors such as nozzle size and nozzle diameter, which play an important role in the performance characteristics.

Literature review shows that when working on AWJT optimization the studies available on this subject focus on a single factor. There are no studies on a multi-objective optimization of the AWJT, and it is believed that this will be the focus of the future experiments. Nevertheless, several experimental tools currently used for optimization (Taguchi method, artificial neural networks, genetic algorithms, response surface methodology (RSM), etc.) may be combined in order to make use of the advantages of these tools simultaneously. Moreover, the literature review revealed that there are no studies for the multiple response optimizations of process variables which call for future research on this field. A limited amount of studies available in the literature took machining parameters such as nozzle feed rate, abrasive flow rate, abrasive size, spindle speed, nozzle diameter, and standoff distance into account while a combined study on parameters such as pump pressure, abrasive material, and cutting depth is still missing. Therefore, this field calls for further investigation.

To improve cutting performance, several new techniques are reported. These techniques are forward angling, controlled nozzle oscillation, and multi-pass cutting which also require further investigation. Since studies focusing on cutting depth, it will be important for ductile material applications and application angle needs to be included in these studies. Modern machines are now able to cut from different angles (3D, multi-axial machines, etc.). It is of utmost importance to evaluate the possibility to cut a free-form object as it is the case for traditional machining. To overcome grit contamination and dirt accumulation, alternative technologies need to be investigated. If it is to be used in many more industrial applications, AWJT requires a fully automated monitoring solution. However, there are not enough research on the automated monitoring of AWJT process which aims to develop a closed-cycle control strategy. Nevertheless, there is a need for an advanced experimental testing apparatus which eliminates the ripples in the water-jet pool and resistant against abrasive particles and corrosion, and will operate underwater for silent operation. To make AWJT process more economic and standardized, development studies are continuing. Combining process modelling studies with detailed experimental studies will bring convenience to these efforts. With micro-AWJ, a material can be tried turning. AWJ turning processes work done under the water level and five-axis turning operations can be done. A turning of cylindrical parts with hole-punching operation can also be performed.

IV. CONCLUSION

A reconsider of the special effects of AWJT process parameters are as below,

- Through surveying we identified that there are several experimental studies involved in cutting and erosion using turning device. The turning test apparatus used in these studies is identical and does not require any special enclosures to protect against pressure water and abrasive particles.
- If a Lathe chuck is used without any enclosure makes the turning process gets even more harder to perform, The surface roughness, waviness of the workpiece and material removal rate are impacted by machining parameters such as spindle speed, nozzle feed rate, standoff distance, abrasive type and size, nozzle diameter, abrasive flow rate, and pump pressure are seen during machining.
- There is no increase in heat at the cutting area while employing the erosion property of the fluid on the workpiece as AWJ Machining is a cold working process. This is an important factor for material removal as significantly affects the machining performance and surface quality of the workpiece.
- Conveniently machine materials are feasible to work under a small metals or non metal.
- Most usually used as abrasive materials are Garnet, silicon carbide dust, and aluminium oxide.
- To Increase pump pressure it leads to increased surface roughness and waviness garnet of 80 mesh was used as the abrasive material.
- Increasing the nozzle feed rate and standoff distance results in increased average surface roughness, while increasing pump pressure and abrasive flow rate results in increased material removal rate.
- In AWJT, while machining in depth, the spindle speed, nozzle feed rate, abrasive flow rate, and standoff distance have an impact on the material removal volume.
- According to AWJT techniques, the offset mode and radial mode can also be used. And it was clearly found that offset mode has a more significant effect on the surface roughness and waviness.
- In AWJ machining process, the noise level can also be reduced.

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