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Turning with abrasive water jet machining – a review

Fuat Kartal*, Hasan Gokkaya**

*Vocational School, Machine Department, Kastamonu University, Kastamonu, Turkey
**Mechanical Engineering Department, Engineering Faculty, Karabük University, Karabuk, Turkey

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A B S T R A C T

Researchers continue to improve resistance of industrial materials in order to fulfill increasing expectations. Production of innovative high-strength materials in industry also resulted in emergence of workability requirement for these materials. Non-conventional machining methods were required in order to fulfill these needs. Abrasive water jet machining (AWJM) is one of these methods and has taken its important place in a short time. Abrasive water jet turning (AWJT) is based on machining by using abrasive water jet as cutting tool in classical turning and turning the work piece with a lathe chuck mechanism and nozzle is fed along the work-piece in a specific distance and axis. While plane work-pieces are easily machined with abrasive water jet technique, machining (Turning) of cylindrical work pieces are difficult. Although there are studies upon workability of plane work-pieces, there is not enough scientific study upon turning of cylindrical work pieces. Nozzle feed-rate, lathe chuck speed, abrasive flow rate, pump pressure, abrasive length and nozzle height are used as working parameter of abrasive water jet turning.

1. Introduction

Abrasive Water Jet Machining (AWJM) which is hydrodynamic machining method was invented by Norman Franz in 1968 and first used in the studies of rock mechanics [1-4]. Abrasive water jet technologies have displayed a rapid improvement in the last twenty years [3]. Method of water jet machining which does not have thermal effect on material have become a popular method [5-17]. Moreover, this technology which has high machining speed, accurateness and wide range of workable material have become to be used in various engineering field; aeronautics and space, shipbuilding and automotive sectors [18-33]. Today various models have explained the effect of different parameters of abrasive jet on cutting result [2-7]. On one hand, it can serve for different machining works such as turning, milling and drilling, contour cutting; on the other hand nearly all the engineering materials can be machined [3-6]. Since machining conditions of two-dimensional plate cutting parameters are quite different, they could not be used in turning and milling processes directly [4-11]. Abrasive water jet turning is a new method in turning pieces which are difficult to machine [2]. Water jet turning and drilling studies have been focused on recently [8-22]. Abrasive water jet turning is rotating work-piece around axis and machining by using abrasive water jet as nozzle is fed along the work-piece in a specific distance and axis [4-15]. Abrasive water jet machining which is one of the non-conventional production methods has superior aspects over other machining technologies. Apart from fragile and temperature sensitive materials, components which have complex shapes and requires to be produced compositely can be machined with an improved production method called abrasive water jet machining [7-32]. Water jet cutting process is carried out in two ways. These are pure water jet cutting and abrasive water jet cutting. Cutting process is named as water jet cutting and abrasive water jet cutting [33-43].

Advantages of abrasive water jet are;

- Although there is no material types that cannot be cut; it is possible to cut materials at hardness value.
- Since there is no cutting force during and after cutting operation, there are no more strain on the material.
- Production operations such as deburring, cutting, drilling, turning, milling can be done easily with multiple machining mode of water jet lathe.
- There is no need to use edges of cutting tools so no loss of time in changing tools.
- It is efficient and economic since it has high rate of machining.
- It is possible to machine materials in macro and micro sizes.
- It is environmental friendly since there is no burning, oxidizing or toxic slag during machining operation.

* Corresponding author. *E-mail address: fuatkartal81@hotmail.com* (F. Kartal).

- It is possible to do machining with the same nozzle for each group of material [44-51].

AWJM is generally used for frozen meat, surgery, cast metal cutting, nuclear power plant, pocketing, drilling, lathe, textile, cutting in leather industry, cutting of soft materials, removal of paint. In this study, an evaluation was made upon turning ability of cylindrical work-pieces with abrasive water jet.

