A review on nozzle wear in abrasive water jet machining application

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A review on nozzle wear in abrasive water jet machining application

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Abstract. This paper discusses a review on nozzle wear in abrasive water jet machining application. Wear of the nozzle becomes a major problem since it may affect the water jet machining performance. Design, materials, and life of the nozzle give significance effect to the nozzle wear. There are various parameters that may influence the wear rate of the nozzle such as nozzle length, nozzle inlet angle, nozzle diameter, orifice diameter, abrasive flow rate and water pressure. The wear rate of the nozzle can be minimized by controlling these parameters. The mechanism of wear in the nozzle is similar to other traditional machining processes which uses a cutting tool. The high pressure of the water and hard abrasive particles may erode the nozzle wall. A new nozzle using a tungsten carbide-based material has been developed to reduce the wear rate and improve the nozzle life. Apart from that, prevention of the nozzle wear has been achieved using porous lubricated nozzle. This paper presents a comprehensive review about the wear of abrasive water jet nozzle.

1. Introduction

Abrasive water jet machining is one of the non-traditional machining processes that was first commercialized in 1993. Abrasive water jet was first used for linear cutting and shape cutting of sheets, plates and casting in wide range of materials. As the technology evolved, the abrasive water jet machining today has been used for various operations such as deburring, polishing, cutting, milling, and turning. It has been used in a broad range of industries, ranging from small machine shops to large industries such as aerospace, automotive and shipbuilding.

Abrasive water jet machining work as the high pressure of water is discharged through a sapphire orifice, thus producing a high velocity jet that passes through a mixing chamber and hit the target material. This process creates a partial vacuum that entrains the abrasive particles which is fed through the hopper. Momentum transfer from the jet to the abrasive particles takes place within a narrow mixing tube, also called the nozzle.Here, the abrasive and the high pressure water mixes together to form a high energy jet that can be used as effective and versatile cutting tools.

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Abrasive water jet machining is one of environmental friendly process as no dust or gases is released upon operating the machine. The sustainability aspect of water jet machining had been studied,where the results show that the water from the process can be reused and the abrasive particles can be recycled using online recycling [1,2]. Apart from environmental friendly, abrasive water jet machining is advantages compared to laser cutting and electro discharge machining as it has no metallurgical deformation and also eliminates after-cut machining in most cases. Besidesthe abrasive water jet does not affect the material properties of the target material as it does not cause chatter, has no thermal effects, impose minimal stresses on the work piece and has high machining versatility and high flexibility [3]. In this paper, a comprehensive review about about abrasive water jet nozzle wear is given and the important finding are highlighted.

2. Nozzle Characteristic

In abrasive water jet machining, nozzle is one of the most important component to the machining process. There are various types of nozzles with different lengths and diameters. Normally the materials used to produce nozzle are silicon carbide, tungsten carbide, boron carbide, tungsten carbide cobalt and also composite carbide. Each material has a different property which indicates the ability of the nozzle to prolong its life cycle.

The physical characteristic of water jet stream has been studied by Yanaida and Ohashi [5,6]. Understanding the physical representation of water jet stream is important because it exhibits the overall flow from the nozzle to the work piece. Figure 3 below shows the physical characteristic of the stream that consists of three different regions. The initial region start with the continuous linear structure as it reaches the transition region the stream start to become droplet and fall apart.

