



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**INVESTIGATION OF NOZZLE HEIGHT OF ABRASIVE
WATER JET MACHINING ON MILD STEEL GEAR SURFACE
CUTTING PARALLELISM**

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology (Process and Technology) (Hons.)

by

MUHAMMAD NIZAM BIN ABD SAMAT

B071210462

900502-01-5063

FACULTY OF ENGINEERING TECHNOLOGY
2015

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: Investigation Of Nozzle Height Of Abrasive Water Jet Machining On Mild Steel Gear Surface Cutting Parallelism

SESI PENGAJIAN: 2015/16 Semester 2

Saya **MUHAMMAD NIZAM BIN ABD SAMAT**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

SULIT

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TERHAD

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:

Cop Rasmi:

No 39 Jalan Mawar 4, Taman Tangkak

Jaya 2, 84900 Tangkak,

Johor.

** Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Investigation Of Nozzle Height Of Abrasive Water Jet Machining On Mild Steel Gear Surface Cutting Parallelism” is the results of my own research except as cited in references.

Signature :

Name : MUHAMMAD NIZAM BIN ABD SAMAT

Date : 29/12/2015

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Engineering Technology (Process and Technology) (Hons.). The member of the supervisory is as follow:

.....

(Project Supervisor)

ABSTRACT

Abrasive waterjet (AWJ) cutting is one of the most recently developed manufacturing technologies. This technology is being increasingly used in various industries especially in gear manufacture. This paper presents the investigation of abrasive water jet nozzle height on cutting parallelism of mild steel gear. There are three objectives of this project that needs to be accomplished. Firstly, to investigate the cutting taper on the mild steel work piece using abrasive water jet machining. Second, to select the best height of the nozzle during cutting process of cutting parallelism and lastly to assess cutting edge condition at different taper ratio. There are 10 mm and 20 mm thickness of mild steel work pieces are machining and 15 readings of cutting width are taken for every size of the sample. From the main effect plot Minitab software analysis, the best nozzle height is proven to get the parallel cutting kerf. The mean value indicated that there is a significant difference height between 5mm, 10mm, and 15mm nozzle height of the mild steel work piece. The lowest nozzle height will produce a smaller erosion on cutting taper and better surface finish. The best selection for waterjet cutting of nozzle height during machining is 5mm because it produce a lowest angle taper and produced a high kerf quality.

ABSTRAK

Abrasive waterjet (AWJ) adalah salah satu teknologi pembuatan yang paling maju baru-baru ini. Teknologi ini semakin kerap digunakan dalam pelbagai industri terutamanya dalam pembuatan gear. Kertas kerja ini membentangkan siasatan ujikaji mengenai ketinggian muncung abrasive waterjet yang memotong keselarian gear keluli lembut. Terdapat tiga objektif projek ini yang perlu dicapai. Pertama, untuk menyiasat tirus pemotongan ke atas sekeping bahan kerja keluli ringan dengan menggunakan mesin abrasive waterjet. Kedua, untuk memilih ketinggian yang terbaik terhadap pemotong semasa proses memotong keselarian dan akhir sekali untuk menilai keadan sudut tepi kesan pemotongan pada nisbah tirus berbeza. Terdapat 10 mm dan 20 mm ketebalan bahan kerja digunakan untuk pemesinan dan 15 bacaan pemotongan lebar diambil untuk setiap saiz sampel. Daripada kesan plot analisis perisian Minitab utama, ketinggian muncung terbaik terbukti untuk mendapatkan memotong kerf selari. Nilai purata menunjukkan bahawa, terdapat perbezaan ketinggian di antara muncung 5mm, 10mm, dan 15mm terhadap bahan kerja keluli lembut. Ketinggian muncung paling rendah akan menghasilkan hakisan yang lebih kecil untuk mengurangkan tirus dan kemas permukaan yang lebih baik. Pemilihan pemotongan yang terbaik untuk memotong ketinggian muncung semasa pemesinan adalah 5mm kerana ia menghasilkan sudut tirus rendah dan menghasilkan kualiti kerf yang terbaik.

