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ANALYSIS OF WEAR ON ABRASIVE WATER JET NOZZLE

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Engineering in Manufacturing Engineering

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ABSTRACT

An abrasive water jet (AWJ) system is a manufacturing tool that uses high pressure (200-400 MPa) water to accelerate abrasive particles through a carbide nozzle they are eroding a target material. Nozzle wear is dependent on the numerous AWJ system and nozzle parameters such as water pressure, orifice diameter, abrasive type, abrasive size, abrasive shape, abrasive flow rate, and mixing chamber dimensions. The present study investigates the wear profile of the nozzle. The nozzles are made from tungsten carbide. They experienced normal wear after standard use between 100 to 120 hours. The roundness of the AWJ nozzle can be seen after the machining process and the roundness can be more resistant to the chipping and damage if the radius of AWJ nozzle is small. For wear profile, the result shows that the nozzle number 1 has bigger diameter at the entranced which are 4.28 mm compared to nozzle number 2 that the diameter are 4.07 mm. Then, the wave structure grows in magnitude and propagates down the nozzle bore. The wear patterns were observed, which are the converged wear pattern occurred at the bore of the AWJ nozzles. From the result, the erosion mechanism that occurs in the AWJ nozzles can be divided into three stages which are an inlet, middle and outlet, and the highest erosion mechanism occured in the inlet area. The wear of the AWJ nozzle can occur through the systematic variation of the system parameters AWJ and the nozzle geometry.

ABSTRAK

Satu sistem jet air kasar (AWJ) adalah alat pemesinan yang menggunakan tekanan air yang tinggi (200-400 MPa) untuk mempercepatkan zarah kasar menghakis bahan sasaran. Muncung akan haus bergantung kepada sistem dan pelbagai parameter AWJ seperti tekanan air, diameter orifis, jenis zarah kasar, saiz zarah kasar, bentuk zarah kasar, kadar aliran yang kasar, dan dimensi ruang pencampuran. Kajian ini menyiasat profil muncung. Muncung diperbuat daripada tungsten karbida. Ia akan mengalami haus selepas digunakan antara 100 hingga 120 jam. Kebulatan muncung AWJ boleh dilihat selepas proses pemesinan dan bulat itu boleh menjadi lebih tahan kepada serpihan dan kerosakan jika jejari muncung AWJ adalah kecil. Untuk profil haus, keputusannya menunjukkan bahawa muncung nombor 1 mempunyai diameter lebih besar di bahagian masuk iaitu 4.28 mm berbanding dengan muncung nombor 2 bahawa diameternya adalah 4.07 mm. Kemudian, struktur gelombang tumbuh di magnitud dan merambat ke bawah lubang muncung. Corak haus diperhatikan, yang corak haus yang berlaku adalah tertumpu di gerek muncung AWJ. Daripada keputusan, mekanisme hakisan yang berlaku di muncung AWJ boleh dibahagikan kepada tiga bahagian iaitu bahagian salur masuk, tengah dan keluar, dan mekanisme hakisan yang paling tinggi berlaku adalah di kawasan salur masuk. Haus muncung AWJ boleh berlaku melalui perubahan sistematik sistem parameter AWJ dan geometri muncung.

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Ø	Diameter

LIST OF ABBREVIATIONS

AWJ	Abrasive Water Jet
SiO_2	Silicon dioxide
Ro	Ratio
ASTM	American Society for Testing and Materials
SEM	Scanning Electron Microscope
AWJM	Abrasive Water Jet Machine
Al203	Aluminium oxide
SiC	Silicon carbide
ANN	Artificial Neural Network
WC	Tungsten carbide
EDM	Electrical Discharge Machining
Co	Cobalt
MM	Micrometric
NM	Nanometric

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Abrasive Water Jet (AWJ) machining is a type of unconventional machining process. The abrasive water jet has been upgraded from Water-jet machining to Water-jet cutter. The idea of abrasive water-jet is began in 1935 by Elmo Smith when the idea to add an abrasive into the water for the use of liquid abrasive blasting. After that, Leslie Tirrell created a mix of high-pressure water and the abrasive which is used for the purpose of wet blasting. Lastly, Dr, Mohamed Hashish has changed and develops the modern of abrasive water-jet technology.

The working principle of abrasive water-jet (AWJ) is the mixture of water and abrasive in a mixing chamber to cutting the harder materials such as composite materials, stainless steel, ceramics, titanium alloys and etc. The abrasive particles are accelerated by the flow of water and then come out the nozzle with the stream. Types of abrasive that is generally used for abrasive water-jet (AWJ) machining are sand (SiO_2), glass beads, aluminium oxide, garnet, and silicon carbide. An abrasive water jet (AWJ) system is a device that uses high-pressure processing (200-500 MPa) of water to accelerate the abrasive particles erodes the target material. High pressure of water is accelerated through fine orifices (0.24 to 0.40 mm diameter) to produce a highly flow velocity of the water. The circulation flow through the mixing chamber to create a partial vacuum by the venturi effect and entrains abrasive particles are mixed and accelerated in the high velocity water flow in the nozzle. Materials from foam to metal, stone and ceramics is capable to cut when the water, abrasive and air is mixed. Through manipulation of robot head to cuts and careful control of cutting parameters, excellent surface quality and accuracy in machining complex geometries can be achieved (Nanduri et al, 2002).

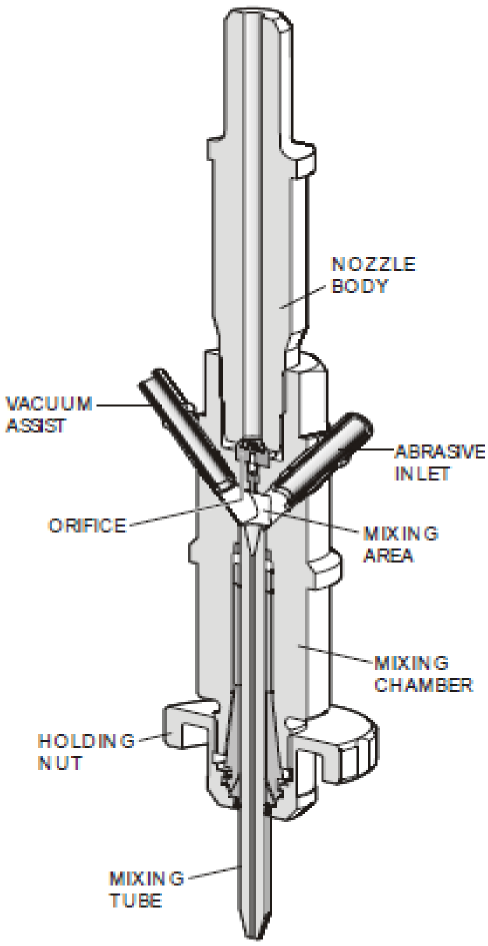


Figure 1.1: Diagram of high-performance abrasive water-jet cutting head

Source: Powell, M. (2009)

There are two kinds of nozzles commonly used for material removal average in abrasive water-jet (AWJ), tungsten carbide nozzles which have a useful life of 12 to 13 hours and sapphire nozzles have a useful life of 3hr (Saurabh Verma et al, 2014).

Nozzle wear can occur depending on the system parameters abrasive water-jet (AWJ) and nozzle geometry. Example system parameters that occur in nozzle are nozzle length, inlet angle, diameter of the nozzle, orifice diameter, and so forth. For the nozzle geometry parameters that affect the nozzle to become wear which are nozzle length, diameter, inlet cone angle of incoming and inlet cone depth (Nanduri et al, 2002).

The wear conditions in the nozzle are difficult to simulate. Although the material properties such as density, hardness and fracture toughness provide some indirect indicators of performance put on nozzle material, a more direct measure wear resistance is required. This wear will affect the efficiency of momentum transfer between water and abrasive and for the wear diameter also has an impact on particularly effect at the width of the cut for machining.

1.2 PROBLEM STATEMENT

The challenge of wear in abrasive water-jet (AWJ) is mainly focused on the system parameters and cost for the types of nozzle. Wear of the nozzle wall also can lead the jet turn into an incoherent, leading to increase in kerf width on the workpiece, surface quality deterioration and loss of precision cutting. The system parameters such as nozzle diameter, it is well known that keeping the ratio, Ro, the diameter of the nozzle with a diameter about 0.3-0.4 (all parameters remaining constant) would lead to mixing and optimum cutting conditions. The rate of increase in the diameter of the exit note here is in line with expectations. The mixing conditions result in the most effective distribution not only improves performance but also increases the wear of cutting nozzle. When the nozzle diameter increases, there is less resistance / interactions lead to a downward trend in the rate of weight loss nozzles.

The wear conditions inside the abrasive water jet nozzle are difficult to find or simulate. While materials such as density, hardness and fracture toughness provide some signs of wear performance of the indirect nozzle material, a more direct measure wear resistance is required. Conditions in standard ASTM wear tests different from those present in the nozzle and therefore often not a reliable indicator of the performance of the nozzle. The nozzle wear is typically monitored by measuring the exit bores using a video measurement system. The erosion mechanism and microstructure of AWJ nozzle had also been studied. Besides that, it was pointed out that short-term growth is not very uniform bore and not a reliable indicator of long-term performance or the life span of the nozzle.

1.3 PROJECT OBJECTIVE

The objectives of this analysis are:

- To analyse the wear profile in terms of roundness and roughness of wear nozzle.
- To analyse the microstructure of the wear tungsten carbide nozzle.

1.4 PROJECT SCOPE

To achieve results when analyse of wear on abrasive water-jet (AWJ) nozzle, there are several experiments and test need to be conducted and calculated. To complete this project, these are the aspect that needs to be experimented and investigated:

- One type of nozzle that will be considered which is tungsten carbide nozzle.
- A hot glue gun was used to make casting the 3D wear profile.
- Scanning Electron Microscope (SEM) will be used to see the microstructure of tungsten carbide nozzle.

1.5 EXPECTED OUTCOME

At the end of this research, the expected outcome is to analyse and to check the comparison between two nozzles wears in terms of roundness, roughness, erosion mechanism and microstructure for the abrasive water jet nozzle.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Abrasive water jet (AWJ) machining technology is one of the most current for non-traditional materials used in processing industries with several advantages such as small cutting forces, high flexibility, high machining versatility and no heat distortion. AWJ is a machine in which water is a very important medium through which to accelerate the removal of materials by using abrasive particles. Came in the late 70`s, this mechanism was built and developed by Franz to cut laminated paper tubes in 1968 and glasses in 1983. In fact, it is used to replace wet saws coated responsible for cutting the stone. From the river water, the cuttings of materials with water are developing. A small stream of abrasive particles are introduced in water jet cutting in such a way that the water jet`s momentum partly transferred to coarse particles. To achieve the high-speed jet of water is accelerated because large quantities of abrasive particles with greater velocity. To achieve this high velocity, the particles are enabled to pass through the nozzle with compressed gas or air carrier. So, this can be an advantage over conventional machining process that allows precise control of material removal rate. Caused by lower cost and more efficient, the cutting stone and tiles are usually made by a water jet abrasive. The plane of water jet cutting is very functional in soft materials such as "paper, food, textile, paper and wood."

Mostly, types of abrasive that use in AWJM are Garnet, aluminium oxide (Al203), Diamond and silicon carbide (SiC). The feed speed was adjusted to allow full jet penetration for each type of abrasive, while maintaining some parameters such as the size of the abrasive, pressure pumps and a standoff. There are also various types of process with the help of water jet cutting that can be performed such as cutting, drilling, milling, surface preparation, cleaning, coating removal, and Penning water jet.

An Abrasive Water Jet (AWJ) is compatible with Laser machining systems. An operator of both types of system exploits the speed of laser cutting systems. When the harden material want to be cut, then the addition of fine abrasive such as Garnet that allows to cut material, so it can be a tool steel or marble up to 8 inches (203.2 mm) thick **(**Sonawane et al, 2015).

AWJ machining using water jets to accelerate the abrasive particles to spread fast enough to cut much harder the workpiece material. Figure 2.1 is a schematic of the AWJ machining process of the head assembly illustrating the cutter and cutting basic principles. Abrasive water jet (AWJ) machine include of four main areas which are the water preparation system, pressure generation system, the jet former and abrasive supply systems.

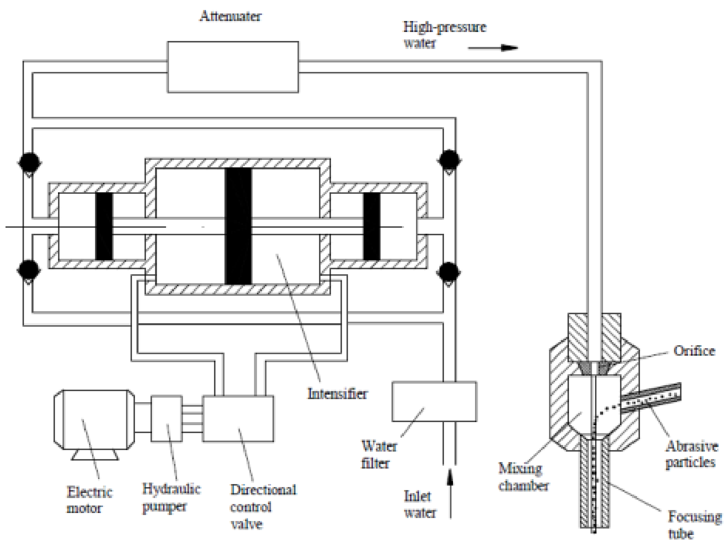


Figure 2.1: Schematic of an AWJ machining system

Source: Pi, V. N. (2007)

2.2 THE NOZZLE GEOMETRIC AND ABRASIVE WATER-JET (AWJ) PARAMETERS

The nozzle of AWJ can become worn and it depends on the nozzle geometric and AWJ parameters. Nozzle wear can happen in terms of the dimensions of the mixing chamber,the flow rate of abrasive, shape and size of abrasive, abrasive type, diameter of the orifice and the pressure of water. After that, for the nozzle geometric parameters that can cause wear include the length of AWJ nozzle, the angle of inlet cone and inlet cone depth, and the diameter of bore (Saurabh Verma et al, 2014; and Kahlman et al, 2001).

The cutting process of abrasive water-jet (AWJ) is quite sensitive in the hydraulic power input due to the variations, the feed rate of abrasive, nozzle alignment, and the mixing of tube geometry. For the abrasive properties, it focuses more to the density of abrasive, abrasive size, the melting point, the shape of the abrasive and abrasive hardness that have been highlighted **(**Kahlman et al, 2001).

