OPTIMIZATION OF ABRASIVE WATERJET PROCESS PARAMETERS FOR THICK MATERIAL CUTTING IN ORDER TO REDUCE JET LAG EFFECT.

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BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

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DEDICATION

Alhamdulillah. I am grateful to Allah SWT for granting me the chance to do my Final Year Project 1 and 2. For students at University Technical Melaka Malaysia (UTEM) who are in their final year of the undergraduate program leading to the degree Bachelor of Manufacturing Engineering Technology (Process and Technology), this final year project 1 was created. First, I want to express my gratitude to my supervisor, Ts. Dr. Hanizam Bin Hashim, who helped me with many tasks during this thesis. I also want to express my gratitude to myfamily, who have continued to support me and inspire me to complete my thesis. Finally, I would like to express my gratitude to my buddy Siti Fatihah Binti Jusoh for her outstanding dedication and cooperation during this semester at University Technical MelakaMalaysia (UTEM).

ABSTRACT

This abstract discusses research into the causes of cutting delays while working with thick metal. The Taguchi method's orthogonal matrix can be used to optimize these variables and get the optimum jet lag angle for a given metal surface. The versatility and efficacy of abrasive waterjet cutting as a metal-cutting technique are emphasized. However, the quality of the cut is compromised when thick metals are being cut because the kinetic energy distribution of the abrasive waterjet might cause jet lag or striation lines on the surface. Predictive modelling is provided as a potentially useful approach to comprehending and mitigating jet lag effects through real-time adjustments to cutting parameters and path optimization. The purpose of this research is to examine the variables that affect the cutting of thick aluminium blocks on the Mach 2 machine flow at UTeM. This study will examine how changing milling techniques and parameters on aluminium blocks might improve surface quality and cut down on travel time. The abrasive material will be 80-mesh garnet sand, and the study's goal is to determine the best possible combination of these factors to mitigate the effects of jet lag on thick-material cutting. There are three variables that will be examined and analyzed water pressure, transverse feed rate, and standoff distance. The research uses MINITAB software and the Taguchi method to find the best strategy for improving surface quality and taper angle, and to capture data from actual samples. The angle of jetlag and surface roughness will also be evaluated with the use of a Mitutoyo portable surface roughness tester machine and a microscope Nikon SMZ 745T. The results of this research should shed light on how to optimize parameters to efficiently cut large metals while maintaining desirable surface quality and jet lag angle.

ABSTRAK

Abstrak ini membincangkan penyelidikan mengenai punca kelewatan pemotongan semasa bekerja dengan logam tebal. Matriks ortogonal kaedah Taguchi boleh digunakan untuk mengoptimumkan pembolehubah ini dan mendapatkan sudut jet lag yang optimum untuk permukaan logam tertentu. Kepelbagaian dan keberkesanan pemotongan jet air yang kasar sebagai teknik pemotongan logam ditekankan. Walau bagaimanapun, kualiti pemotongan terjejas apabila logam tebal dipotong kerana pengagihan tenaga kinetik pancutan air yang melelas mungkin menyebabkan jet lag atau garisan striation pada permukaan. Pemodelan ramalan disediakan sebagai pendekatan yang berpotensi berguna untuk memahami dan mengurangkan kesan jet lag melalui pelarasan masa nyata untuk memotong parameter dan pengoptimuman laluan. Tujuan penyelidikan ini adalah untuk mengkaji pembolehubah yang mempengaruhi pemotongan blok aluminium tebal pada aliran mesin Mach 2 di UTeM. Kajian ini akan mengkaji bagaimana menukar teknik pengilangan dan parameter pada blok aluminium mungkin meningkatkan kualiti permukaan dan mengurangkan masa perjalanan. Bahan yang melelas adalah pasir garnet 80 mesh, dan matlamat kajian adalah untuk menentukan kombinasi terbaik faktor-faktor ini untuk mengurangkan kesan jet lag pada pemotongan bahan tebal. Terdapat tiga pembolehubah yang akan diperiksa dan dianalisis tekanan air, kadar suapan melintang, dan jarak kebuntuan. Penyelidikan menggunakan perisian MINITAB dan kaedah Taguchi untuk mencari strategi terbaik untuk meningkatkan kualiti permukaan dan sudut tirus, dan untuk menangkap data daripada sampel sebenar. Sudut jetlag dan kekasaran permukaan juga akan dinilai dengan penggunaan mesin penguji kekasaran permukaan mudah alih Mitutoyo dan mikroskop Nikon SMZ 745T. Hasil penyelidikan ini harus memberi penerangan tentang cara mengoptimumkan parameter untuk memotong logam besar dengan cekap sambil mengekalkan kualiti permukaan yang diingini dan dan sudut jet lag.