DEDICATIONS

To my parents loved that never cease to teach me how to stand with their feet, but never tired to stand behind me and prayed that I managed to spend learning the bachelor's degree level. Thanks also to my colleagues where you are constantly helping me and encouraging me when are in distress. I wish a thousand thanks that can not be paid with money to friends at home, I never give up to provide translation and enlightening for me to understand the problems that I have faced. I went through all this is a challenge to myself to be successful in the future. Thanks go to lecturers who have taught me, Mr. Engr Hanizam bin Hashim and other lecturers who were not my call. Do not forget also to assistant engineer who helped me during the workshop. In addition, I also say thousands of thanks to the people who helped me and I regard you all as a family on my own. We are all one big family.

ACKNOWLEDGMENTS

Bismillahirrahmanirrahim.

In the name of Allah, the Almighty, who guide us to the truth, the knowledge and with regards to Prophet Muhammad S.A.W for guiding us to the light. I thank to Allah for giving me the chance to finish the writing of this report.

I would like to take this opportunity to express my appreciation to my supervisor, Mr. Engr Hanizam Bin Hashim and co-supervisor Mr. Mohd Kamal Bin Musa for his kindness, advice and guidance to help me accomplish this project from day one and beyond. I cannot pay back for all his contributions were definitely helped me a lot in this project.

I would also like to thank all partners for their significant advice and help. And also for my beloved one, who always supported me throughout this project and for helping me get through it. Just calm can repay all the kindness you all. Furthermore, I also thank my parents Abd. Samat Bin Ithnin and Kamisah Binti Haji Md Dis which helped a lot in terms of finance, advice and encouragement.

Finally, I would like to thank to any other individual or group that I no longer had also played an important role in doing my final year project and report.

I hope that the report of this final year project will meet the requirements as requested in the format. Thanks.

TABLE OF CONTENTS

DECLARATION	iv
APPROVAL.....	v
ABSTRACT.....	vi
ABSTRAK	vii
DEDICATIONS.....	viii
ACKNOWLEDGMENTS	ix
TABLE OF CONTENTS.....	x
LIST OF FIGURES	xiv
LIST OF TABLE	xv
LIST OF SYMBOLS AND ABBREVIATIONS	xvi
CHAPTER 1	1
1.0 Introduction	1
1.1 Project Background	3
1.2 Problem Statement	4
1.3 Objective	4
1.4 Work Scope	5
CHAPTER 2	6
2.0 Introduction	6
2.1 Abrasive Waterjet Machining	6
2.2 Working Principle of Abrasive Waterjet Machining.....	9

2.3	Abrasive.....	10
2.4	Gear Fabrication	11
2.4.1	Method of Gear Manufacturing	12
2.5	Mild steel	13
2.6	Cutting Parameter of Abrasive Waterjet Machining.....	14
2.6.1	The Effect of Water Pressure	15
2.6.2	The effect of water pressure	15
2.7	Cutting Parameter of Abrasive Waterjet Machining.....	16
2.7.1	Kerf taper	16
2.7.2	Kerf characteristics.....	18
2.7.3	Cutting Kerf	21
2.7.4	Condition Edge on cutting Kerf.....	23
2.8	Statistical Analysis	24
2.9	Main Effect Plot	24
CHAPTER 3		26
3.0	Introduction	26
3.1	Project Planning	26
3.2	Material Equipment.....	28
3.2.1	Water Jet Machining	28
3.2.2	Profile Projector	30
3.2.3	Inverted Research Microscope.....	31
3.3	Material Selection.....	33
3.3.1	Mild Steel.....	33