2.2.1 Nozzle length

The nozzle length is increased if the exit of the bore growth and weight loss rate is decreased. If the mixing tube is longer, then it will slow the wear rate at the exit area. The nozzle bore profiles reveal despite the internal profile has developed a identical, direct influence on the growth of the nozzle length, which is having a direct influence and also delay the development of the nozzle to become worn from reaching the exit. Besides that, the increasing of nozzle length doesn't unchanged the flow pattern upstream.

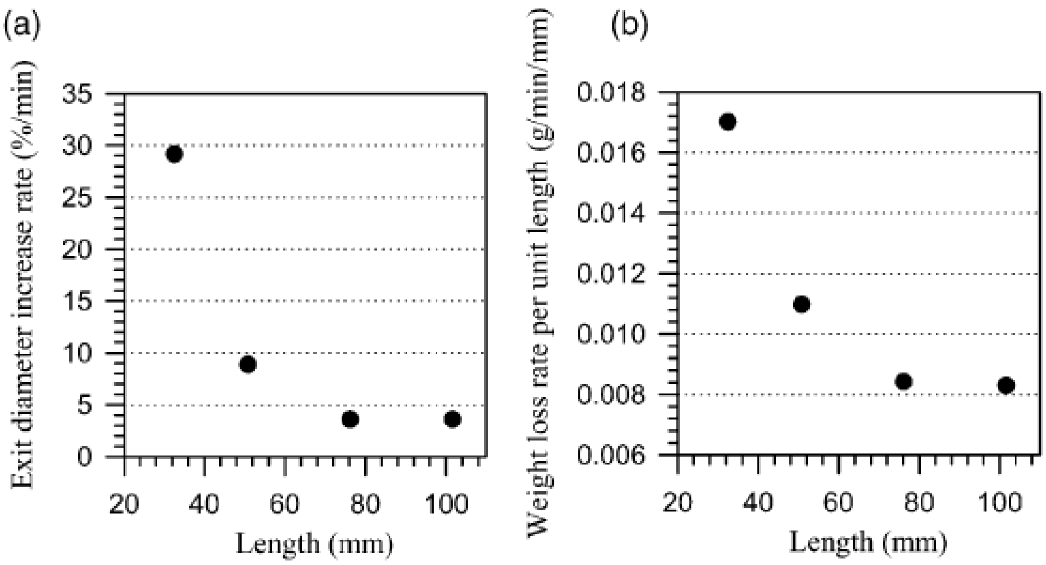


Figure 2.2: The effect of nozzle length on nozzle wear

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2002)

For the effect of focus length of abrasive water-jet nozzle (AWJ) on skin friction is the analysis that has been made for the coefficient of friction skin and the jet exit, which is slightly reduced the kinetic energy decreases as the increasing focal length because in terms of using the law of Bernoulli`s law, increased energy loss with an increase in the length of the nozzle (Verma et al, 2015).

2.2.2 The nozzle diameter

The diameter of nozzle also can be categorized as one of the nozzle geometric and Abrasive Water-jet (AWJ) parameters. The nozzle wear will be increased at cutting process in term of when the mixing condition results in the way that mostly the particles not making any improvement in the performance.

The focusing of the nozzle and the orifice of AWJ diameter can affect the quality and efficiency of water-jet process. There are some solutions to maintain the nozzle desire quality also for the efficiency, which is it must be monitored or maintain the specification and condition of the abrasive water-jet nozzle. In this experiment, any changes in the size of the orifice nozzle that related to decrease the depth of cut and make a detailed on the influence that focus on the nozzle and the orifice size that perform in the abrasive water-jets. To maintain the process of abrasive water-jets cutting has kept the orifice size in the good range such as from 0.25 mm to 0.3 mm. After that, the range of focusing nozzle starts from 0.76 mm to 1.2 mm (Jegaraj et al, 2005; and Schwetz et al, 1995).

In neuro-genetic approach, the process parameter for abrasive water-jet is focus more on the variation in terms of the diameter of focusing nozzle. The purpose of neuro-genetic is to give some ideas or to suggest the process parameters of AWJ cutting processes such as to maintain the desired depth of cut. It also can improve the process such as developing an artificial neural network (ANN) that function to make prediction depth of cut abrasive water-jet nozzle. There are many functions of artificial neural network (ANN) which is it also considering the diameter of the focusing AWJ nozzle (Srinivasu et al, 2008).

2.2.3 Inlet angle of nozzle

The inlet angle of the abrasive water-jet nozzle, the trend is reduced out of the bore by increasing the entry angle and the tests have been conducted in a short duration. After continuing the tests on a different nozzle inlet angle, it reveals that the life expectancy of the nozzle inlet angle is same. The wear in bore profile revealed that it has a significant difference in the profile of different angle of nozzle inlet. When the non-linear exit bore growth increases, the profile result becomes more undulating as the entry of nozzle inlet angle increases. As a conclusion, it`s much better if the size of the inlet angle of the nozzle is smaller because it will produce the linearity in the growth out of the nozzle hole (Nanduri et al, 2002).

2.2.4 The pressure of water

The wear of nozzle also can occur from the pressure of water itself. Therefore, the exit wear rates and the rate of the weight is displayed with increased the water pressure to the maximum level. The occurrence of abrasive particle fragmentation due to excessive pressure and one way to reduce the occurrence of abrasive particles increases the solution is to wear the nozzle. Besides that, a reduction in wear is insignificant even at the upper limit of the range considered.

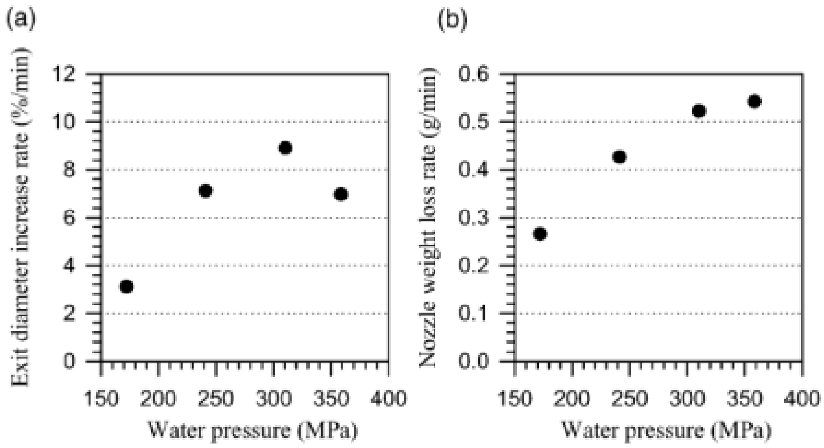


Figure 2.3: The water pressure effect of the nozzle wear

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2002)

In addition, the pressure of water that use in abrasive water-jet nozzle can create a defect on the surface roughness of the materials. So, the surface roughness of the material can be analyzed in conjunction with using the thickness of the cut. When the pressure at the water-jet increased, it will cause the increased for the surface quality. Thus, it will cause a decrease in the surface roughness. Therefore, the effect of the pressure of water is when the depth of cut increases, then the surface roughness also will increase due to the depth of cut (Sonawane et al, 2015).

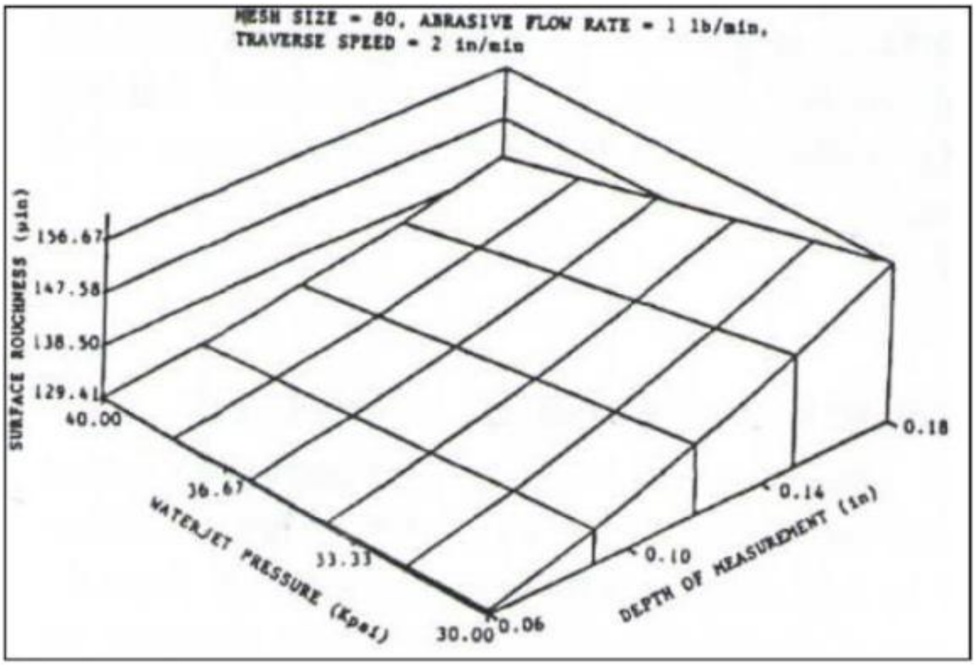


Figure 2.4: Effect of the abrasive water-jet pressure on the surface roughness

Source: Sonawane, G. D., and Bachhav, R. M. (2015)

2.3 NOZZLE MATERIAL

There are many types of nozzle materials that have been used in abrasive water-jet (AWJ) such as tungsten carbide nozzle, sapphire nozzle, boron carbide, and etc. As we known, nozzles is the cheapest individual components for the process of the water blast system, but the nozzle also can make the difference which is twice or more productiveness compared to other most expensive component in the high pressure pump.

The quality of the new water-jet nozzle depends on the design of the nozzle itself, it also can differ in the range of 60 percent between one type of nozzle to another type of nozzle. All the ingredients of the nozzle wear can cause deterioration of the quality of jet and also can reduce the production rate. An additional, result of wearing the nozzle may be can reduce some of the pressure of pump because the wear will increase the size of the nozzle, which requires an increase in term of the flow rate to maintain the same value of pressure.

2.3.1 The carbide nozzle

The tungsten carbide has been labelled as the nozzles that are usually regarded as the most durable nozzle materials of all kinds of nozzle materials. Moreover, the tungsten carbide also is the most durable in cases without the filter dirty water. There is some limitation of carbide nozzle to operate because when the performances of pressure reach to 10000 psi an above also with the water filtered to 25 microns or more, it will affect the duration life of a carbide nozzle which is it will make the carbide nozzles duration time to perform as short as 10 to 20 hours. The erosion of the material will make the nozzle to become wear and the wear also can be quite constant, as the size increases uniformly for the nozzle orifice and it still produces a coherent jet (Wright et al, 2003).

There are other types of failure that occurs when the carbide nozzle erosion does not take place uniformly. After that, there has a little change in term of size at the orifice, but the major changes occur in the resulting of jet quality. The tungsten carbide collected the carbide particles with a binder that has been cemented together. From the both of the variables may affect the strength also the corrosion resistance of the nozzle (Wright et al, 2003).

Figure 2.5: Comparison of new in the same material and design at the right, the jet pattern which is produced by the 5% binder nozzle until 15 hours on the left

Source: Wright, D., Wolgamott, J., and Zink, G. (2003)

2.3.2 The steel nozzles

Since the nozzles that fabricated from steel, it is quite widely in design section also in terms of quality. The steel nozzle was built to replace the threaded inserts, or also can be made by drilling into the head of a disposable or less, also can be used in the cleaning tube. When replaced the nozzle with better quality of the nozzle, usually it will have longer life and have a good operation. When use a purified of water to 25 microns or better and the impact of pressure that increase up to 140 MPa, with properly constructed steel nozzles can have the duration of the operation range that could be used within 150 until 200 hours, which is more longer than the carbide nozzles (Wright et al, 2003).

There are two types of mechanisms of steel nozzles wear which is the first one is cavitation erosion and the second is abrasive erosion. For the cavitation erosion, the rates are depending mainly on the design of the steel nozzle. As for the abrasive erosion, it usually will happen in all the steel nozzle with the rough particles into the water (Wright et al, 2003).

2.3.3 The sapphire nozzles

The operating pressure that commonly used in sapphire nozzles is above 140 MPa. The sapphire nozzles reduce a highly in terms of quality of the jet in orifice size is less than 1 mm, but the disadvantages have a lower quality jet in terms of the larger size, differentiate to carbide nozzles and have a good quality of steel nozzles. The sapphire nozzles can be the best nozzle for water-jet process compared to steel and carbide because with a good condition of the sapphire nozzles, it useful life can be reach to 200 hours or more, if the materials do not undergo a corrosion problem (Wright et al, 2003). Nevertheless, the material of sapphire nozzle is very fragile, and some small chips that have on the edge of the orifice will destroy the quality of the water-jet. When the particles pass through the nozzle it will cause this chip, and the sapphire nozzle also can be cracked if a larger particle strikes the sapphire nozzles. Because of that, the sapphire nozzles are commonly used in the waterblasting machine that operates which is the pressure are below 140 MPa (Wright et al, 2003).

As a conclusion, all the nozzle materials is not suitable for the operating conditions. The process of selection to use the nozzle should depend on how the operating pressure function and how to filter the water. The design of the nozzles also will make some effect on the operating life of the nozzles (Wright et al, 2003).

2.4 NOZZLE WEAR STRUCTURE

The AWJ nozzle wear profile is characterized by a wave pattern. Figure 2.6 shows the tungsten carbide, WC nozzle that was exposed with garnet abrasive wear for 3 hours at a pressure of 310 MPa and a gross flow rate of 3.8 g / s. The casting silicone nozzle prior to sectioning is also shown in the figure. It can be seen that a series of waves was developed along the bore. This wave-like structure is clearer in Figure 2.7, which is the bore radius of the plot through the nozzle. After that, the actual profile, as measured at the nozzle cut off, and embeds the profile, measured before sectioning, shown to correlate well. The profile embed in Figure 2.8, while only characterize steps in creating a radius along the length of the nozzle, provides a very good description of the developments in the nozzle. The profiles taken at 1.2 and 3 hour intervals revealed that as wear goes, wave structure as it grows in magnitude and propagates down the nozzle bore (Nanduri et al, 2002).

Ordinary commercial life as ROCTEC nozzle, 100 under the standard AWJ is approximately 50-100 hours. An accelerated wear test has been developed to carry out parametric studies on the nozzle wear quickly and cost effectively.