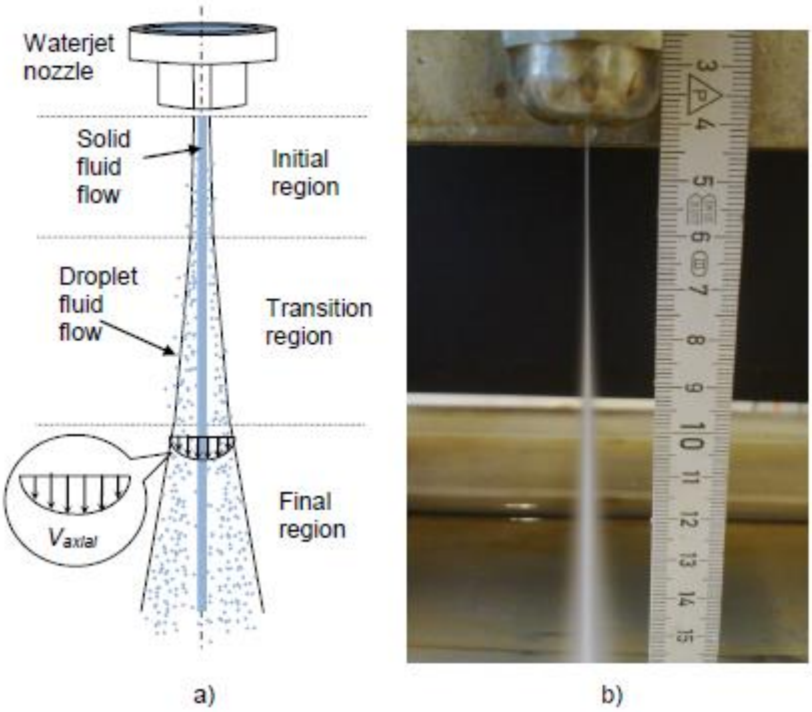

Figure 1. a) Physical characteristics of water jet stream[5,6] b) a typical flow of water jet stream[4].

The water droplet form due to the interaction of the stream flow with the surrounding air. In this region the velocities of the water lumps and droplets remain largely unchanged. However, as it moves further the velocities of the droplet will reduce and the water stream becomes dispersed because of the continuous interaction with the surrounding air.

3. Wear Characteristic

In abrasive water jet machining, nozzle is the shortest-lived component and critically important as it will directly influences the precision, performance and economics of the abrasive water jet machining process [7]. Furthermore, wear of the nozzle will lead to the degradation of the quality of the cut surfaces and causes the undesirable changes in the geometry of the work pieces. Nozzle wear is the result of the process of material removal as the two surfaces are in sliding contact [8].

3.1 Wear Profile

Wear test has to be done in order to get the nozzle wear profile. Nozzle wear test typically falls into two categories which are accelerated wear test and regular wear test. Accelerated wear test is either using soft nozzle material or using hard abrasive such as aluminium oxide or silicon carbide. The tests are useful for a quick screening and comparing the nozzle material. While, regular wear test or actual test is conducted using application-specific nozzle or standard nozzle and standard abrasive material that are used in the industry to determine the wear performances [7,9].

Nozzle wear profile can be determined using several methods which are nozzle bore profile, weight loss method and gage pin method. Nozzle bore profile can be found out by sectioning the nozzle longitudinally and measuring the profile using coordinate measuring machine. The other method is by making casting of the bore using a silicon resin [10,11]. M. Nanduri et al. (2002) analyzed nozzle wear in abrasive water jet machining using accelerated wear test. The nozzle materials used were WC/Co, ROCTEC (R100, REXP) and aluminium oxide and garnet as the abrasives. The parameters are shown in the Table 1.

Table 1. The parameters used in the test.

Parameters	**Tested Value**	**Typical Value**
Nozzle Length	32.5, 50.8, 76.2, 106.6 mm	50.8 mm
Nozzle Diameter	0.79, 1.14, 66.3 mm	1.14 mm
Nozzle Inlet Angle	10°,20°,30°,40°,50°,180°	60°
Orifice Diameter	0.28,0.33,0.38,0.43 mm	0.38 mm
Water Pressure	172,241,310,359 MPa	310 MPa
Abrasive Flow Rate	1.9,3.8,5.7,7.6,9.5,11.4 g/s	3.8 g/s

Figure 2 below shows the sectioned nozzle made of WC. The waves like patterns are more visible in Figure 3 below which is a plot of the initial bore radius after standard hours of used along the nozzle radius. The standard hours of used for every nozzle were around 100 hours.

Figure 2. The sectioned nozzle and the silicon casting of WC.