2. Literature Survey

Zhong and Han (2002); in the study called abrasive water jet turning of glass they have designed lathe experiment mechanism for abrasive water jet turning and made production (Figure 1). In the experiment mechanism, lathe chuck was directly connected to mill of electric engine and no transfer element was used. Lathe chuck was not isolated against pressure water and abrasive particles. Cylindrical glass samples with 25 mm diameter were used as experiment sample in experimental studies. Lathe chuck speed, nozzle distance, pump pressure, nozzle feed-rate and abrasive flow rate were used as variables of machining parameters. In their study, Zhong and Han stated that as nozzle feed-rate increase, the volume of removed chip increase, while there was decrease in the quality of surface roughness and surface waviness. It was observed that there was improvement on work-piece surface quality depending on increase of work-piece speed. The lowest surface roughness value was attained in low nozzle feed-rate and high speed. Increase of nozzle distance resulted in high surface value. The lowest surface roughness value was attained with the value of 300 g/mm according to abrasive flow rate. Increase of pump pressure resulted in high value of surface roughness [52].

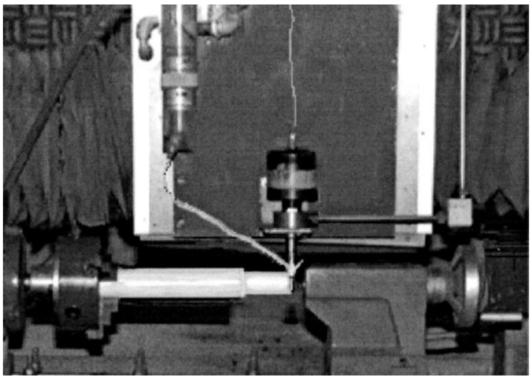

Figure 1. Turning with abrasive water jet of the glass test specimen [52].

Uhlmann et al (2012); Turning of titanium aluminum alloy with abrasive water jet and conventional turning was studies. 5-axis water jet lathe was used in abrasive water jet. Lathe experimental mechanism was designed by Uhlman et al. in order to do turning operation and production was made. Schematic display of lathe experimental mechanism was given in Figure 2. Variables between 100 g/min and 600 g/min were chosen as abrasive flow rate in the experiments. Abrasive (80 mesh size, garnet type), nozzle feed-rate (10 mm/min), pump pressure (550 MPa), nozzle height (50 mm) and nozzle distance (30°) were chosen as stable values. As a result of study, they reported with SEM images that there is no micro surface hardness since there is no thermal effect in abrasive water jet turning, while there is enthalpy chip on cutting tool due to cutting force and friction in classical turning operation. It was presented in Figure 2 that faults such as breaking or distortion on the edges of materials are observed more in classical turning operation. It was determined that the most chip volume was obtained with abrasive water jet (13 cm^3) according to volume of removed chip. Average values of surface roughness obtained from abrasive water jet turning vary between 5 and 20 µm [53].

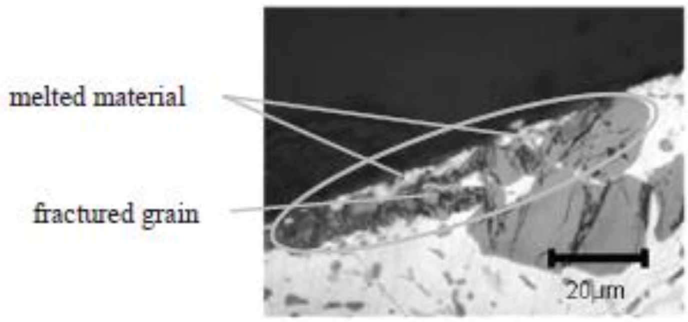

Figure 2. Cutting edge of the cutting tool consisting of chips formation of fractures SEM image. [53].

Axinte et al (2009); studied effects of operation parameters in abrasive water jet turning of cloth grinding disk. Lathe experimental mechanism was designed by Axinte et al. in order to do turning operation and production was made. Schematic display of lathe experimental mechanism was given in Figure 3. Convex and concave profile geometry was formed in order for nozzle to operate in a single pass on cloth grinding disk. They stated in the study that abrasive water jet turning is a new technique. In the experiments, two grinding disks with 50 mm and 140 mm diameter and Al_2O_3 structure were used. 5-axis KMT brand 413.7 MPa ultra high-pressure water jet pump was used as water jet lathe. Orifice diameter was chosen as 0.3 mm and nozzle diameter was 1.1 mm. Cycle movement coming from engine was transmitted to a lathe chuck mechanism whose operation was enabled with lathe mechanism timing belt pulley. Lathe speed was 90-168 rpm; speed rate of nozzle in z-axis was 1-120 mm/min, nozzle distance was 5-60 mm, pump pressure was 69-415 MPa, abrasive flow rate was in the range of 0-0.8 kg/min and in 80 Mesh size and abrasive garnet form as operation parameters. As a result of study, it was observed that under the effect of chosen operation parameters, as the nozzle feed-rate is increased from 10mm/min to 30mm/min cutting width decreased from 3.6mm to 2.6mm. Measurement accurateness of grinding disk and profile sections were deformed when nozzle distance was increased. They stated that accurateness of measurement depends on diameter and focusing of jet, more accurate results are obtained with on-dispersive jet formation, jet which has 285 g/min abrasive amount would provide more linear and on-dispersive jet formation [54].