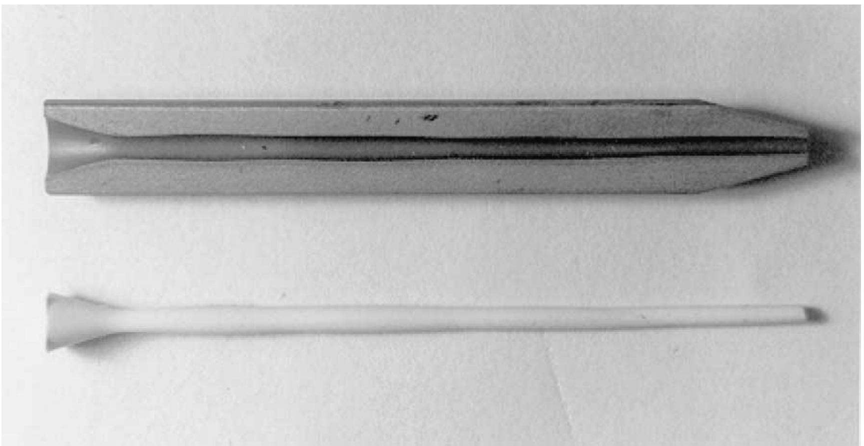


Figure 2.6: Sectioned nozzle and casting of tungsten carbide,WC nozzle after 3 hours of testing

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2002)

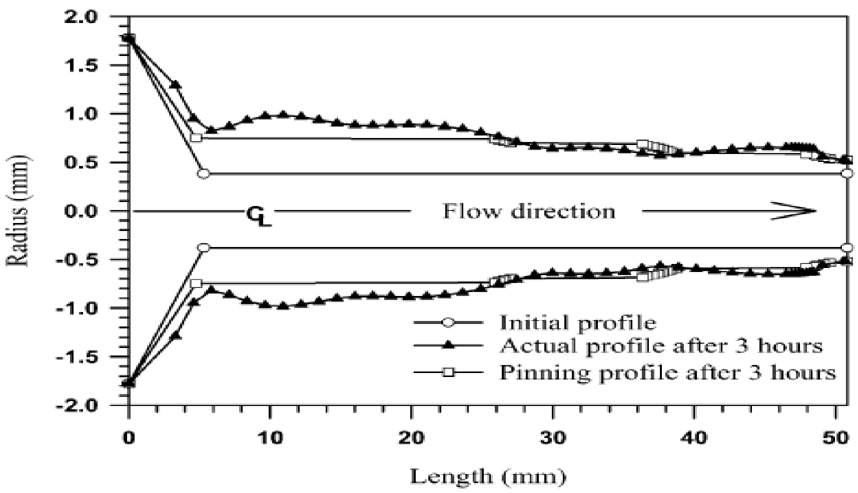


Figure 2.7: Comparison of pinned and actual profiles of tungsten carbide,WC nozzle after 3 hours testing

Source: Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2002)

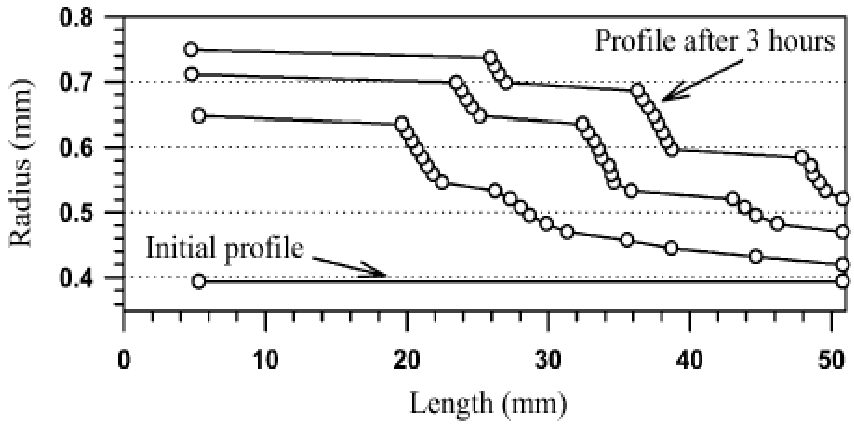


Figure 2.8: Bore profiles of tungsten carbide, WC nozzle

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2002)

Figure 2.9 and Figure 2.10 also show about the geometric and system parameters in the AWJ nozzle. The nozzle wear also occurs because of material parameters such as hardness, strength and microstructure (Nanduri et al, 2000). In most cases, the result of the nozzle wear is the diameter of the exit has the smallest size compare to the entry size.

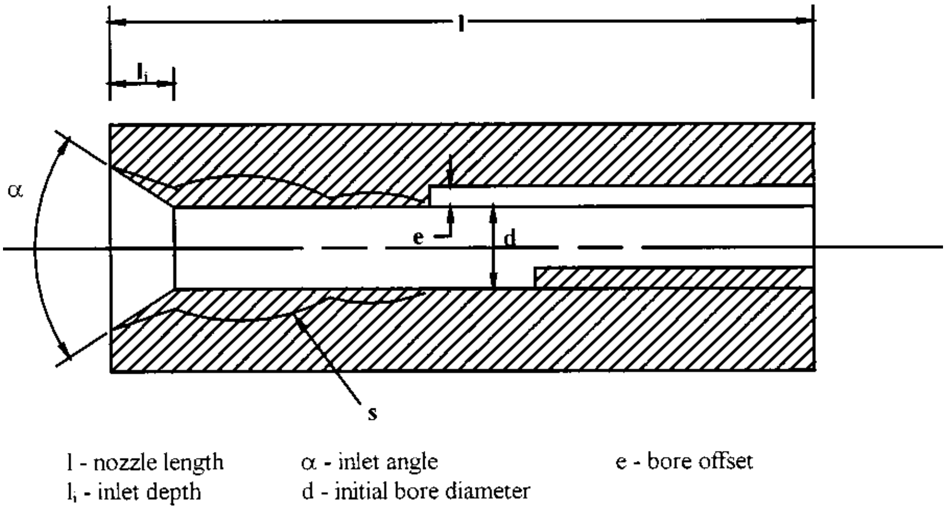


Figure 2.9: Abrasive water jet nozzle wear; geometric parameters

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2000)

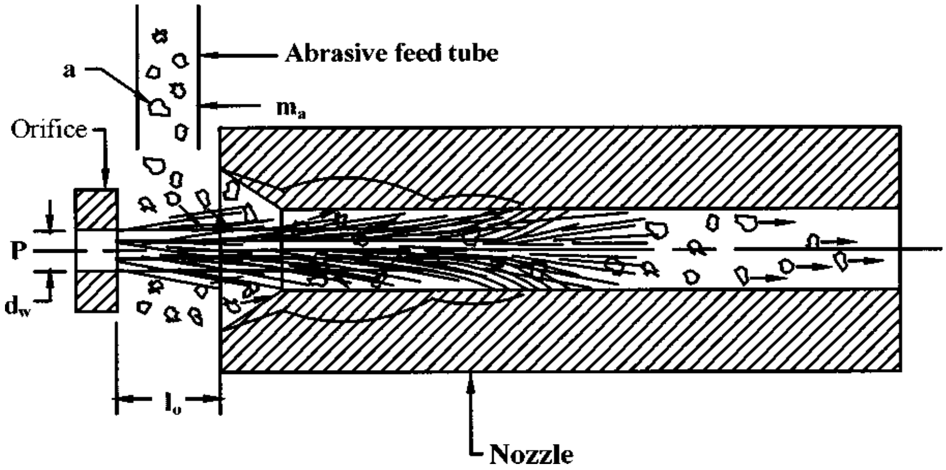


Figure 2.10: Abrasive water jet nozzle wear; system/ process parameters

Source: Nanduri, M., Taggart, D. G., and Kim, T. J. (2000)

For axisymmetric nozzle, the nozzle is made of a porous, 316 stainless steel and machined using EDM. EDM machining parameters needed to maintain the porosity has been established and confirmed by observation using a scanning electron microscope (SEM). Figure 2.11 and Figure 2.12 shows the SEM image of the top and each cut section of the porous nozzle. The surface quality varies considerably, depending on the method used for the manufacture of porous material, and EDM machining parameters, such as energy levels, fireworks frequency and cutting speed (Anand et al, 2003).

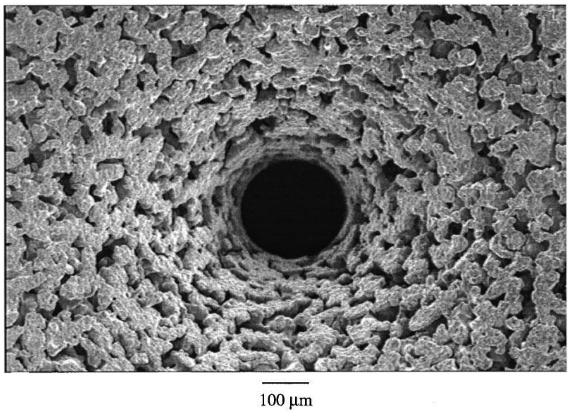


Figure 2.11: SEM micrograph of the top of the axisymmetric nozzle

Source: Anand, U., and Katz, J. (2003)

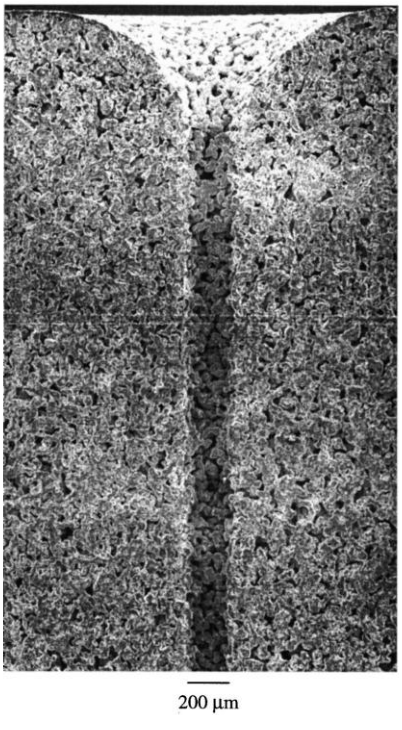


Figure 2.12: SEM micrograph of the cut section of the axisymmetric nozzle

Source: Anand, U., and Katz, J. (2003)

2.5 MICROSTRUCTURE AND WEAR RESISTANCE OF TUNGSTEN CARBIDE, WC NOZZLE

Tungsten carbide (WC) is a well-known candidate for the application of wear-resistant / corrosion due to extraordinary hardness. The overall performance (ie, toughness) tungsten carbide,WC can be improved by adding a ductile metal, such as cobalt (with a content of 3-30% by weight). This type of carbide has very high strength and high toughness related with very good wear resistance **(**Katiyar et al, 2016).

Hardmetals based on tungsten carbide (same with cobalt or cobalt binder / nickel binder) was subject to slurry erosion jet, using silica sand or alumina erodent entrained in a water jet. A wear process had been identified in some hard metal and the results correlated with conventional parameters used to evaluate hard metal (hardness, linear intercept binder, WC grain size) (Gant et al, 2015). The tungsten carbide, WC grades with a binder 3-15% and grain size below 1 µm have a high hardness and excellent in compression strength, related with a wear resistance property (Katiyar et al, 2016). Figure 2.13 shows the very fine grade (<0.5 µm) of WC/Co material.

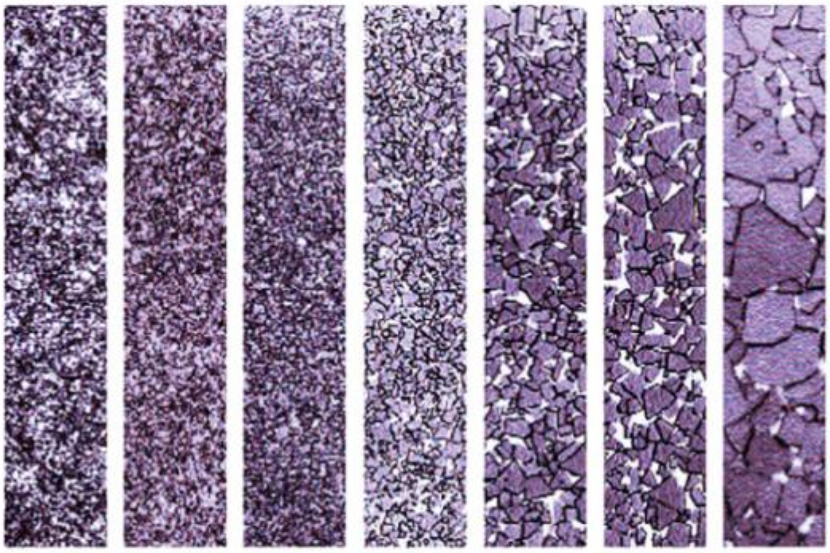


Figure 2.13: Grain size classification of tungsten carbide tool bit materials (WC/Co) and the light matrix phase is formed by Co

Source: Katiyar, P. K., Singh, P. K., Singh, R., and lava Kumar, A. (2016)

The abrasive water jet (AWJ) cutting is known as the accelerated erosion technology, where the coarse aggregate particles are introduced into the jet of water (Thomas, D. J., 2013). The erosion wear trial was conducted with a volume fraction of 25% round silica sand (212-300 μm size) in the nozzle flow channel with pH 6.3 mains water as the carrier medium; selected as representative wellstream mature subsea oil. Five minutes early for agitation sand, transient entrainment and delivery to achieve steady state is sufficient to achieve the delivery of sand over and over through 300 mm long nozzle with velocity jet of 19.9 ms-1, using a standoff distance of 25 mm, with 45 ° and 90 ° angle of impingement. The samples were swung into position after the initial five minute period under the jet impingement angle presets appear in the standard period of 20 minutes (Gant et al, 2015).

The extensive scanning electron microscope was conducted before to extend the understanding of the current mode and reported at length, but the main findings of repeated below with examples in the form of surface erosion micrograph from Figure 2.14 until Figure 2.21. From figure 2.14, the larger tungsten carbide, WC grains tend to break easily, but less easily extracted from the smaller grains. Longer binder intercepts have a tendency to promote tungsten carbide, WC re-embedding fragments at Figure 2.14. The combination of fine WC grains and low intercept binders generally generate the greatest erosion resistance and proven with a high incidence planar, commonly seen in grade NK07 (Figure 2.15 and Figure 2.16). Figure 2.17 shows the tendency of large WC grains to resist picking out at 90 ° impingement, and also the tendency to oppose the removal of the grain group in any way. The use of alumina as an erodent also can be seen to produce plastic grooving, even in subtle, hard, low binder grades fines fraction as NK07; see Figure 2.18. The inspection of mars 11A cross-sections exposed a high occurrence of subsurface cracking when subjected to flow regular occurrence erosion stream (Figure 2.19 and Figure 2.20) (Gant et al, 2015).