3.3.2	Mild Steel.....	34
3.4	Experiment Setup	34
3.4.1	Mild Steel Workpiece Preparation	35
3.4.2	Clamping Position.....	36
3.4.3	Clamping Position.....	37
3.4.4	Profile Projector Procedure	38
3.5	Data Collection.....	39
3.6	Data Collection.....	40
CHAPTER 4	.....	43
4.0	Introduction	43
4.1	The Effect of Angle Taper Ratio using Different Nozzle Height	43
4.1.1	Comparison of Angle Taper Ratio using Different Nozzle Height.....	43
4.2	Statistical Analysis of Angle Cutting Taper using Main Effect Plot Minitab Software	47
4.3	Cutting Edge Condition at Different Taper Ratio	48
4.4	Comparison of Results	50
CHAPTER 5	.....	51
5.0	Introduction	51
5.1	Conclusion.....	51
5.2	Future Work	52
APPENDIX A	.....	55
APPENDIX B	.....	57
APPENDIX C	.....	59

REFERENCES.....	61
-----------------	----

LIST OF FIGURES

Figure 2.1 : A schematic diagram of an abrasive water jet.....	8
Figure 2.2 : Schematic of AWJ machining system	9
Figure 2.3 : Abrasive Grain 80 Mesh.....	11
Figure 2.4 : Gear cut using AWJM	12
Figure 2.5 : Schematic of a through-cut kerf	19
Figure 2.6 : Schematic of a non-through cut kerf	19
Figure 2.7 : Characteristics of the Taper of the Cutting Gap.....	20
Figure 2.8 : Cutting kerf.....	21
Figure 2.9 : Typical Cutting kerf on mild steel.....	22
Figure 2.10 : Schematically Condition Edge on Cutting Kerf of waterjet.....	23
Figure 2.11 : Statistical analysis main effect plot.	25
Figure 3.1 : Research development flow.....	27
Figure 3.2 : Water Jet Machine Type Mach 2 1313b.....	29
Figure 3.3 : Profile Projector.....	31
Figure 3.4 : Inverted Research Microscope	31
Figure 3.5 : Mild steel workpiece	33
Figure 3.6 : Workpiece dimension for AWJM cutting experiment	35
Figure 3.7 : Clamping positon for AWJM cutting process	36
Figure 3.8 : Sample of data Main Effect Plot in Minitab 17.....	40
Figure 3.9 : Sample of graph Main Effect Plot in Minitab 17	41
Figure 3.10 : Characteristics of the Taper of the Cutting Gap.....	42
Figure 4.1 : Line graph relationship between nozzle height againt angle taper ratio	46
Figure 4.2 : Main effects plot for angle taper ratio means	47
Figure 4.3 : Schematic illustrated of abrasive waterjet on the mild steel.	48

LIST OF TABLE

Table 2.1 : Major AWJM Process Parameters	14
Table 3.1 : Specification of Mach 2 WJM	28
Table 3.2 : Specification of Profile Projector.....	30
Table 3.3 : Specification of Inverted Research Microscope	32
Table 3.4 : Physical properties of mild steel as work piece	33
Table 3.5 : Specification of Abrasive.....	34
Table 3.6 : Procedure of AWJM using Flow Mach2 1313b	37
Table 3.7 : Procedure of Profile Projector	38
Table 3.8 : Angle taper ratio	39
Table 4.1 : Angle taper ratio for material thickness 10mm.....	44
Table 4.2 : Angle taper ratio for material thickness 20mm.....	45
Table 4.3 : Cutting Edge Condition at Different Nozzle Height.....	49

LIST OF SYMBOLS AND ABBREVIATIONS

AWJM	=	Abrasive Waterjet Machining
HAZ	=	Heat Affected Zone
CNC	=	Computer Numerical Control
NC	=	Numerical Control
w_t	=	Top kerf width
w_b	=	Bottom kerf width
P_0	=	Pressure water
v_n	=	Traverse speed
θ	=	Inclination angle
H_0	=	Null Hypothesis
LED	=	Light emitting diode
WJM	=	Waterjet Machining