Figure 3. Experimental setup of textile grinding wheel turning mechanism. [54].

Andersson et al (2003), compared abrasive water jet and conventional turning method in the study of preparing test sample with abrasive water jet. They developed lathe experiment mechanism (Figure 4) for abrasive water jet. They prepared two different test samples in their studies (Figure 5). They stated that there is no thermal effect on work-piece during sample preparation with abrasive water jet, materials in different hardness characteristics can be cut with the same nozzle, cost of time and machining was lower. Necessary surface roughness values were attained for fatigue test in the end of study, average surface roughness values (Ra) were measured as 2 µm. They stated that abrasive water jet machining method was suitable method for preparing tensile and fatigue test sample. They stated that another advantage of ASJ is that it protects real values of samples taken from welded areas without deforming their surface roughness characteristics and creating thermal effect [55].

Figure 4. AWJ experimental setup with the turning. [55].

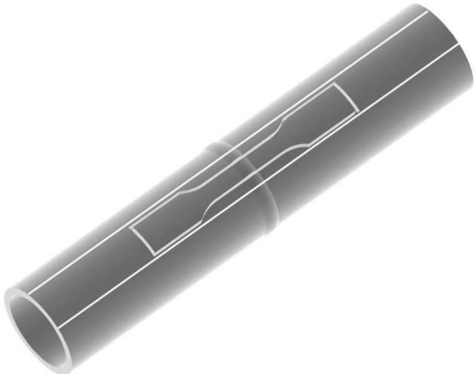

Figure 5. Extraction the weld sample (left), the cylindrical test sample image (right) [55].

Manu and Babu (2009); in their study which was carried out in order to create erosion model in abrasive water jet, they developed mathematical model depending on erosion model of Finnie. They developed the model as impact angle of abrasive and water on work-piece in abrasive water jet as the function of diameter reduction. Local impact angle of water jet on work-piece was presented in Figure 6. Aluminum 6063 was used as experiment sample in experimental studies. In order to confirm mathematical model, lathe experiment mechanism which was shown in Figure 7 was designed and used in obtaining data with abrasive water jet machining. As operation parameters, pump pressure (250 MPa), abrasive flow rate (5 g/s), abrasive length (80 Mesh garnet), three different nozzle diameter (0.76 mm, 1.2 mm and 1.6 mm), nozzle distance 2 mm, four different lathe chuck speed (13 rpm, 25 rpm, 37 rpm and 50 rpm), twelve different nozzle feed-rate (1 mm/min, 1.5 mm/min, 2 mm/min, 2.5 mm/min, 3 mm/min, 4 mm/min, 5mm/min, 10 mm/min, 20 mm/min, 30 mm/min, 40 mm/min, 50 mm/min) and five different radial jet distance (11.7 mm, 10.7 mm, 9.7 mm, 8.7 mm, 7.7 mm) were used. It was stated that values obtained as a result of experiments and values estimated with mathematical model were close to each other [56].

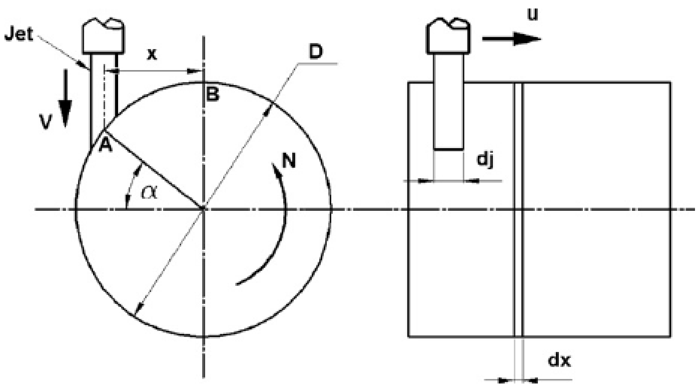

Figure 6. Water jet impact angle view [56].