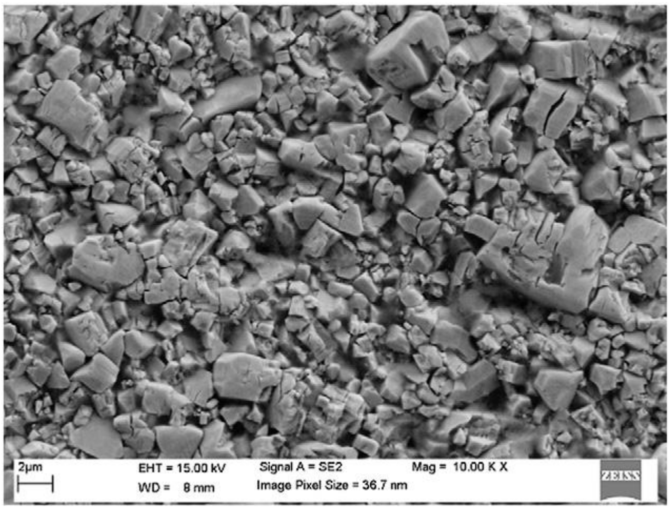


Figure 2.14: 45° impingement

Source: Gant, A. J., and Gee, M. G. (2015)

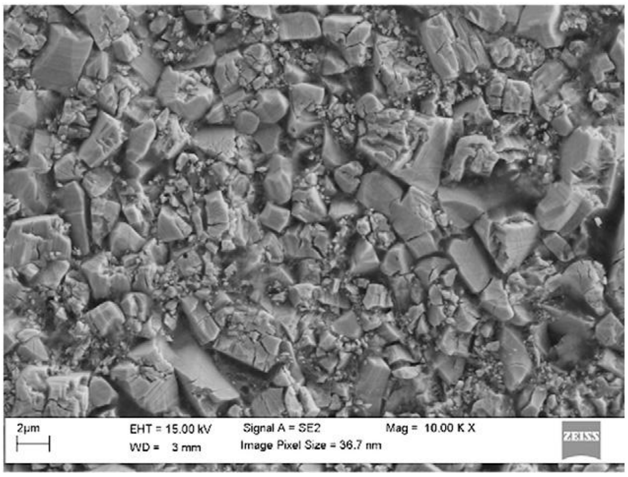


Figure 2.15: 90˚ impingement, tungsten carbide, WC grain fracture and the slip lines, edge chipping, binder denudation and debris re-embedment

Source: Gant, A. J., and Gee, M. G. (2015)

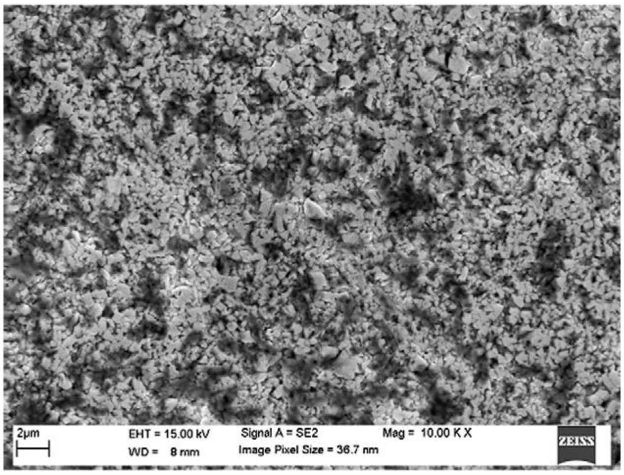


Figure 2.16: 45˚ impingement

Source: Gant, A. J., and Gee, M. G. (2015)

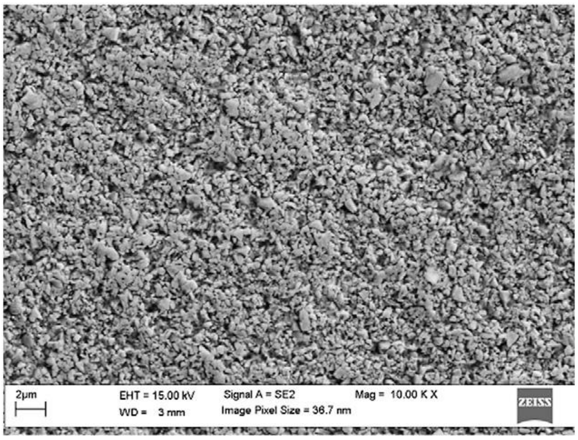


Figure 2.17: 90˚ impingement, plastic grooving

Source: Gant, A. J., and Gee, M. G. (2015)

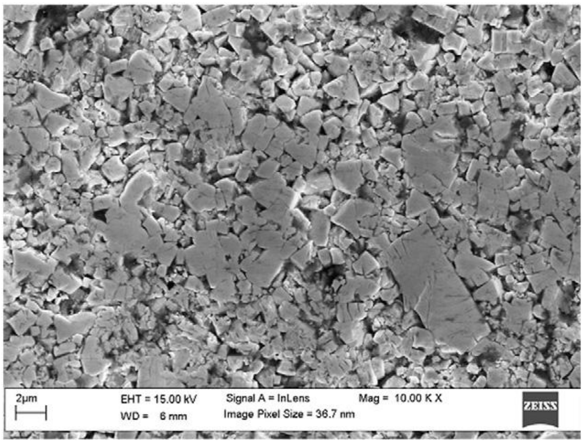


Figure 2.18: 90˚ impingement using alumina slurry, apparently mild wear regime in the larger grains and grain clusters

Source: Gant, A. J., and Gee, M. G. (2015)

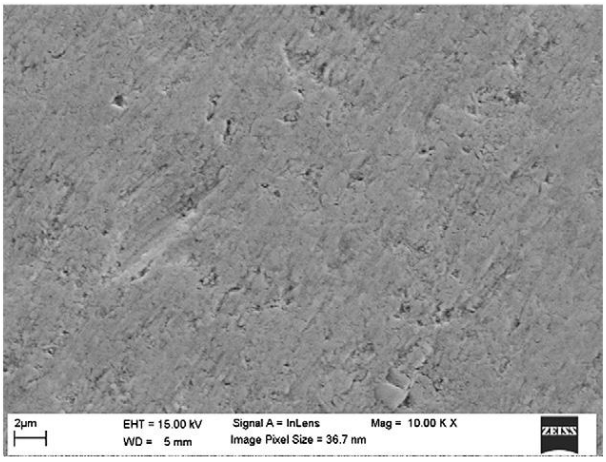


Figure 2.19: 45˚ impingement using alumina slurry

Source: Gant, A. J., and Gee, M. G. (2015)

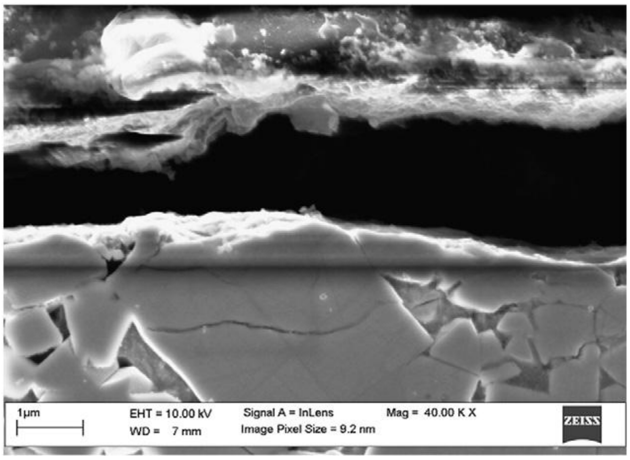


Figure 2.20: 90˚ impingement, Cross section through wear scar in mars 11A, lateral crack in large tungsten carbide, WC grain

Source: Gant, A. J., and Gee, M. G. (2015)

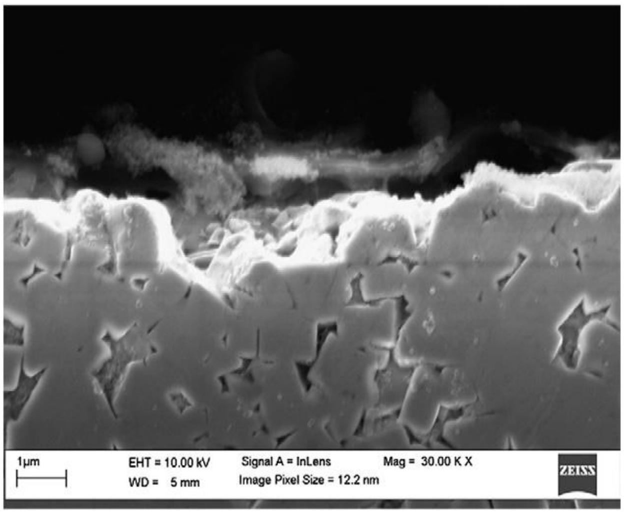


Figure 2.21: 45˚ impingement, cross section through wear scar in mars 11A, apparent pluckout (tungsten carbide, WC grain removal)

Source: Gant, A. J., and Gee, M. G. (2015)

2.6 AWJ DIAMETER

The diameter of AWJ is one of the parts that difficult to measure. The AWJ almost can machine any types of material as long as the hardness must be lower than the hardness of the abrasive that being used. The AWJ nozzle size was the main point that can affect the entrance and the exit hole areas (Schwartzentruber, J., and Papini, M., 2015). Figure 2.22 shows the two nozzles with different focusing tubes, but the diameter is nominal which is 0.8 mm. The difference between these two nozzles is the time usage, one of the nozzles was brand new (Figure 2.22(a)) and one was being used for machining within 10 hours (Figure 2.22(b)) (Orbanić et al, 2009).

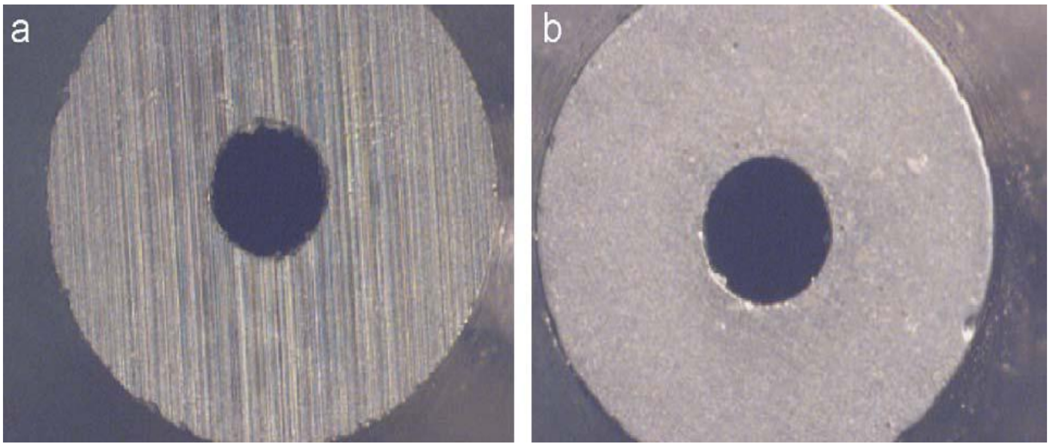


Figure 2.22: (a) New focusing tube d_t = 0.8mm and (b) used focusing tube d_t = 0.86mm

Source: Orbanić, H., Junkar, M., Bajsić, I., and Lebar, A. (2009)

2.7 EROSION MECHANISM OF AWJ NOZZLE

The erosion is a form everywhere degradation of surface engineering components. The loss of material in abrasive wear, always occurs with hard particles or bulge on the counter surface. There is also the possibility of the three body abrasion which is when the abrasive particles are free to roll and slide between two different surfaces. The erosive wear happened because when the hard particles trapped in gas stream or a fluid that hitting the surface**.** Figure 2.23 shows the worn surface of the micrometric (MM) and nanometric (NM) WC-12Co microwave clads are illustrated for the three body abrasion (Zafar, S., and Sharma, A. K., 2016).

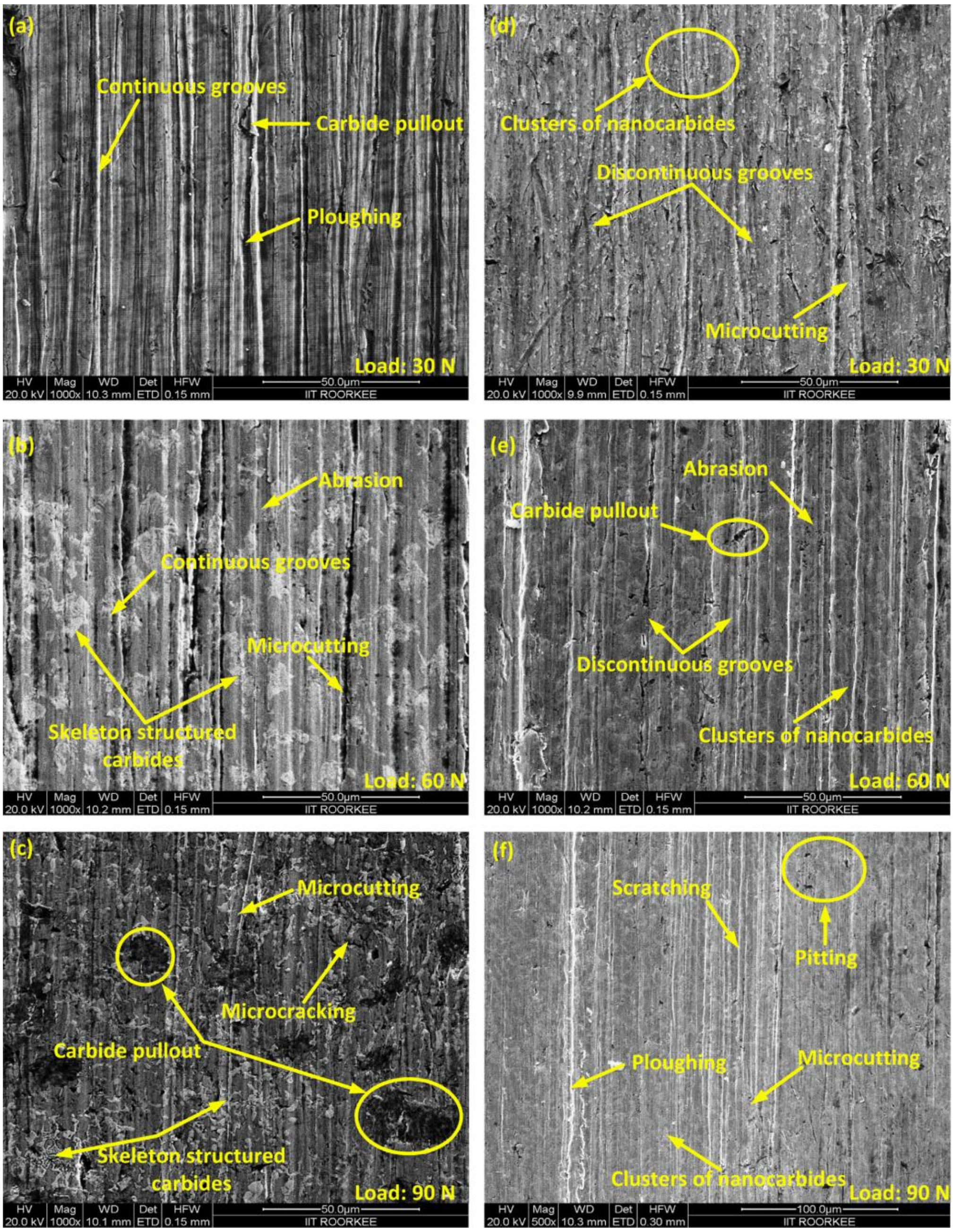


Figure 2.23: Typical SEM micrographs of worn surfaces after abrasive wear test, (a-c) MM and (d-f) NM WC-12Co

Source: Zafar, S., and Sharma, A. K. (2016)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all methods and processes used is based on an earlier study will be compromised. Methodology is the proper way of operating performance that hinted usually right at the end of each level. The purpose of this methodology is to ensure that the review process is followed from the beginning to the end of the project. Figure 3.1 shows an example of a simple flow chart showing the process flow.