CHAPTER 1

INTRODUCTION

1.0 Introduction

Abrasive Water Jet Machining (AWJM) is a well-established non-traditional machining process. Abrasive water jet machining makes use of the principles of both abrasive jet machining and water jet machining. AWJM is a non-conventional machining process where material is removed by impact erosion of the high pressure, high velocity of water and entrained high velocity of grit abrasives on a work piece. Abrasive Water Jet Machining is accepted effective technology for cutting various material as of its advantages over other non-conventional techniques such as No heat is generated in the cutting process, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces, the abrasives after cutting can be reused which allows for possible reduction of the cutting cost of the process, machining can be easily automated. The process has some limitations and drawbacks. It may generate loud noise and a messy working Environment, the machining is not applicable for machining too thick pieces, limited number of materials can be cut economically, taper cutting is also a problem with water jet cutting in very thick materials (Jun Wang, 2003). In a machining process, high-pressure waterjet is used to cut a workpiece. With an addition of abrasive particles, the machining capability of the waterjet is significantly improved. Various machining processes can be performed including cutting, drilling, milling, etc. A wide range of materials and thicknesses can be cut with good cutting quality and small taper. However, different processing parameters and material properties have to be carefully assessed as to produce the desired cutting qualities. Using only water at a relatively low pressure, cleaning of surfaces from dirt or coats can be achieved (Hashish, M.,2007). This technology is most widely used compared to other non-conventional technology because of its distinct advantages. It is used for cutting a wide variety of materials ranging from soft to hard materials. This technique is

especially suitable for very soft, brittle and fibrous materials. This technology is less sensitive to material properties as it does not cause chatter. This process is without much heat generation, so machined surface is free from heat affected zone and residual stresses. AWJM has high machining versatility and high flexibility. The major drawback of this process is, it generate loud noise and a messy working environment (P. K. Mishra, 2005).

This technology is most widely used compared to other non-conventional technology because of its distinct advantages. It is used for cutting a wide variety of materials ranging from soft to hard materials. This technique is especially suitable for very soft, brittle and fibrous materials. This technology is less sensitive to material properties as it does not cause chatter. This process is without much heat generation, so machined surface is free from heat affected zone and residual stresses. AWJM has high machining versatility and high flexibility. The major drawback of this process is, it generate loud noise and a messy working environment (P. K. Mishra, 2005).

Gears have existed since the invention of rotating machinery. Gear is a tooth wheel mechanical device used to transmit power and motion between machine parts. Gears are used in many applications, such as automobile engines, household appliances, and computer printers. Gear provides long life cycles and can transmit power at to 98 percent efficiency. Gear manufacturing refers to the making of gears. Gears can be manufactured by a variety of processes, including casting, forging, extrusion, powder metallurgy, and blanking. As a general rule, however, machining is applied to achieve the final dimensions, shape and surface finish in the gear. A gear also can be described as a toothed wheel that when meshed with another smaller in diameter toothed wheel (the pinion) will transmit rotation from one shaft to another. The primary function of a gear is to transfer power from one shaft to another while maintaining a definite ratio between the velocities of the shaft rotations. The teeth of a driving gear mesh push on the driven gear teeth, exerting a force component perpendicular to the gear radius. Thus, a torque is transmitted, and because the gear is rotating, power is transferred (Prof. K. Gopinath & Prof. M.M.Mayuram, 2007).

Mild steel is material that made of low carbon and iron, with much more of iron than carbon. Mild steel is commonly used as construction materials and it is

known as mild because of the relatively low carbon content. Mild steel also made of low carbon components of ingot iron. Mild steel also known as plain-carbon steel, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form. Mild steels suffer from yield-point run out where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If low carbon steel is only stressed to some point between the upper and lower yield point. Low-carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle (totalmateria.com, 2001)

1.1 Project Background

Abrasive Water Jet Machining (AWJM) cutting has been widely used in various industries for cutting such as reinforced concretes, cutting metal structure, cutting food as well for cleaning and coating removal. However, the application of AWJM technique has found mostly in metal manufacturing, automotive, glass and aerospace industries. Ceramics, marble composite layer, titanium sheet as well as pattern cutting of various materials uses an AWJM technique because those are difficult to cut material.