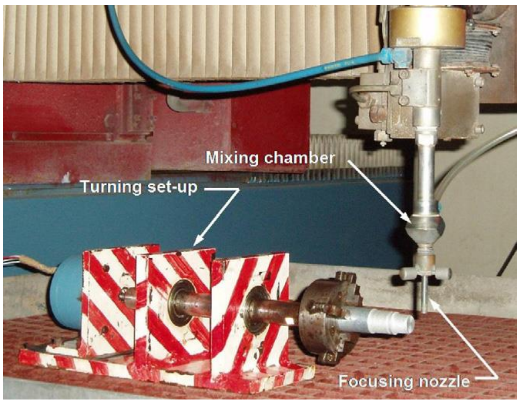

Figure 7. Turning experimental setup view [56].

Ansari and Hashish (1995); have carried out study of abrasive water jet turning of AA6061-T6 alloy in order to determine effect of operation parameter on chip removal volume. Turning speed was stabilized in all experiments as 360 rpm and abrasive 60 mesh garnet. Pump pressure, abrasive flow rate, nozzle feed-rate, abrasive size, abrasive type, nozzle diameter were used as variables in their experiment. As a result of experimental study, it was observed that increase of pump pressure and nozzle feed-rate increased volume of chip removal (Figure 8). As a result of study, parameters which have the most impact on chip removal parameter were abrasive flow rate, water pressure, outlet velocity of water respectively [57].

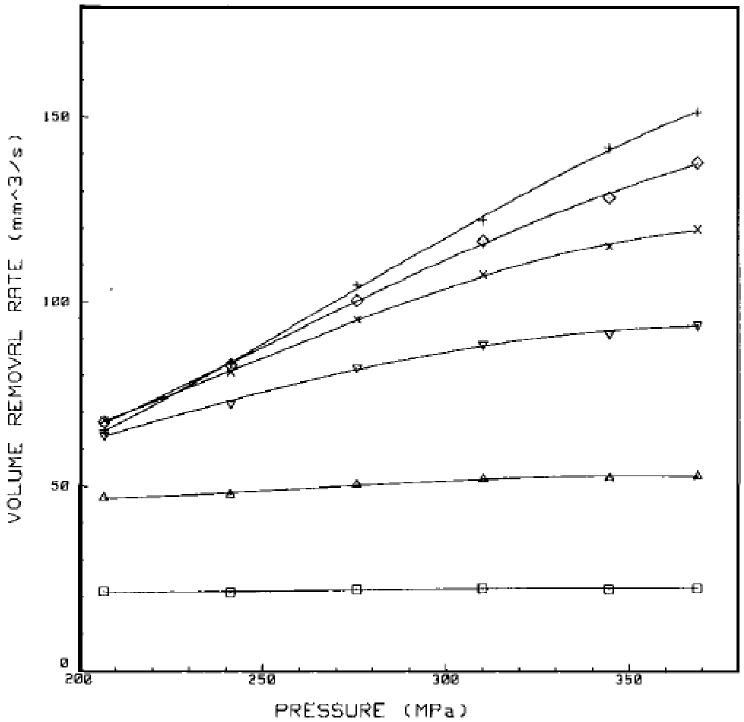

Figure 8. The amount of feed pump pressure and nozzle effect of the volume of material removal [57].

Hashish (2001); in his study titled as analysis of macro characteristics of surfaces with abrasive water jet turning, he has put forwards visual traces left on lathed surfaces by operation parameters. Longitudinal and facing turning were done on work-piece (Figure 9). Thermal resistant Inconel in 25 mm diameter and aluminum samples were used in experimental studies. Surface waviness was observed on work-piece surface after chip removal process. As a result of experiments, he reported that as the nozzle height increase there was a decrease in the amount of chip removal and the jet lost its effect. Surface waviness on the face which is formed with increase of nozzle distance in facing was shown in Figure 10. Macro views of longitudinal turning studies on aluminum sample with different nozzle feed-rates by using stable nozzle distance were given in Figure 11. He reported that as the feed-rate increase, so does the value of surface roughness [58].