For this experiment, procedure and condition for analysis of wear on abrasive water jet nozzle has been designed. After that, the flow chart is very important to investigate in order to achieve that goal. Provides a flow chart before starting the research for the experiments. The experimental work of this study is based on a flow chart. For the first step, see the roundness of the nozzle using the video measurement system. In this analysis, the nozzle wear depends on the water pressure and the time spent of the nozzle that being used. The next step is to cut the nozzle into half using EDM wire cut to see the profile wear inside the nozzle. After that, clean the AWJ nozzle using the Branson CPX3800H Ultrasonic cleaner.

The next stage is the Video Measurement System were used to see the wear profile of AWJ nozzle. This video measurement system can measure the wear profile of the AWJ nozzle.After that, Metallurgical microscope used to seeing the erosion mechanism inside the AWJ nozzle. Then, make a casting process. This process is to make a 3D wear profile of the abrasive water jet nozzle. The abrasive water jet nozzle was subjected to 100 hours of garnet abrasive wear at a water pressure of 56000 psi or 386 MPa. Then, scanning electron microscope (SEM) will be used to see the microstructure of the nozzle wear. The last step is make and write the conclusion from overall analysis and the result documented in a form of report.

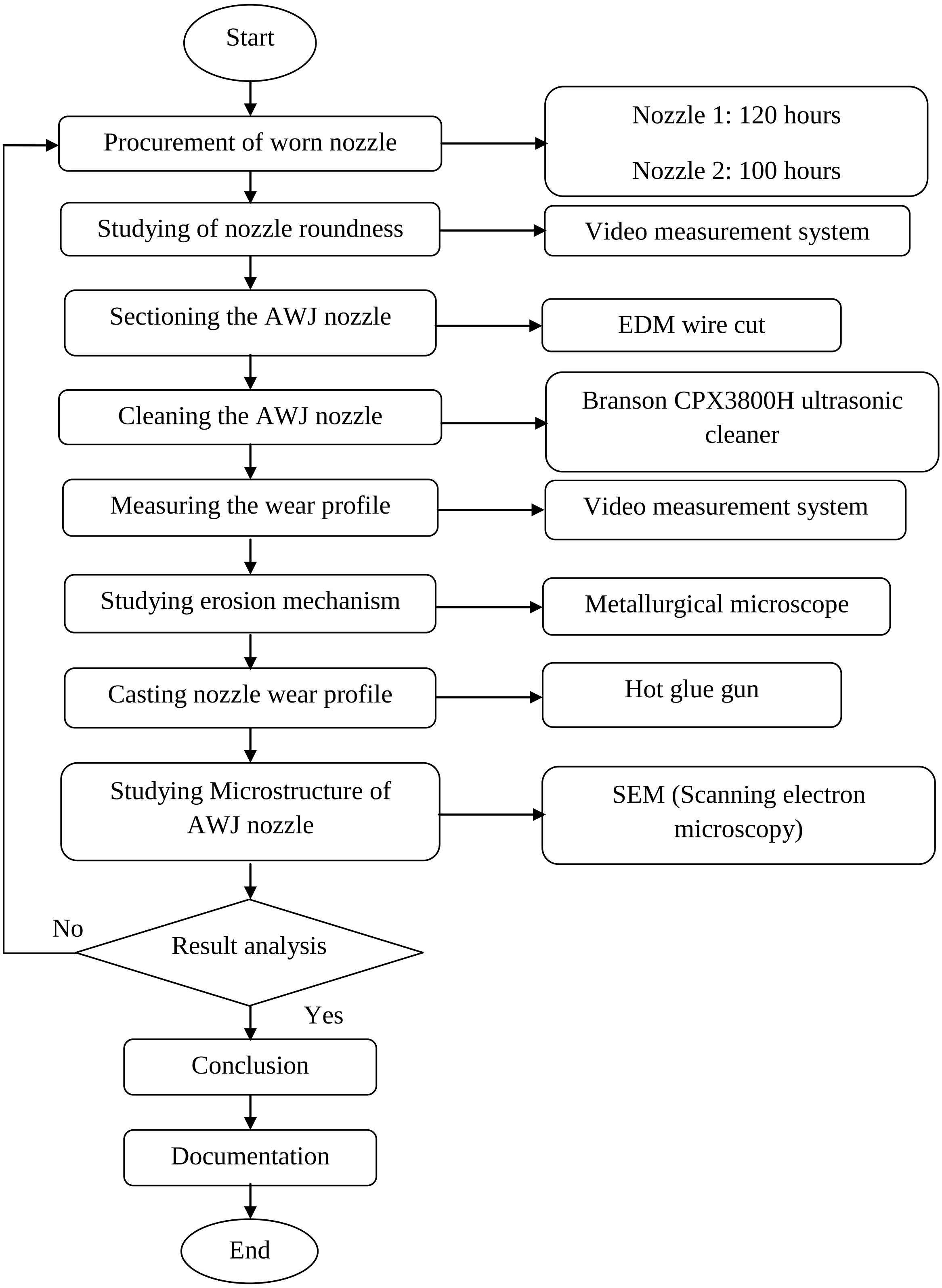


Figure 3.1: Methodology flow chart

3.2 RAW MATERIAL

In this experiment, tungsten carbide nozzle will be used as the raw material. This type of nozzle is often used in AWJ and the function of tungsten carbide nozzle is used for the mixing tube. Tungsten carbide has a higher toughness compared to boron carbide and composite carbide (Ness, E., and Zibbell, R., 1996). The tungsten carbide nozzle has been used for 100 hours and 120 hours. The pressure of water is 56000 psi or 386.10641 MPa for the nozzle to wear. The type of abrasive that been used for the nozzle to wear is garnet. The flow rate of the cutting process is approximately 0.08 to 0.5 kg/min or 15 to 30 kg/h and the size of the garnet is about 0.3mm.

3.3 TOOL

The selection of cutting tool is the most important factors to cut the AWJ nozzle into half. The wire diameter is typically about 0.30 mm for roughing cuts and 0.20 mm for finishing cuts. The wire is usually made of brass, copper, tungsten, or molybdenum; zinc- or brass-coated, multicoated, and steel-cored wires also are used, but in this cutting process, copper wire was used to cut the nozzle. The wire should have high electrical conductivity and tensile strength. It usually is used only once, as it is relatively inexpensive compared with the type of operation it performs.

3.4 MACHINE

3.4.1 EDM wire cut

In this analysis, EDM wire cut Sodick VZ300L shown in Figure 3.2 is used to cut the AWJ nozzle into half. EDM machine Electric discharge machining (EDM), also referred to as spark machining, spark eroding, burning, drowning, burning wires or wire erosion, is a manufacturing process in which the desired shape is obtained using electrical discharges (sparks).In the wire electrical discharge machining (EDM), also known as wire-cut EDM and wire cutting, single-strand thin metal wire, usually copper, is fed through the workpiece, submerged in a tank of liquid dielectric, usually deionized water.Wire-cut EDM is usually used for cutting thick plates of 300 mm and to make punches, tools and dies from hard metals that are difficult to machine by other methods.

The wire moving at a constant velocity in the range of 0.15 to 9m / min and a constant gap constant (kerf) is maintained during the cut. The cutting speed normally is given in terms of cross-sectional area cut per unit time. The wire-cut process uses water as a dielectric fluid, controlling the resistivity and the electrical properties of different filters and the de-ionizer unit. The water will flushes the cut, debris away from the cutting zone. Flushing process is an important element in determining the maximum feed rate for a given material thickness.

Wire-cutting EDM is generally used when low residual stress, because it does not require high cutting forces for removing material. If the energy or power per pulse is expected due to these low residual stresses, in spite of the fact that materials hasn`t been stress-relieved can distort in the machining process.

Figure 3.2: EDM wire cut machine, Sodick VZ300L

3.4.2 Metallurgical microscope

The function of Metallurgical microscope in this analysis is to see the erosion mechanism in AWJ nozzle whether the erosion mechanism is constant or randomly occurs inside the AWJ nozzle. This microscope can focus more accurate view and scale of the erosion mechanism in the AWJ nozzle because it had 4 types of optical.

Figure 3.3: Metallurgical Microscope

3.4.3 Video measurement system

The video measurement system is used for getting the wear profile of AWJ nozzle. This video measurement system can be used to measure the flat surface or little difference in height of the workpiece. Besides that, this microscope has many functions such as 12 rotating the light source, workpiece snapshot, geometry labels, geometric tolerance, automatic drawing and other functions.

Figure 3.4: Video Measurement System

3.4.4 Scanning Electron Microscope (SEM)

The Phenom ProX desktop scanning electron microscope (SEM) is the ultimate all-in-one imaging and X-ray analysis system. With the Phenom ProX, the sample structures can be physically examined and their elemental composition determined. It also can check whether are cracked or hole occur in the bore of the abrasive water jet (AWJ) nozzle. Figure 3.5 shows the Phenom ProX machine.

Figure 3.5: Phenom ProX Scanning Electron Microscope (SEM)

Sources:
http://www.nanoscience.com/files/cache/1408c9aecde5f7222647e0a42eab97d0_f775.png

3.5 EXPERIMENTAL SETUP

The cutting process was carried out on an EDM wire cut machine. To make sure the wire is not cut off during the cutting process, the cutting conditions and parameters must be set in a correct way to get a smooth process. The table 3.1 shows the dimension of the AWJ nozzle the type of wire for an EDM wire cut.

Table 3.1: The dimension of AWJ nozzle and EDM wire cut

<table>
<tr><th>MATERIAL</th><th>DIMENSION</th></tr>
<tr><td>1. Nozzle 1 (a)
</td><td>Length : 50 mm
Diameter : 7 mm</td></tr>
<tr><td>2. Nozzle 1 (b)
</td><td>Length : 55 mm
Diameter : 7 mm</td></tr>
<tr><td>3. Nozzle 2
</td><td>Length : 76 mm
Diameter : 7 mm</td></tr>
<tr><td>4. EDM Cut Wire

</td><td>Diameter : 0.20 mm
Weight : 5 kg</td></tr>
</table>

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter four will discuss about the result obtained after conducting the analysis. The AWJ nozzle was worn during the machining process using the Flow Mach machine. The results for this analysis will be shown in graph and figures. This chapter also provided the detailed explanation of the figures and graph. The data of the nozzle profile have been collected after EDM wire cut process and analysed the wear profile, the erosion mechanism, casting the wear of nozzle and analysed the microstructure of the AWJ nozzle. In this project, EDM wire cut is used to cut the AWJ nozzle into half. The Video measurement is used to see the roundness and the profile of the AWJ nozzle after wear, Metallurgical microscope is used to see the erosion mechanism and Scanning Electron Microscope, SEM use to see the microstructure in AWJ nozzle.

4.2 RESULT OF NOZZLE ROUNDNESS ANALYSIS

The roundness of AWJ nozzle can be seen after the machining process. The parameters of the cutting process is, the pressure of the water is 56000 psi or 386 MPa, the duration of the cutting process is 100 hours and 120 hours, and the types of abrasive are garnet mesh # 80 and the abrasive flow rate is 7.0 g/s. From the result, there are two types of AWJ nozzle to be compared which is the first nozzle is the nozzle number 1 and another one nozzle is nozzle number 2. Figure 4.1 below show the two types of nozzle that will be compared in this analysis.

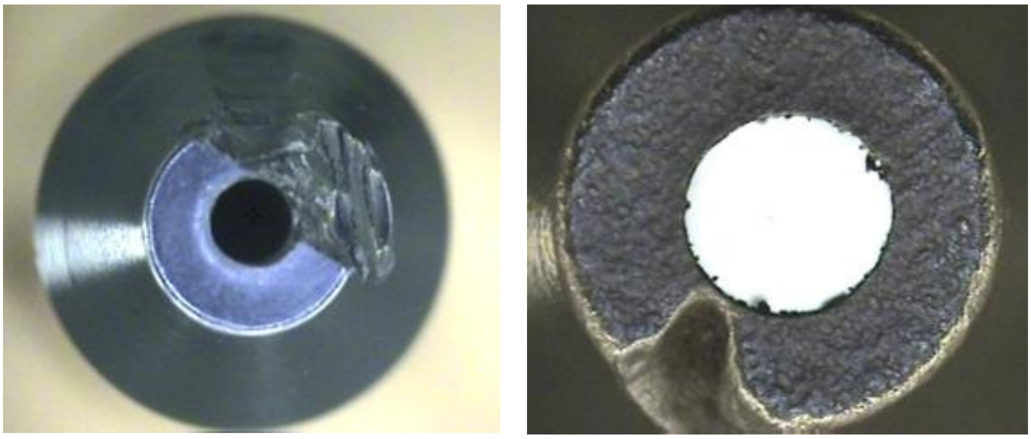
(a)

(b)

Figure 4.1: Two types of AWJ nozzle (a) nozzle number 1 and (b) nozzle number 2.