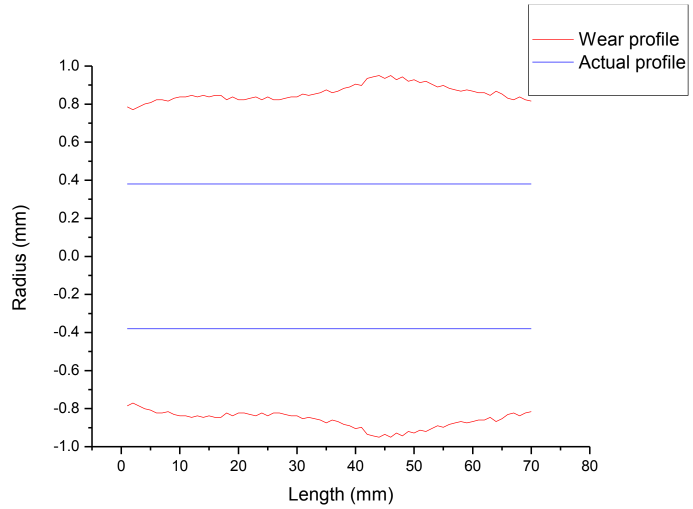

Figure 3. Nozzle bore profiles of worn WC nozzle.

3.2 Effect of parameters on nozzle wear

Nozzle acts as three important functions in the abrasive water jet machining process. The first function is to enable the action of jet pumping for abrasive entrainment and also provides the environment for abrasive acceleration. Nozzle also helps in focusing the abrasive during the machining process. Parameters that are used in abrasive water jet machining process will affect the wear of the nozzle. The results shows are subjected to 3 hours of garnet abrasive wear at 310MPa of water pressure and 3.8 g/s of abrasive flow rate [9].

Nozzle length is considerably important in getting the best performance during the machining process. The length of the nozzle has a direct influence on the exit bore growth as the longer the nozzle, the slower the wear rate at the exit section. This is because the length of the nozzle will delaying the developing of the wear from reaching the exit section. Figure 4 shows the effect of the nozzle length on the nozzle wear. As the nozzle length increase the exit diameter will decrease same goes to nozzle weight loss rate.

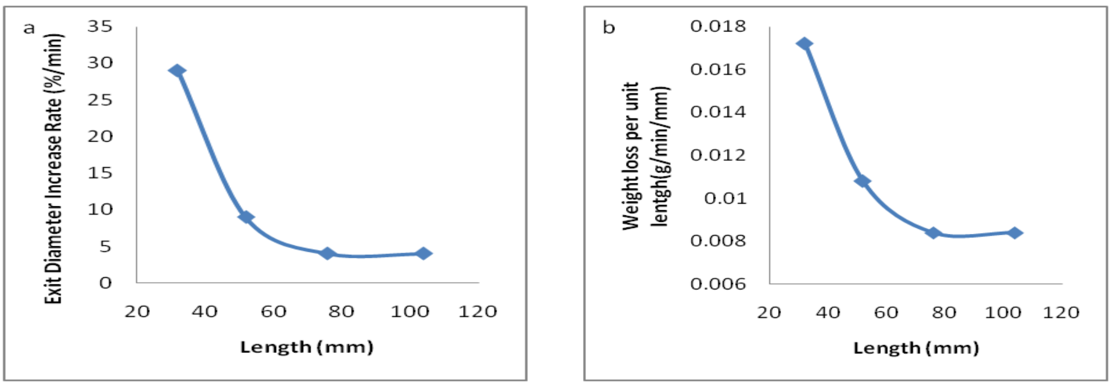

Figure 4. Effect of nozzle length. (a)Exit diameter increase rate ;(b) Nozzle weight loss rate [9].