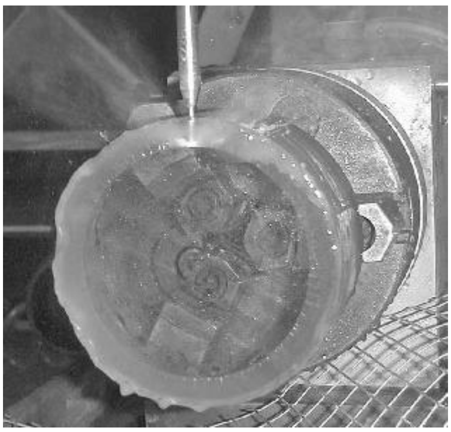

Figure 9. Face turning process view [58].

Figure 10. After the turning process image of a waviness of the center face [58].

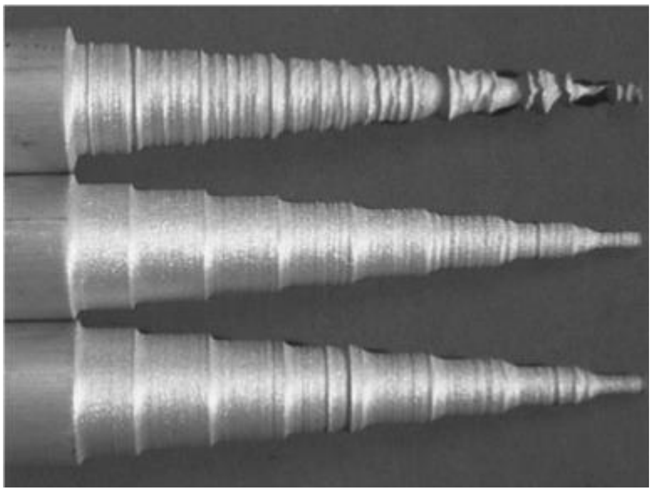

Figure 11. Macro-surface images of the progress in the amounts of different types of nozzles.[58].

Zohourkari and Zohoor (2010); set a mathematical model for estimation of final diameter after chip removal process in abrasive water jet turning of ductile material. In their study, they modeled manu and hashish models again and set a third mathematical model. They carried out an experimental study with abrasive water jet in order to compare accurateness of theoretical studies with actual production. As a result of their study, they stated there was compatibility between theoretical model and experiment result (Figure 12) [59].

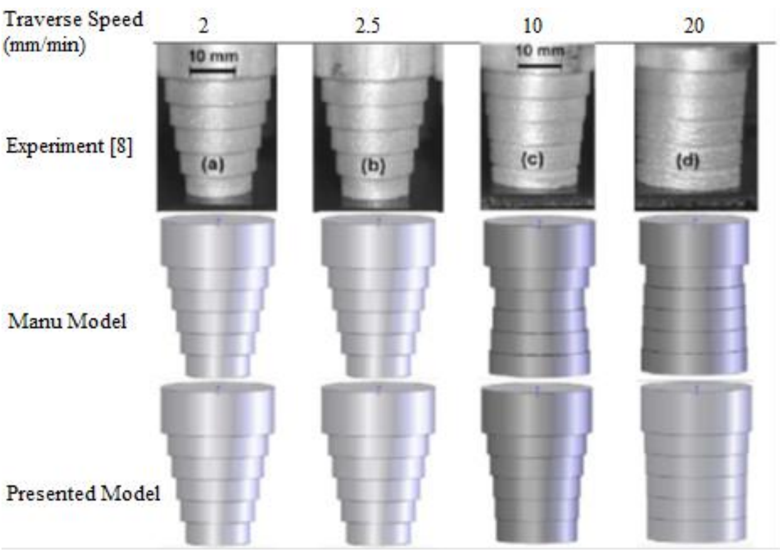

Figure 12. Comparison of experimental results with the Manu model [59].