The importance of this project is to encourage the consideration of cutting taper in cutting process for the manufacturing industries with the appropriate parameter for the machining process. This is because, cutting taper effected the accuracy of the material that being cut. This is because the cutting taper of cutting materials varies in AWJM techniques.

1.2 Problem Statement

Accuracy of the water jet cutting is mainly defined by the form of the cutting gap. Form of cutting gap is one of the main problems having an effect on the accuracy of abrasive water jet cutting. The form of the kerf has been always complex, cut surfaces are almost never parallel. In most cases the kerf is wider at the upper side than the lower side, where the jet goes out from the work piece. For gears fabrication, the process required accurate cutting process, especially for fitting purposes. Therefore, the taper issue on cutting surface should be avoided. One of the common cutting processes of such product is using an abrasive water jet cutting. In this research, the best cutting parameters, such as nozzle height, pressure, and abrasive are being focused on.

The aim of the research work was to get connections between the technological parameters and the taper of the kerf in order to find cutting parameters which can get parallel cut surface.

1.3 Objective

In order to complete the Final Year Project, there are some objectives that must be accomplished. The objectives are:

- i. To investigate the cutting taper on the mild steel work piece using Abrasive Water Jet machining.
- ii. To select the best height of the nozzle during cutting process of cutting parallelism.
- iii. To assess cutting edge condition at different taper ratio.

1.4 Work Scope

In this project, the experiment conducted at the FTK Manufacturing Process Laboratory by using the AWJM machine use is modelled Mach2 1313b with 80 mesh of abrasive size. The software for AWJM is Flow Master Software and the catcher tank content is tap water. The parameter that used in this project are traverse speed, hydraulic pressure, abrasive flow rate, standoff distance and type of abrasive. The work pieces materials are mild steel. Overall data for kerf width and tapering of kerf will be analyzed using Main effect plot of Minitab Software. To measure the cutting width, the instrument used is profile projector.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Literature review discussed the relevant topics and a guide for studies. This section will give part in order to get more information about Abrasive Water Jet Machining (AWJM) and will give an idea how to operate the machine. At an early stage of the studies, some gap analysis has been carried out in order to ensure the relevance of this research. Reference books, research journals and online conference article were the main source in the thesis guides. This section will include the principle of AWJM, machining properties and cutting taper at the cutting area. History of the AWJM will be story little bit in this section.

2.1 Abrasive Waterjet Machining

Abrasive Water Jet Machining has been one most recently developed non-traditional cutting processes. It was first introduced as a commercial system in 1983 for the cutting glass. Because of its various distinct advantages over the other cutting technologies, such as no thermal distortion on the work piece, high machining versatility to cut virtually any materials, high flexibility to cut any direction, and small cutting process, it is being widely used machining difficult-to-machine material like ceramic, composites and titanium alloy where conventional machining is often not technically or economically feasible, as well as for pattern cutting on various materials (J. Wang, 2003)

In the early 60's O. Imanaka, University of Tokyo applied pure water for industrial machining. In the late 60's R. Franz of University of Michigan, examine the cutting of wood with high velocity jets. The first industrial application manufactured by the McCartney Manufacturing Company and installed in Alto

Boxboard in 1972. The invention of the abrasive water jet in 1980 and in 1983 the first commercial system with abrasive entrainment in the jet became available. The added abrasives increased the range of materials, which can be cut with a Watergate drastically (R. V. Shah,2011)

This technology is most widely used compared to other non-conventional technology because of its distinct advantages. It is used for cutting a wide variety of materials ranging from soft to hard materials. This technique is especially suitable for very soft, brittle and fibrous materials. This technology is less sensitive to material properties as it does not cause chatter. This process is without much heat generation, so machined surface is free from heat affected zone and residual stresses. AWJM has high machining versatility and high flexibility. The major drawback of this process is, it generate loud noise and a messy working environment (P. K. Mishra, 2005)