Figure 5 and 6 below shows the effect of nozzle inlet angle and nozzle bore diameter to the nozzle wear. The result shows increasing in inlet angle lead to decreasing in exit diameter of the nozzle. As the inlet angle increases, the wave of the bore profile become more pronounced resulting in increasingly non-linear exit bore growth. The diameter of the nozzle effects wear, mixing and suction characteristics of the nozzle. By keeping the ratio of orifice diameter to the nozzle diameter around 0.3-0.4 mm will result in optimum mixing and cutting condition. Large diameter of nozzle cause inefficient of abrasive entered respectively.

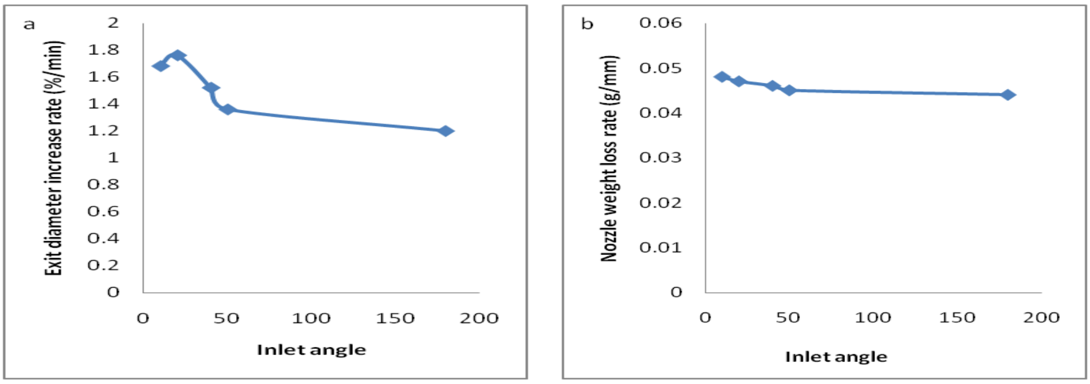

Figure 5. Effect of inlet angle. (a)Exit diameter increase rate; (b) Nozzle weight loss rate [9].

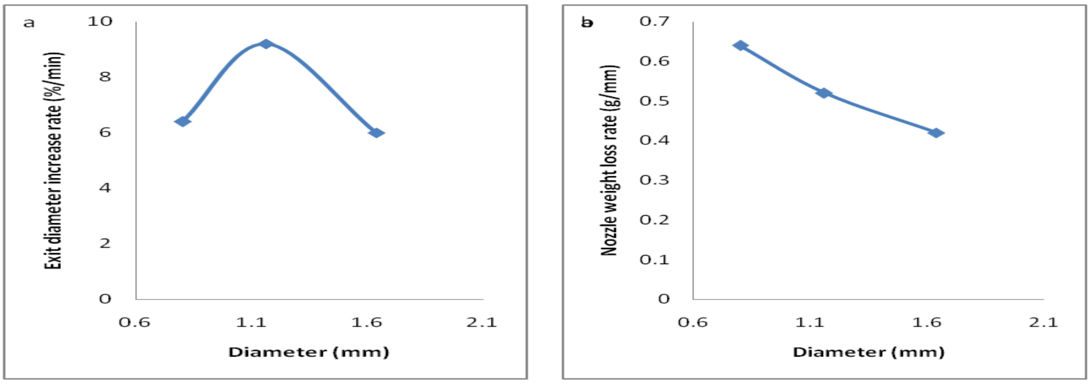

Figure 6. Effect of bore diameter. (a)Exit diameter increase rate; (b) Nozzle weight loss rate [9].

Figure 7 and 8 below shows the effect of orifice diameter and abrasive flow rate on nozzle wear. Increasing in orifice diameter will increases the water flow rate and decreases the abrasive concentration. Significantly, increasing in orifice diameter is likely to effect the cutting efficiency and also the material removal rate [12]. The abrasive flow rate is increasing linearly to the exit diameter growth and weight loss rate.