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In the Name of Allah, the Most Gracious, the Most Merciful.

Alhamdulillah. I am grateful to Allah SWT for granting me the chance to do my Final Year Project 1 and 2. For students at University Technical Melaka Malaysia (UTEM) who are in their final year of the undergraduate program leading to the degree Bachelor of Manufacturing Engineering Technology (Process and Technology), this final year project 1 and 2 was created. First, I want to express my gratitude to my supervisor, Ts. Dr. Hanizam Bin Hashim, who helped me with many tasks during this thesis. I also want to express my gratitude to my classmate, who has continued to support me and inspire me to complete my thesis. Finally, I would like to express my gratitude to my buddy Siti Fatihah Binti Jusoh for her outstanding dedication and cooperation during this semester at University Technical Melaka Malaysia (UTEM). Last but not least, I would like to thank my beloved parents for their endless support, love, and prayers. Finally, thank you to all the individual(s) who had provided me with the assistance, support, and inspiration to embark on my study

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LIST OF SYMBOLS AND ABBREVIATIONS

D, d	Diameter
AWJ	Abrasive Water Jet
SOD	Standoff Distance
CNC	Computer Numerical Control
LBM	Laser Beam Machining
EDM	Electrical Discharge Machining
Mpa	Megapascal
Psi	Pound Per Square Inch
CMM	Coordinate Measuring Machine
Ra	Surface Roughness

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CHAPTER 1

INTRODUCTION

1.1 Background

To cut through materials with various mechanical qualities, abrasive waterjet cutting uses a high-speed waterjet with abrasive particles suspended in it. To ensure effective and efficient cutting without use of heat in this procedure, three input parameters must be used: waterjet pressure, standoff distance, and abrasive flow rate (Chen et al., 2022) The kinetic power of the jet, nozzle wear rates, and residual abrasive particles are only a few of the variables that affect an abrasive waterjet's capacity to cut effectively and maintain the integrity of the surface. The method is frequently used in a variety of sectors, particularly when cutting thick materials sinceit yields high-quality holes with less surface that is caused by the inclusion of hard particles between two sliding or rolling surfaces. Despite its versatility, abrasive waterjet cutting still poses challenges to achieve optimal cutting efficiency and surface integrity, especially in terms of the quality of the machined holes, the residualstress and fatigue behavior of the material, and the mechanical behavior of the machined material (Chen et al., 2022). A wide range of machining processes, including cutting, milling, drilling, and polishing can be performed using abrasive waterjet (AWJ) technology. Even while AWJ machining has distinct advantages over conventional machining techniques, such as low heat production, machining adaptability, minimal cutting power, jet lagand taper, still pose a significant barrier to its widespread use. Particularly, the constraints of jet lag still apply when using AWJ to cut thick materials, which impactsthe contour of the bottom machined surface of the freeform surface. The impact of the material removal process and variations in the kinetic energy distribution of an AWJ on jet lag have been the subject of extensive investigation in recent years. To investigate how an AWJ's kinetic energy distribution changes and how material removal works in relation to jet lag (Chen et al., 2022). In the past, research on jet lagformation's micromechanics was conducted. A study that sought to understand the cause of jet lag on the cut surface revealed that it may result from the machining process, jet dynamic properties, and machine vibration. Another study found that particles on the workpiece at shallow angles generated a smooth wear-cutting regionbut at greater angles of attack, the jet produced a striated surface, deforming the wear-cutting region (Chen et al., 2022). The wear cutting zone was deformed because the jet at larger angles of attack generated a striated surface. Additionally, the surface formation mechanism is made possible by a wavy distribution of abrasive energy, which results in a change in the distribution of abrasive kinetic energy. Highspeed images taken during experimental experiments revealed that the shape of the cut frontaffects the jet deflection while cutting transparent materials. One study used Bitter'stheory of erosion to computationally simulate the cutting front of attacking abrasiveparticles to determine the cutting surface's jet trajectory (Vikram & Babu, 2002).