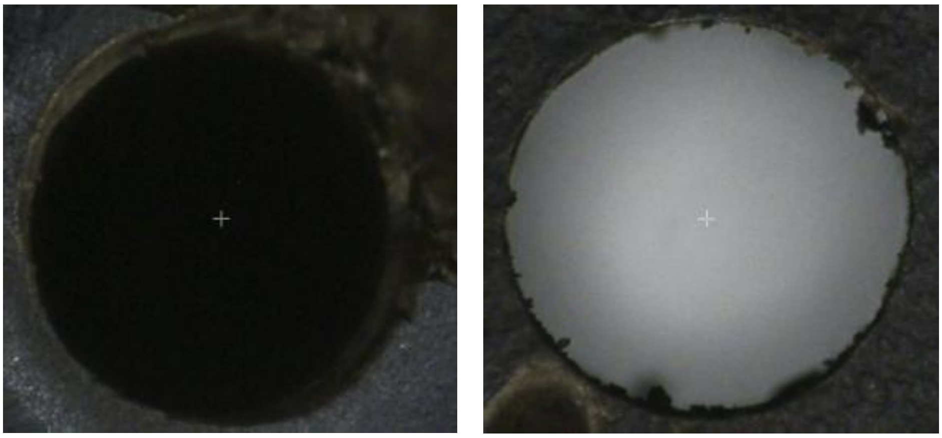
The AWJ can machine and cut about any types of material as long as the abrasive hardness is higher than the hardness of the material that want to cut or machining. In this analysis, it is found that the roundness of the AWJ nozzle can be seen after the 100 hours and 120 hours of machining. This roundness occurs because of the abrasive particles in the high pressure of water stream (Powell, M., 2009). The water also supplied to the cutting head which is the pressure of the water is 386 MPa. The roundness of the AWJ can be more resistant to the chipping and damage if the radius of the AWJ nozzle is small (Powell, M., 2009). The result also the same as the AWJ nozzle was used about 10 hours of machining and the pressure of the water was 300 MPa (Orbanić et al, 2009).

Figure 4.2 shows the top view of this two AWJ nozzle and the result of the AWJ roundness has been shown in Figure 4.3. This two nozzle shows that the shape of the roundness is not too different and not too noticeable because the water pressure that have been used in the machining process and the materials of the nozzle is the same which is the pressure of the water is 386 MPa and tungsten carbide is the material of the AWJ nozzle. Only the usage period has a little bit different which is nozzle 1, the operation hour of machining is 120 hours and 100 hours machining operation for nozzle 2.



(a) (b)

Figure 4.2: Top view of AWJ nozzle (a) nozzle number 1 and (b) nozzle number 2.

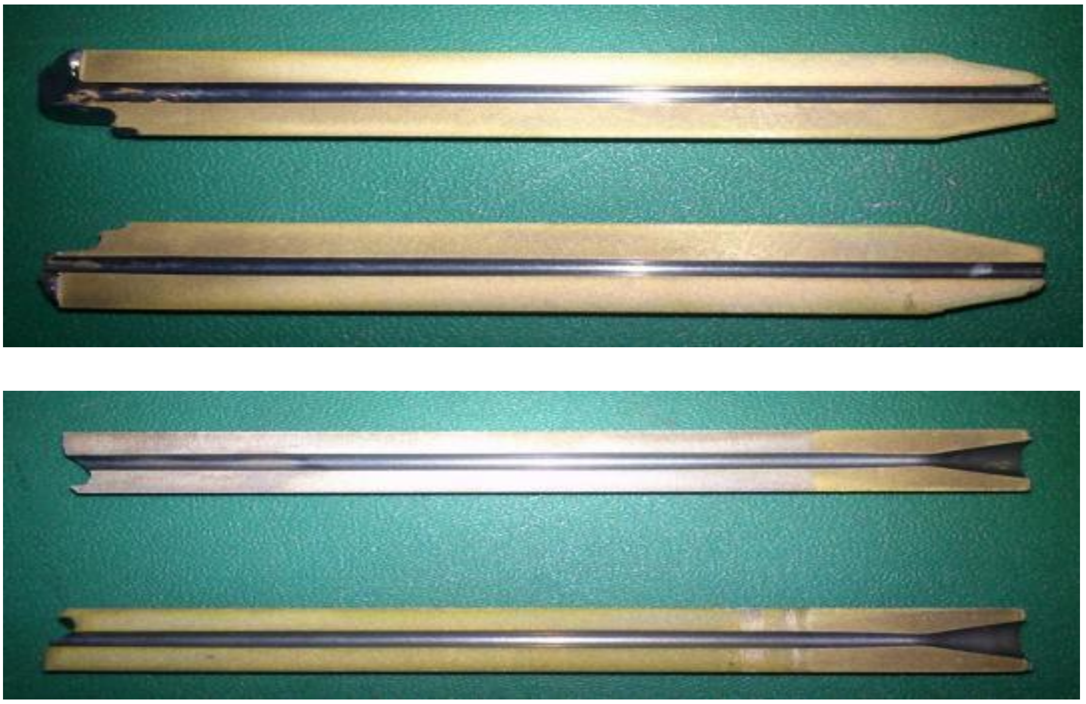


(a) (b)

Figure 4.3: Roundness of two AWJ nozzle (a) nozzle number 1 and (b) nozzle number 2.

4.3 RESULT OF THE AWJ NOZZLE WEAR PROFILE

In this analysis, it is found that the wear profile of the AWJ can be seen after the certain time of the machining process. The nozzle wear is dependent on the many of the AWJ systems and the nozzle parameters (Nanduri et al, 2002; Anwar et al, 2013; and Anwar et al, 2013). The nozzle wear is usually can be seen through the diameter exit bore of the nozzle. The weight loss rate was observed to be almost perfectly linear over the life of the nozzle and thus can be used in comparative performance evaluation (Nanduri et al, 2002). This result is also confirmed by (Nanduri, Madhusarathi, David G. Taggart, and Thomas J. Kim) study the effects of system and geometric parameters on abrasive water jet nozzle wear (Nanduri et al, 2002). Figure 4.4 shows the picture of the AWJ nozzle after the EDM wire cut process.



(a)

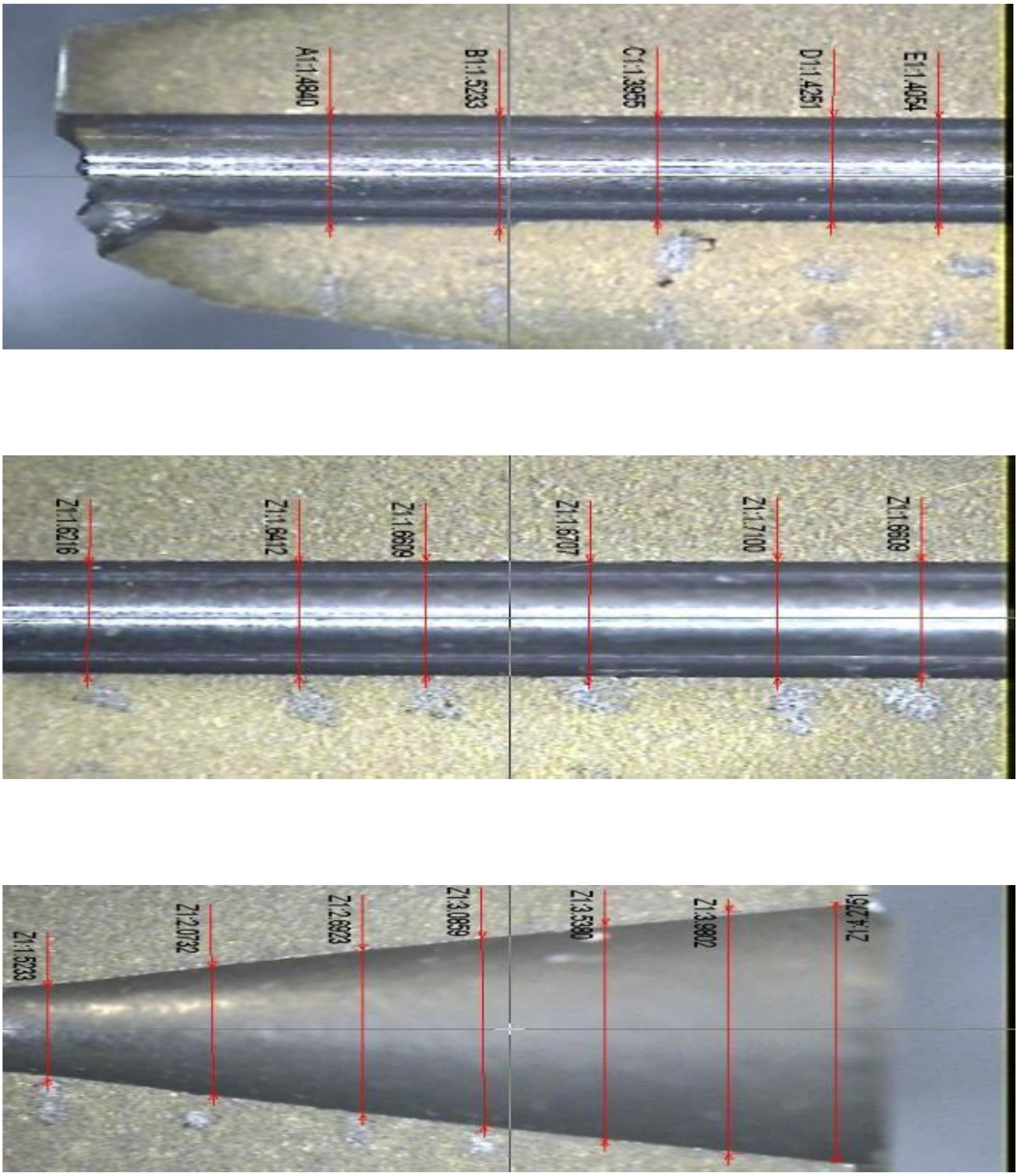
(b)

Figure 4.4: AWJ nozzle after the EDM wire cut process (a) nozzle 1 and (b) nozzle 2.

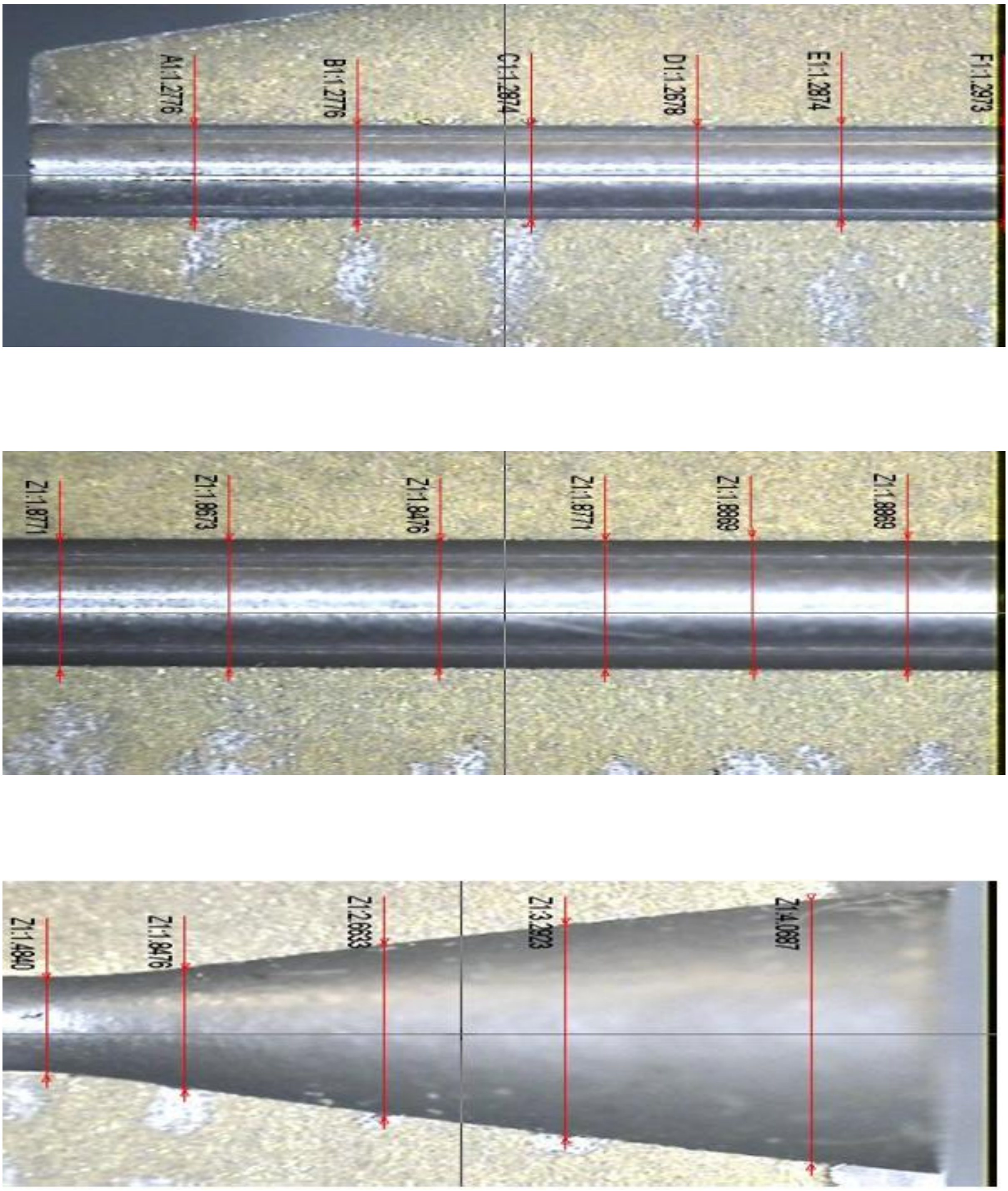
The result to measure the wear profile can be divided by three methods. The first method is a direct measured of the wear profile by using the Video Microscope System because this video microscope system can labels the geometry of the AWJ nozzle. The second method plots the graph of the video microscope system data. From the graph, it can be seen that a series of wave shape have developed along the bore. Lastly, the result of the wear profile can be seen by making a casting of the bore using the hot glue gun. It will help to see the 3D visualization of the wear profile. From these three methods, it can compare the difference between these two AWJ nozzle wear profiles.

4.3.1 Wear profile using the Video Measurement System

From the image, it was found that there a slightly different dimension of the wear profile between this two AWJ nozzle. Figure 4.5 shows the image of this two wear profile nozzle using the Video Measurement System. The result shows that the nozzle number 1 has a bigger diameter at the entrance of the AWJ nozzle which is 4.275 mm compared to nozzle number 2 that the diameter, 4.068 mm. The nozzle diameter also effects the nozzle wears. The mixing conditions cause the most effective distribution of the particles not only improves performance but also raise the nozzle wear (Nanduri et al, 2002). The diameter of the worn tungsten carbide for the inner bore along the nozzle is longitudinal directions, mostly at the entrance of the nozzle (Deng, J., 2009).


A1:1.4840
B1:1.5233
D1:1.4251
E1:1.4054
Z1:1.6216
Z1:1.6412
Z1:1.6609
Z1:1.6707
Z1:1.7100
Z1:1.6609
Z1:1.5233
Z1:2.0732
Z1:2.6923
Z1:3.0659

(a)



(b)

Figure 4.5: Wear profile using the Video Microscope System for (a) nozzle number 1 and (b) nozzle number 2.