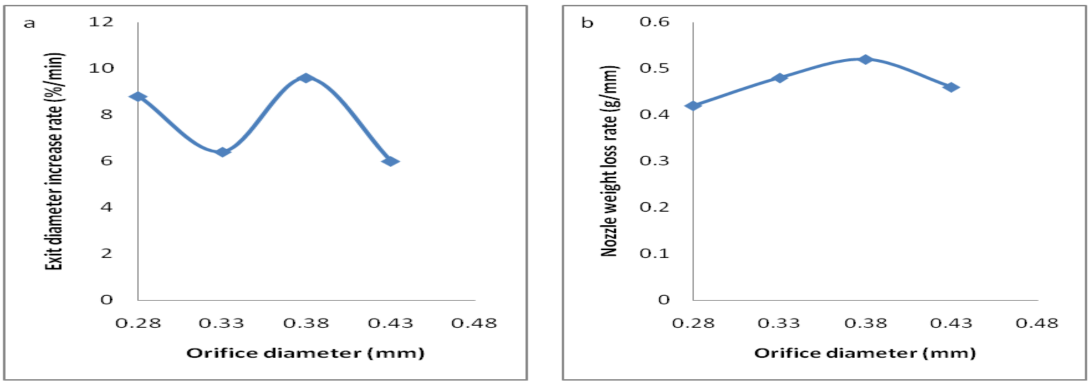

Figure 7. Effect of orifice diameter. (a)Exit diameter increase rate; (b) Nozzle weight loss rate [9].

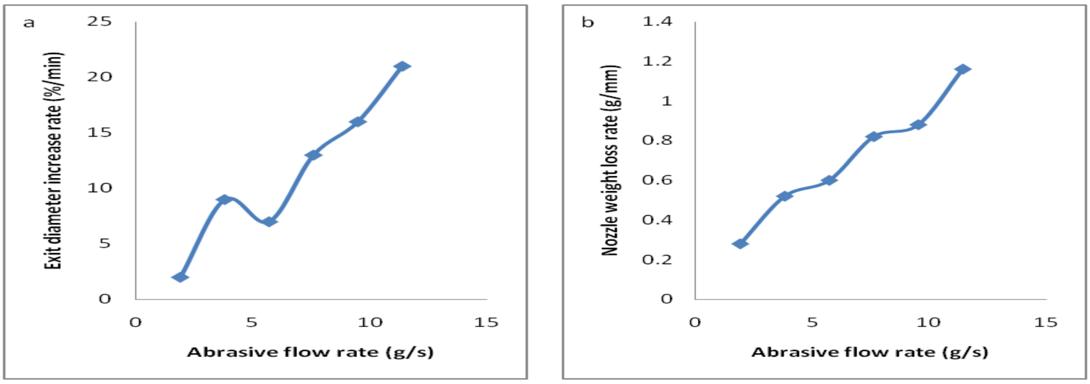

Figure 8. Effect of abrasive flow rate. (a)Exit diameter increase rate; (b) Nozzle weight loss rate [9].

The effect of water pressure is summarized in Figure 9. It shows that the exit diameter and weight loss rate demonstrate a maxima with increasing water pressure. The nozzle wear is reduces as the excessive pressure may increased the fragmentation of the abrasive particles thus reducing the effectiveness in wearing the nozzle. As the water pressure increase the rate of material removal increases resulting in increasing the weight loss rate[13].