Kartal and Gokkaya (2012) set hybrid turning experiment mechanism in order to make abrasive water jet turning of cylindrical samples. They developed safety cabinet for lathe chuck and drive motor influenced by abrasive and water in abrasive water jet turning. Due to safety cabinet they developed, it was proved that problems were removed with experimental studies [60].

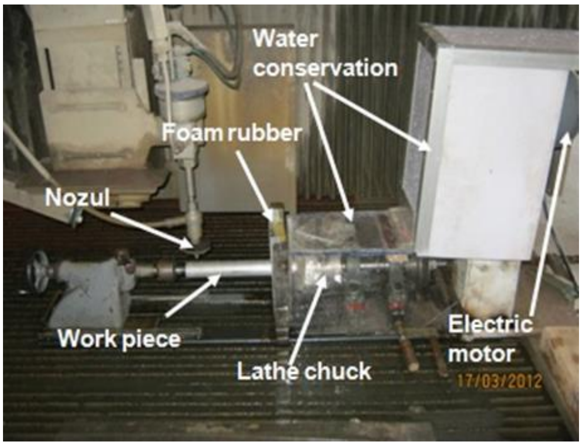

Figure 13. The image of Turning experimental setup [60].

Kartal and Gokkaya (2012); analyzed the effect of (Cu-Cr-Zr) copper alloy on surface roughness, macro surface characteristics and chip removal rate during abrasive water jet turning. In the experimental studies, pump pressure was stabilized at 350 mpa, in abrasive garnet form and 80 mesh size, nozzle diameter was 1.2 mm. In their experiments, (Cu-Cr-Zr) alloy in ∅30 and 240 mm sizes were machined with abrasive water jet in parameters of nozzle feed-rate (10, 15, 20 and 25 mm/min), abrasive flow rate (50, 150, 250 and 350 gr/min), lathe chuck speed (25, 50, 75 and 100 speed/min) and nozzle distance (2, 5, 8 and 11 mm) (Figure 14). According to experiment results, when nozzle feed-rate and nozzle distance increase, it causes increase of average surface roughness varying between 2.5- 5.5 µm [61].

Figure 14. (Cu-Cr-Zr) alloy of copper with the turning of abrasive water jet [61].

3. Summary

There were a few studies on abrasive water jet turning. As the common characteristic of studies, work-piece was circulated with lathe experiment mechanism and made turning with abrasive water jet parameters. Abrasive water jet turning was done with restricted number of engineering material. As a result of studies, average values of surface roughness and values of chip removal volume were analyzed as experiment output.

4. Conclusion

In comprehensive literature review, it was observed that there were various two-dimensional studies about abrasive water jet but restricted number of experiments about abrasive water jet turning. First experiments were carried out in previous years and this subject was not analyzed for a long time then. Lathe mechanism made with abrasive water jet resemble to each other in the sense of mechanism.

It was seen that resemblances and inadequacies of experiment mechanisms have been removed in recent studies. Variables such as lathe chuck speed, nozzle feed-rate, abrasive flow rate, nozzle distance, nozzle diameter, abrasive size, pump pressure were used as operation parameters in abrasive water jet turning. The effect of operation parameters in different levels on average surface roughness, chip volume removed on work-piece and surface roughness waviness were taken as output. According to the results of experiment studies, it was determined that the amount of nozzle feed-rate was the most important parameter which increases surface roughness. It was determined that abrasive flow rate does not change surface roughness after a specific level (300 g/min) and pump pressure enhances roughness until 350 MPa level then increase roughness in higher values. It was determined that as lathe chuck speed increases, value of surface roughness decreases, large nozzle diameter is a factor which increases surface roughness, lower average surface roughness values were obtained with small nozzle diameter. In abrasive water jet turning process, as the distance between water jet and work-piece decreases, sonic boom and noise increase. In the sense of chip removal volume; it was observed that chip volume removed from work-piece increased with the increase of lathe chuck speed in the process of abrasive water jet turning, it decreases when the amount of nozzle feed-rate increases, it increases with the increase of abrasive flow-rate and nozzle distance. On the other hand, increase of pump pressure increased chip removal volume. Chip removal volume increases as the abrasive size increased. In the literature study, it was observed that there was not adequate number of studies about abrasive water jet turning.

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