In AWJ machining process, the workpiece material is removed by the action of a high-velocity jet of water mixed with abrasive particles based on the principle of erosion of the material upon which the water jet hits. Comparing with other complementary machining processes, no heat affected zone (HAZ) on the workpiece is produced . High speed and multidirectional cutting capability, high cutting efficiency, ability to cut complicated shapes of even non flat surfaces very effectively at close tolerances, minimal heat build up, low deformation stresses within the machined part, easy accomplishment of changeover of cutting patterns under computer control, etc. are a few of the advantages offered by this process which make it ideal for automation. AWJM is widely used in the processing of materials such as titanium, steel, brass, aluminium, stone, Inconel and any kind of glass and composites . Being a modern manufacturing process, abrasive waterjet machining is yet to undergo sufficient superiority so that its fullest potential can be obtained (M. Korat,2014)

The basic components of AWJM are schematically illustrated in Figure 2.1. As seen, the performance of AWJM depends on a series of factors associated with the technology itself and the characteristics of the material to be cut. Among these factors, the characterization of technology itself and operating variables can be controlled in cutting process. However, the characterization of the material may present difficulties in controlling due to the nature of the materials.

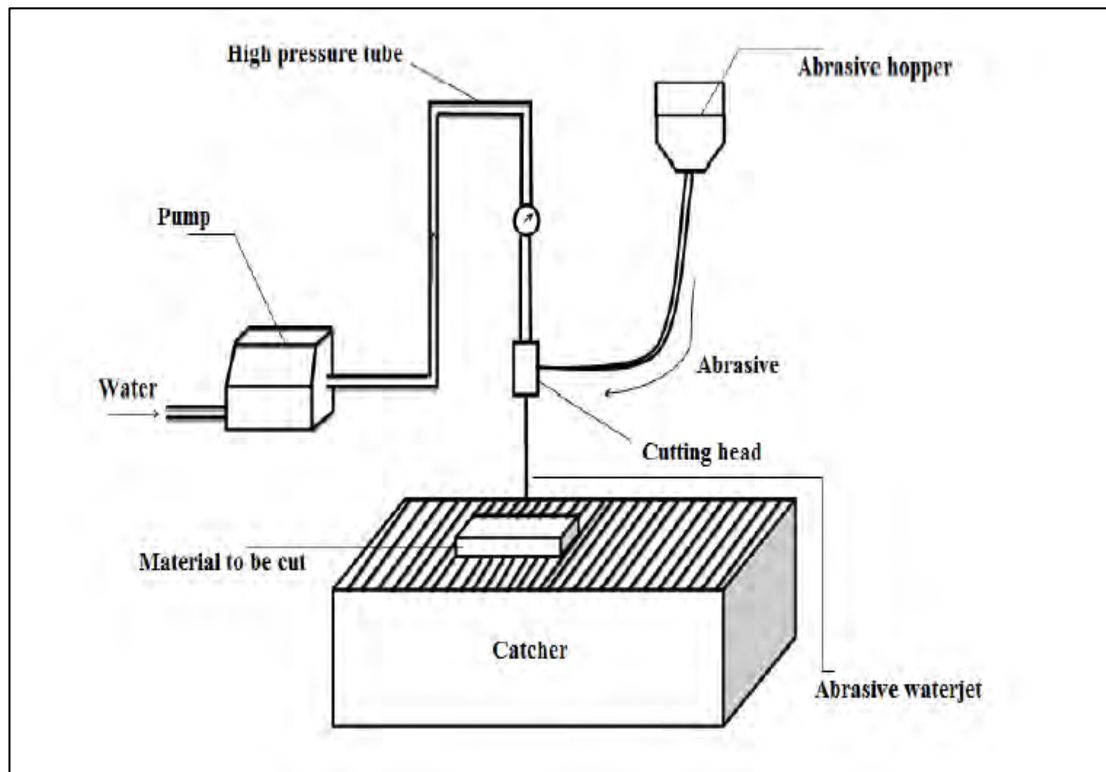


Figure 2.1 : A schematic diagram of an abrasive water jet.
 Source: International Journal of Advances in Engineering & Technology,2011.