4.3.2 The graph of the wear profile

The main parameters that make the AWJ became wear have been identified and analysed under different conditions and finally optimized. The parameters that play an important role in the wear of the AWJ nozzle are the water pressure, abrasive flow rate, orifice diameter, nozzle length, diameter and inlet angle (Nanduri et al, 2002). The graph for the nozzle number 1 that has a bigger wear profile compared to the nozzle number 2. This graph shows the wave structure of the wear profile in Figure 4.6, the plot of the bore diameter was made along the length of the nozzle which is more obvious compared to the result that used the Video Measurement System. The initial diameter of the bore before wear is 1 mm. There are two types of wear patterns were observed, which is the convergent wear pattern and divergent wear pattern. The convergent wear pattern occurs when hard mixing tube materials are relatively soft abrasives were used and for the divergent wear pattern occur otherwise (Saurabh et al, 2014). The efficiency will affect the momentum transfer between water and abrasives because of these wear. From the result, it shows the convergent wear pattern occurs in these analyses.

The highest point of wear that occurs in the nozzle on the graph of AWJ nozzle is nozzle number 1 at the length 28 mm which is the radius of the nozzle is 0.963 mm. For the AWJ nozzle number 2, the highest point of wear is at the length 23 mm and the radius of the nozzle is 0.953 mm. This result may have a little bit different because the operation hours are different between these two nozzles which is nozzle number 1 is 120 hours machining operation and 100 hours machining operation for nozzle number 2.

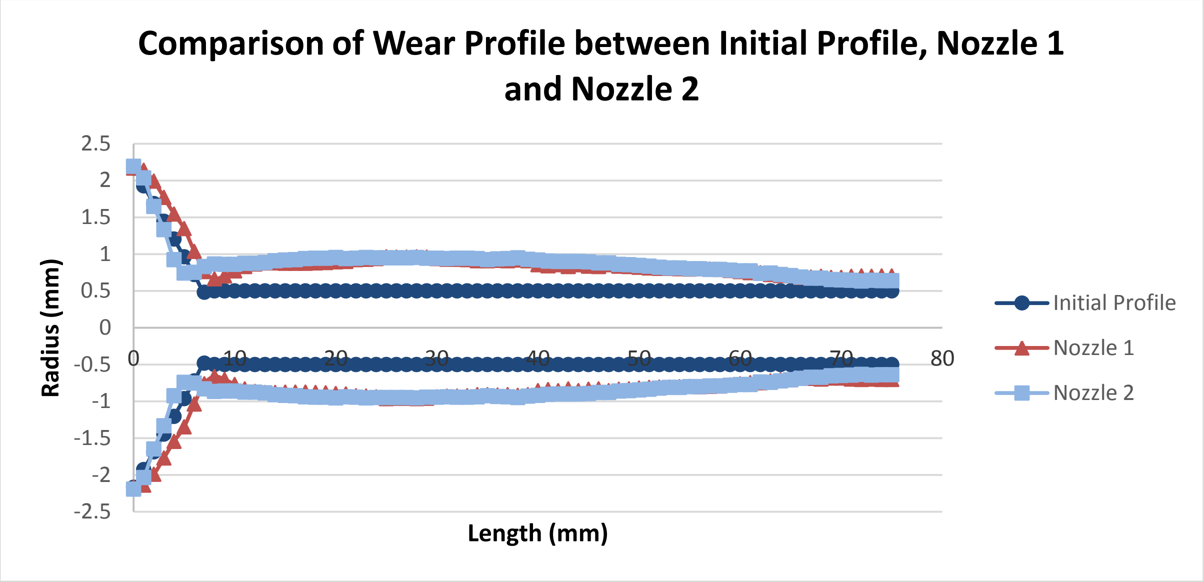


Figure 4.6: Wave structure of the wear profile for initial profile, nozzle 1 and nozzle 2.

4.3.3 The casting of the AWJ nozzle

Figure 4.7 shows the result of the casting process for the AWJ nozzle. The casting process of the wear profile was made by using the hot glue gun. The casting result help to see the wear result in the 3 D images or the real visualization of the tungsten carbide nozzle. It can be seen that the wave of the wear profile that occur in the AWJ nozzle have evolved along the bore of the nozzle. Therefore, this result agrees that this casting process will help to see the visualization of the wear profile of the AWJ nozzle (Nanduri et al, 2002). It also helps the profile appears as propagating steps or the wave shape of the bore at AWJ nozzle.

(a)

(b)

Figure 4.7: Casting result for (a) nozzle 1 and (b) nozzle 2.

4.4 MICROSTRUCTURE OF WEAR TUNGSTEN CARBIDE NOZZLE

The effect of the abrasive flow will produce friction between the abrasive particles and the surface of the bore profile. From the Figure 4.8, 4.9 and 4.10, it was found that the abrasive particles will hit the wall of the bore in the nozzle and will make the friction mark and the erosion track of the abrasive particles. Figure 4.8 shows the inlet area where the abrasive particles that has attached in the bore of the nozzle and the erosion track, which is the flow of the water and the abrasive particles.

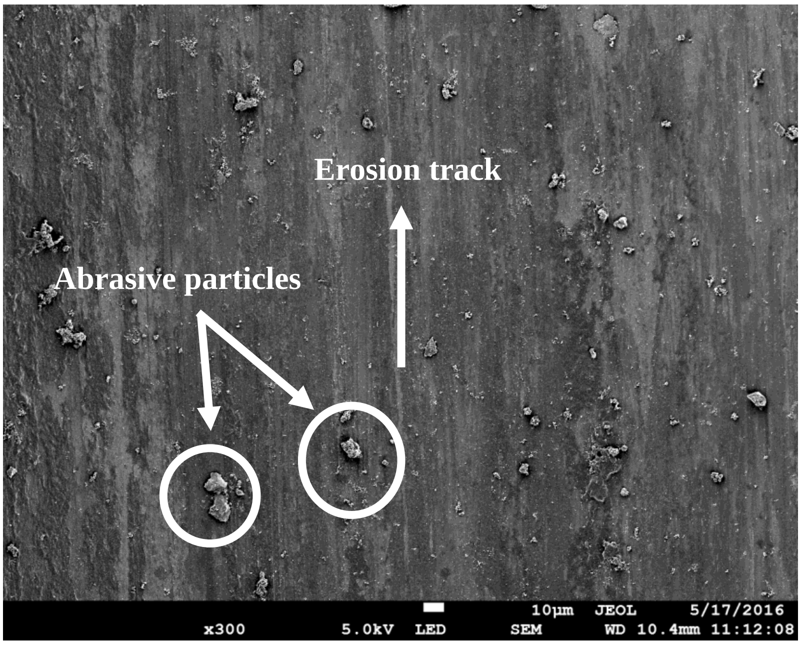


Figure 4.8: SEM image of inlet area in the bore of the AWJ nozzle.

Figure 4.9 shows the middle area in the bore of the nozzle. In the middle area, it can be seen that there are also have some abrasive particles but in smaller size.

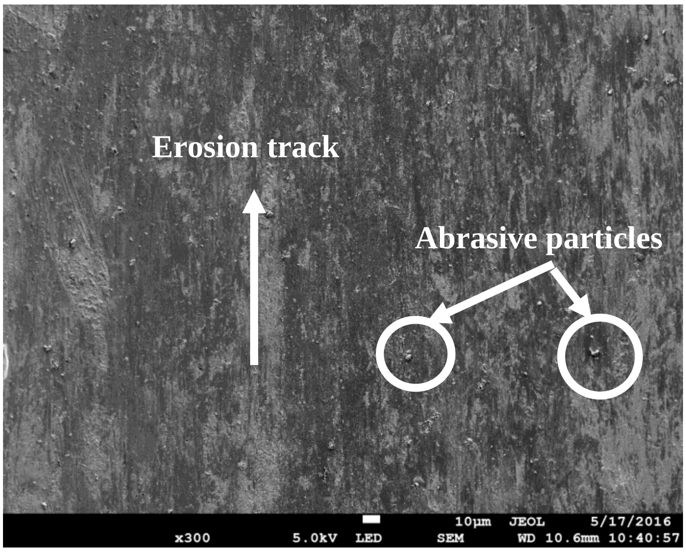


Figure 4.9: SEM image of middle area in the bore of the AWJ nozzle.

Figure 4.10 shows the outlet area in the bore of the AWJ nozzle. There are some of the abrasive particles also in a smaller size and the flows of friction are less compared to the inlet and middle areas.

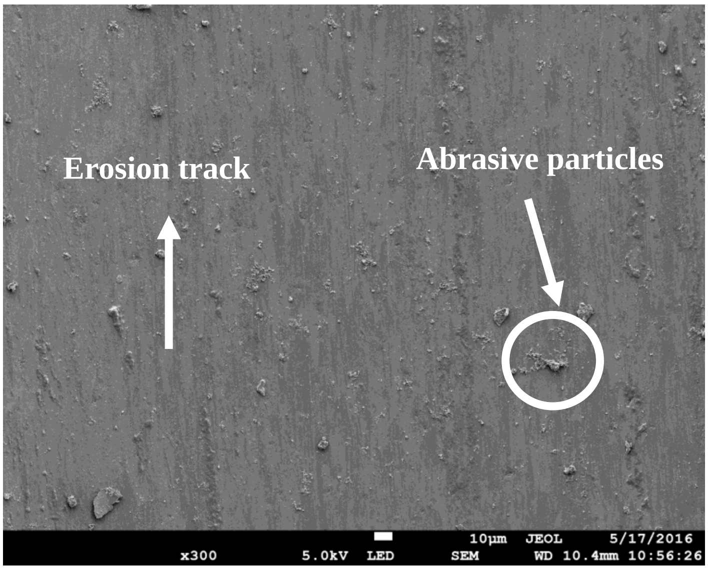
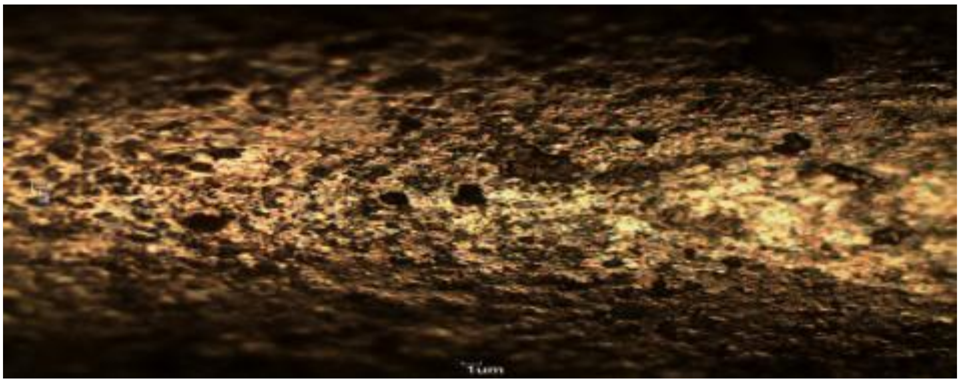


Figure 4.10: SEM image of the outlet area in the bore of the AWJ nozzle.

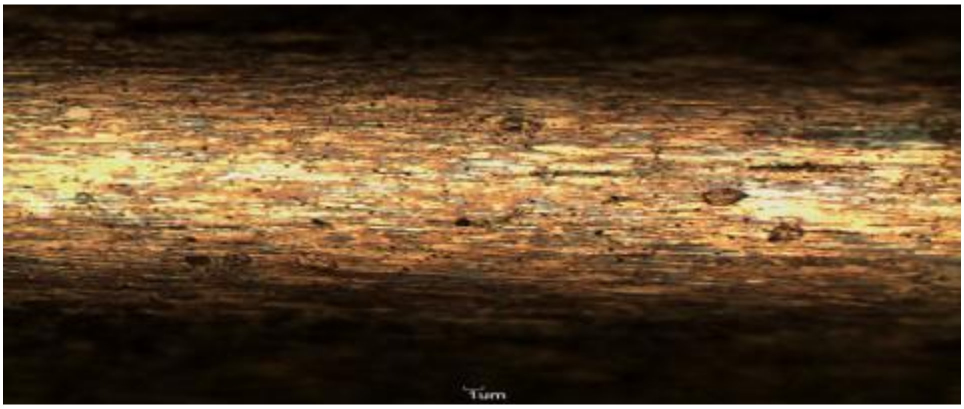
4.5 EROSION MECHANISM

The effects of solid particles are fundamental event in the removal of material by abrasive water jet machining in which a jet of high pressure and velocity, water and abrasive slurry used to cut the target material by means of erosion (Pramanik, A., 2014). Abrasion and erosion are a ubiquitous form of degradation of surface engineering components. The abrasive particles moving at about 70% of the velocity of the water jet impinge on the workpiece surface and significantly will increase the rate of erosion of material from the workpiece (Farayibi et al, 2014). The pressure of the water that has been used in this process is 56000 psi is equal to 386 MPa.

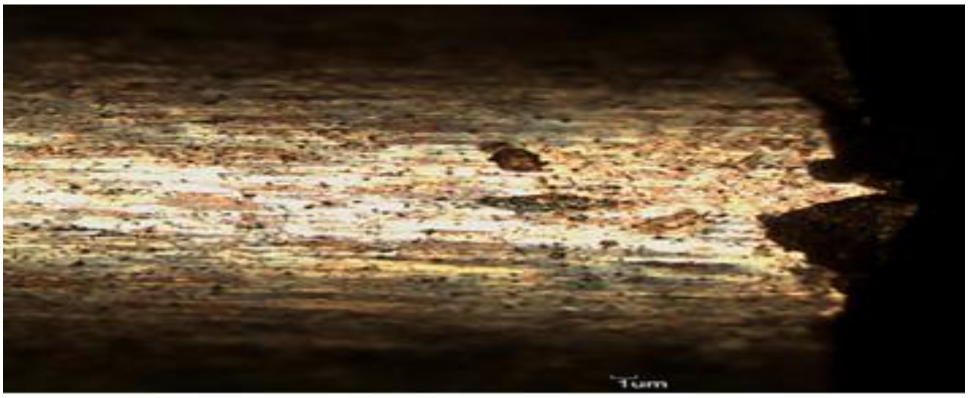
Figure 4.11 shows the result of the erosion mechanism of AWJ nozzles in 1 µm. After the machining process, it can be seen from figure 4.8 that the erosion mechanism that occur in the AWJ nozzle can be divide into three stages which is an inlet, middle and outlet. From the result, there are many erosion will happen at the inlet of the AWJ nozzle because the abrasive particles will accumulate on the inlet of the AWJ nozzle compared to middle and outlet or exit area. After that, in the middle of the AWJ nozzle there a some abrasive particles will hit the wall of the nozzle but less than the inlet area. Lastly, the abrasive particles will flow uniformly out from the AWJ nozzle. Figure 4.12 shows the schematic diagram of the flow of the abrasive particles in the inlet, middle and outlet of AWJ nozzle.