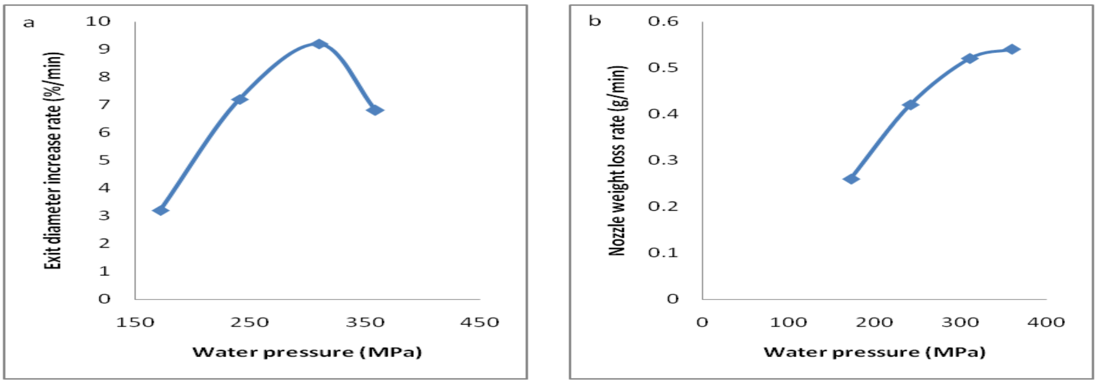

Figure 9. Effect of water pressure. (a)Exit diameter increase rate; (b) Nozzle weight loss rate [9].

4. Wear Mechanism

Wear mechanism of abrasive water jet nozzle is similar to the traditional cutting tools as it also involves the erosion and abrasion. Ness and Zibbell (1996) has been studied about the abrasion and erosion of hard materials related to the wear in abrasive water jet. The experiment used three hard material tungsten carbide cobalt, boron carbide and composite carbide were compared using three different abrasion and erosion test which are dry erosion, rubber wheel abrasion and wet steel wheel abrasion. The results of the test were compared based on hardness and toughness of the material. Boron carbide which has highest hardness was better than tungsten carbide cobalt in erosion but tungsten carbide which has highest toughness was better than boron carbide in abrasion. However, the result shows that the composite carbide has the lowest wear rate compared to others in overall test. This is because the composite carbide consist a particular combination of toughness and hardness that withstand the test resulting in the lowest wear rate. [15,16]also stated that the hardness of the nozzle will determined the rate of erosion wear.

5. Wear Prevention

As nozzle wear brings problem to the performance of the abrasive water jet machining,[17] proposed an on-line tracking device to track the wear of abrasive water jet using wear sensor. The wear sensor consists of conductive loops which divided into four sections. Each conductive loop will be placed on the ceramic's substrate and implanted at a particular location within the tip of the nozzle. The wear sensing system works based on the wear probe which is conductive loops that exposed to the effect of the erosion and abrasion of wear. The result of the study shows that the sensing system is able to detect the direction of the wear propagation also it will provide the necessary information about the positioning control in order to compensate the increasing in inner diameter of the nozzle. Even though this system does not help in preventing the nozzle wear but it can be used to detect the wear before kerf width exceeds acceptable limits.

As a solution to prevent the nozzle from wear Unand and Katz (2003) had come out with the method using porous lubricated nozzle. The nozzle was made of porous material and is surrounded by reservoir containing high velocity of lubricant. From the study, it can be concluded that the porous lubricated nozzle can considerably reduce the wear of the nozzle. It shows that the presence of the oil help in reducing the collision between abrasive particles and nozzle wall thus reducing the wear. Generally, the wear rate can be control by controlling the viscosity of the lubricant as increasing in viscosity lead to decreasing in wear rate.

The nozzle wear is a common problem in abrasive water jet machining application. Many researchers and also manufacturers attempt to solve the problem. A new nozzle using a tungsten carbide-based material has been developed to reduce the wear rate and improve the nozzle life [19]. The wear also can be reduced by using soft abrasive materials or nozzles made of hard materials.

6. Conclusion

Abrasive water jet machining is widely used in various industries include aerospace, automotive, shipbuilding etc. Hence it is important to study about the nozzle wear because it influences the precision, performance and economics of the abrasive water jet machining. Nozzle wear can be test using regular wear test and accelerated wear test. The wear profile can be determined by using nozzle bore profile method, nozzle weight loss method and pinning profile. The parameters that influence the nozzle wear are nozzle length, nozzle diameter, nozzle inlet angle, orifice diameter, water pressure and abrasive flow rate. Wear mechanism of abrasive water jet nozzle is similar to the traditional cutting tools as it also involves the erosion and abrasion. In the long run, further study should be done to find the solution on the nozzle wear.

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