Figure 2.1.2 is a schematic of an entrainment water jet system illustrating the cutting head assembly and the basic jet formation principle. As mention above, a tiny orifice with a diameter form less than 0.1 mm is used to generate water jet form high pressure water. The high velocity water jet creates a vacuum which sucks the abrasive from the abrasive supply tube and mixes them with the water in the mixing chamber. Part of the water jet’s momentum is transferred to the abrasive, whose velocities rapidly increase. As the result, a focused, high-velocity stream of abrasive exits the nozzle and performs the cutting action on the work piece.

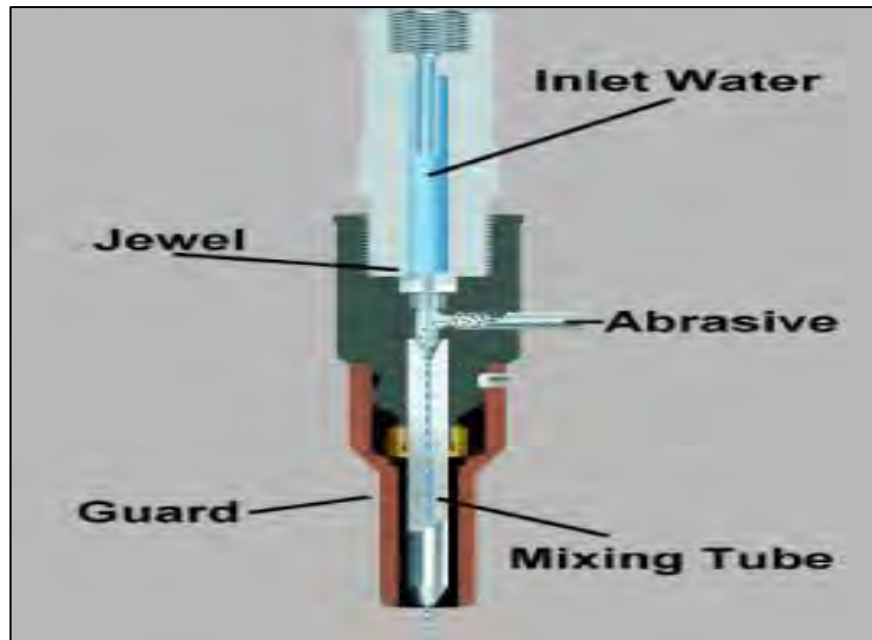


Figure 2.2 : Schematic of AWJ machining system
 Source: Water cutting machine,2008.
 <<http://waterjet-cutting.blogspot.com>>

2.2 Working Principle of Abrasive Waterjet Machining

The water jet machining is also known as hydrodynamic machining. The water acts as a saw and cuts a narrow groove in the material. High water pressures range from 60ksi to 200ksi is required to cut from soft to hard materials.

The basic methodology of the process: water is pump at a sufficiently high pressure, 200-400Mpa (2000-4000 bar) using intensifier technology. An intensifier works on the sample principle of the pressure amplification using hydraulic cylinders of the different cross sections. When the water at such pressure is issued through a suitable orifice (generally of 0.2-0.4 mm diameter), the potential energy is converted into kinetic energy, yielding a high velocity jet (1000 m/s). Such high velocity water jet can machine thin sheets/foils of aluminium, leather, textile, frozen food, etc. In pure WJM, commercially pure water (tap water) is used for machining purpose.

However, as the velocity water jet is discharged from the orifice, the jet tends to entrain atmospheric air and flares out decreasing its cutting ability. Hence, quite often stabilizers (long chain polymers) that hinder the fragmentation of water jet are added to the water.