(a)

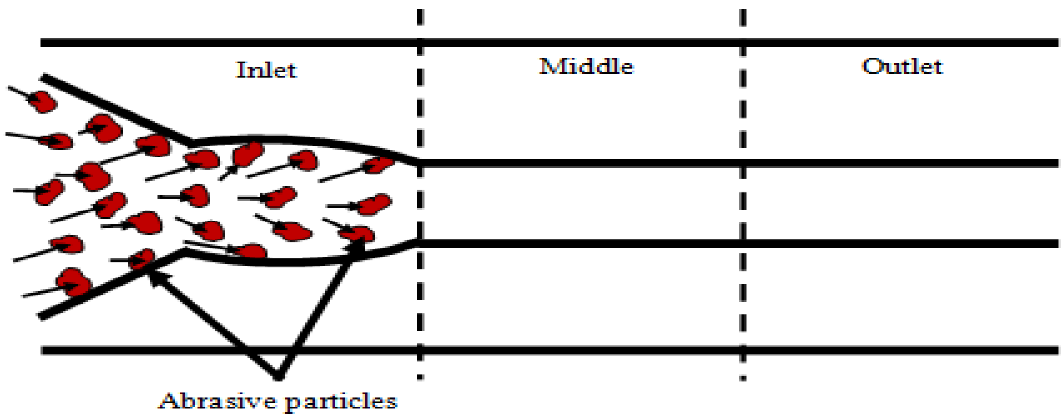


(b)

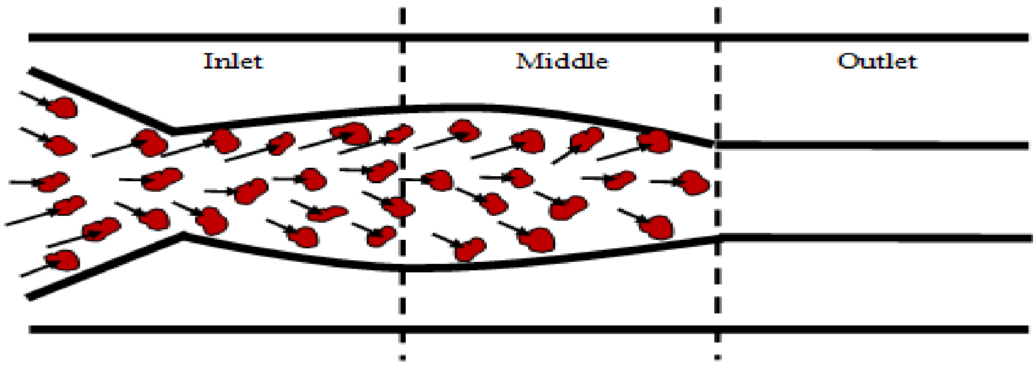


(c)

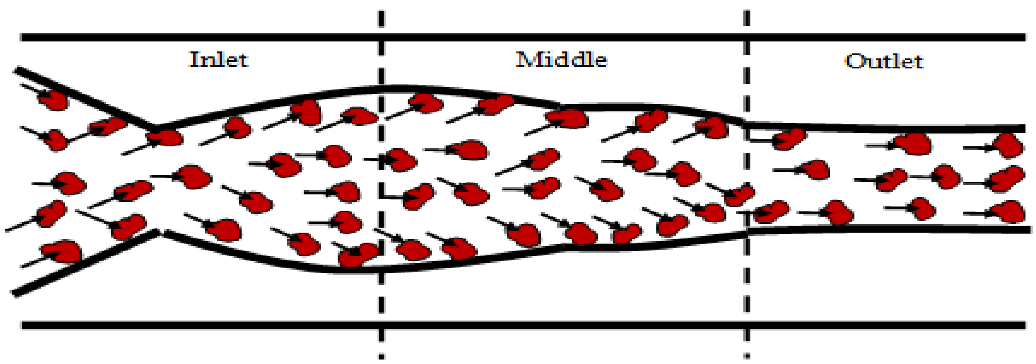
Figure 4.11: Erosion mechanism for (a) inlet, (b) middle and (c) outlet in AWJ nozzle.



(a)



(b)



(c)

Figure 4.12: Schematic diagram of the flow of the abrasive particles in the (a) inlet, (b) middle and (c) outlet AWJ nozzle.

4.6 DISCUSSION

From this chapter, the nozzle wear are influenced by Abrasive Water Jet system and also nozzle parameters such as nozzle length, water pressure, abrasive size, bore diameter and abrasive types (Nanduri et al, 2002; and Saurabh Verma et al, 2014). The abrasive flow rate, the pressure of water, orifice diameter, inlet angle and nozzle length are important parameter that will make the AWJ become worn (Nanduri et al, 2002). From this two nozzle, it can be seen that there are not much different wear because the material of nozzle, water pressure and abrasive types are the same in this analysis.

In this analysis, the roundness, wear profile, erosion mechanism and microstructure of the tungsten carbide nozzle after machining process and turn into wear. This two nozzle has a same water pressure, which is 386 MPa, tungsten carbide is the nozzle materials and types of abrasive are garnet mesh # 80. The difference is the time of the machining operation or the usage period, nozzle number 1 is 120 hours and nozzle number 2 is 100 hours machining operation.

Generally, the nozzle roundness can be seen using the video microscope system. From this two nozzle, the roundness of the nozzle is quite similar because the water pressure and the size of the abrasive is same during the machining operation. The range of the operation time is not too large because it only 20 hours difference between these two nozzles. If the period of nozzle 1 is a little bit longer such as 200 hours, maybe we can see the different roundness or cracks that will occur at the roundness of the nozzle.

The wear profile in the nozzle depends on the nozzle diameter, water pressure and abrasive flow rate (Nanduri et al, 2002; and Saurabh Verma et al, 2014). Actually, the nozzle diameter will increase the nozzle wear because a mixing condition causes the most effective distribution of the particles to enhance the cutting performance. The pressure of the water also very important to nozzle wear. If the pressure of the water are increased, it may increase the rupture of the abrasive particles so that it will minimize their effectiveness in wearing the AWJ nozzle (Nanduri et al, 2002). Besides that, as increased the abrasive flow rates will increase the wear rate without modifying the wear shape that showed in nozzle bore profiles. In the wear test, the top area of the nozzle which are the abrasive particles are so active in the formation of the wave. Therefore, uniform of wavy wear pattern in the exit area of the nozzle bore and lead to a uniform exit bore growth (Anwar et al, 2013). The total amounts of average wear of the worn nozzle are 0.026 mm. The wear shapes of the bore profile are converged wear pattern because the abrasive particles make the parallel flow through inside the bore of the nozzle.

The result of this analysis showed that the erosion rate of the AWJ nozzle are increased in the focusing tube wall because of the change of the abrasive shape and the abrasive mass flow rate is too high then the competence of the jet are decreases (Saurabh Verma et al, 2014). The length of AWJ nozzle also can affect the wear of the nozzle because the longer the length of the nozzle, it will make the wear of the nozzle become slower at the exit section. The erosion of AWJ nozzle is mostly accompanied by abrasive chipping in the nozzle inlet compared to middle and outlet section (Deng, J., 2009). The abrasive particles flows near the exit are well aligned as the nozzle length increases (Nanduri et al, 2000). The erosion of the nozzle will occur mainly in the inlet area because when the length of the nozzle is too long, then the abrasive particles will hit the wall at the inlet area are more than the middle and exit area. The nozzle inlet having a rough surface because suffers severe from abrasive impact which can cause the subsurface cracks.

From the result of the microstructure of wear tungsten carbide nozzle, it can be seen that there are different wear in the bore of the nozzle. At the inlet area has a highest roughly friction flow compared to middle and outlet area because in the inlet area, the abrasive particles will try to enter inside the nozzle and it will strike the wall of the nozzle more hardened at inlet area.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will conclude and summarize the study in various sections. For the first section gives a brief overview of the study and analysis, it covers the methodology and findings that related to the research questions and hypothesis. After that, based upon the Chapter 4 which is a discussion of the findings, the conclusions section puts all the research in the measurement of the quality of web-based library services. Finally, the recommendation for this analysis and guide for the future research.

5.2 CONCLUSIONS

The abrasive water jet nozzle wear phenomenon was studied in detail. From the result and analysis of the project, it can be concluded that the wear of the abrasive water jet (AWJ) nozzle can occur through the systematic variation of the system parameters abrasive water jet (AWJ) and the nozzle geometry. It also can be concluded that the wear nozzle can occur because of the different machining time can give a different of the wear profile of the abrasive water jet nozzle. The longer the machining time will make the bigger wear profile compared to the 100 hours of machining time.

From the literature review, the result of the nozzle roundness shows that the diameter of the nozzle roundness became larger compared to the initial because the pressure of the water and the abrasive flow rate that makes the diameter of the nozzle became larger. The size and the type of the abrasive particles also will make the abrasive water jet nozzle became worn.

From the experimental study, it is found that from the comparison of two different machining time will give a different of wear profile. It can be concluded that almost always, the outlet diameter or the exit diameter of the abrasive water jet nozzle is the smallest measurement compared to the middle area and the inlet area. The shape of the wear pattern is convergent pattern.

Thus, the water pressure (386 MPa) with the abrasive flow rate (7.0 g/s) will produce the erosion mechanism result. When the abrasive particles flow in the bore of the AWJ nozzle, it will hit the wall of the nozzle but mostly the critical area of the abrasive particles to hit the wall of the bore which is the inlet area. When the compressed air enters the converging into the end of the nozzle bore it accelerates straight, and the abrasive particles suspended in the flow. The abrasive particles will come out of the exit nozzle with a tight flow and produce a narrow, it will concentrate the blast pattern upon impact.

The casting result shows the 3D result of the wear profile of the bore of the nozzle. From the casting result, it can be seen the series of the waves of wear pattern that has been developed along the bore of the abrasive water jet nozzle. The tungsten carbide is the one of the extraordinary hardened material and also well-known for the wear resistance and corrosion in terms of application. During the 100 hours to 150 hours, the wear of the abrasive water jet are not too critical compared to the 200 hours to 300 hours of machining time.

5.3 RECOMMENDATIONS

Therefore, from the analysis result that have been obtained in the previous chapter, the future analysis works can be recommended such as:

1. The amount of the abrasive water jet nozzle should be at least more than four nozzles which can help to see the difference of the wear profile.
2. Use the different material of the abrasive water jet nozzle such as boron carbide and composite carbide.
3. Use more of the system parameter and nozzle geometry in the analysis.
4. Do the machining time at least more the 150 hours until 350 hours and above to see the result of wear nozzle.

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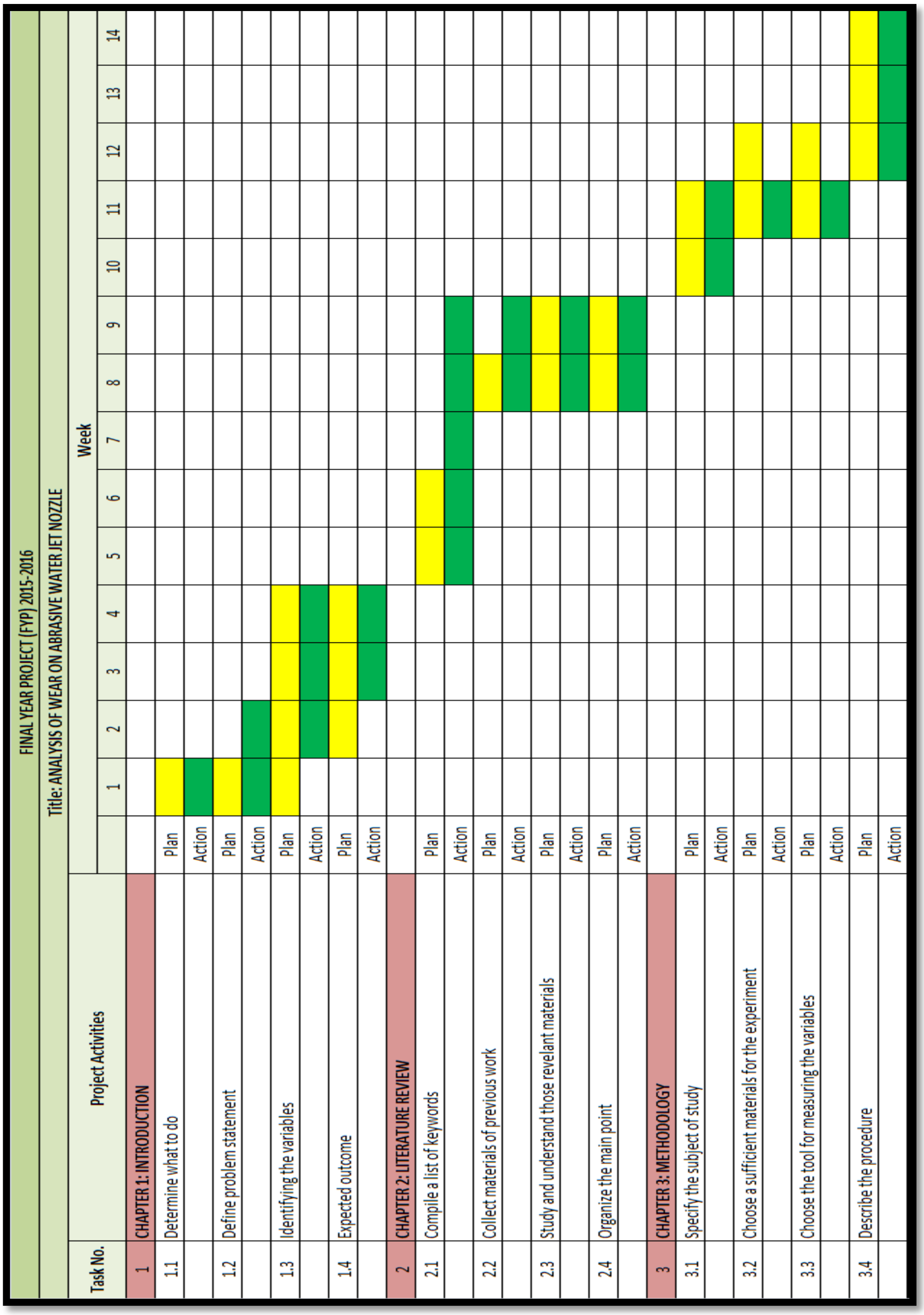
APPENDICES A

GANTT CHART

A.1 Gantt chart FYP1



A.2 Gantt chart FYP 2