1.2 Problem Statement

As a variable and high-efficiency method of cutting metal, abrasive waterjet cutting has been created as a cutting technique. When cutting thick materials (metal), the kinetic energy distribution of an AWJ might cause the development of jet lag or striation marks at the cutting surface. The jet lag causes the surface to be of poor quality, and as a result, extra processes, such as grinding and polishing, are typicallyrequired. These processes add both time and money to the manufacturing process. Researchers and engineers have tried many different things to solve this problem, and predictive modelling has emerged as a promising answer. Predictive modelling is the process of making mathematical models and algorithms that can correctly predict jet lag and help people deal with it. By figuring out what causes jet lag and making models that can predict it, it will be possible to change the cutting settings and optimize the cutting path in real time, which will lessen the effects of jet lag. Although, a substantial quantity of research on the micromechanics behind the development of jet lag has been published, researchers have used a wide array of apparatuses, materials, and environments for their studies. Because of this,the objective of this study is to evaluate the factors that influence the cutting of thick aluminium blocks using machine flow Mach 2 at UTeM.

1.3 Research Objective

The objectives of this project as the following:

- To identify the parameters that have significant impact on jet lag issue for thick metal cutting.
- To optimize the parameters using an orthogonal matrix of Taguchi method.
- To determine the smallest jet lag angle attainable on metal surface using microscope.

1.4 Scope of Research

This project's objective is to investigate the impacts of various waterjet processes and parameters on an aluminium block to enhance the surface quality and lessen the impact of jet lag. Will be carried out using an Abrasive Waterjet Mach 2 MachiningFlow. In this research, the abrasive type will be garnet sand, and the size will be Mesh 80.These two variables will be manipulated to find the ideal combination for minimizingthe jet lag effect while cutting thick materials. This project's goal is to determine which parameter should be utilized most effectively so that a satisfactory outcome may be achieved for both the surface quality and the angle of jet lag. The water pressure, the transverse feed rate, and the standoff distance are the following parameters in the order they will be discussed. This project will make use of MINITAB software applications in situations when such software helps to save timewhile determining the optimal course of action. In this MINITAB programmed, the Taguchi approach is used to determine the optimal solution and to record the sampledata for the purpose of developing a procedure for enhancing the surface quality andthe taper angle depending on the data recorded by the parameter. In addition, a Mitutoyo Portable Surface roughness Tester and microscope Nikon SMZ 745 are used to determine the angle of jetlag and surface roughness, respectively, for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review and the project's historical context are discussed in this chapter. It is important as it could help in achieving a successful system as it could identify problems that occur according to previous projects and research. Literature evaluation helps in the technique to identify the machine parameters, optimize the machine parameters, and determine the minimum jet lag angle on metal surface using angle using scope. Therefore, this chapter is used to look up proper techniques that are suitable for our parameter where we can make improvements based on past research. This literature also review has been conducted with the intention of providing a complete picture of current research andadvancements in the predictive modelling approach for reducing jet lag while cutting thick materials in repeated passes with an abrasive waterjet. It will look at the most important studies, methods, and techniques used in this field, pointing out the pros and cons of each one. The review will also talk about the main things that affect jet lag, such as the cutting speed, the properties of the material, the waterjet settings, and the weather. Understanding these factors is important if you want to make accurate models that can help you deal with jet lag.

2.2 Jet Lag

Jet lag is a common problem when cutting thick materials with a rough waterjet in more than one pass. Figure 2.1 show an abrasive waterjet cutting process. The process utilizes a high-pressure waterjet that is combined with abrasive particles to effectively sever materials such as metals, composites, and ceramics. But becausethe cutting process is so complicated, jet lag can have a big effect on the quality and speed of the cutting activity. Jet lag is when the waterjet doesn't follow the cutting path that was planned. Instead, it goes in a different direction. It can lead to several bad things, such as wrong measurements, rough surfaces, and less work getting done. In industrial cutting, getting over jet lag is a must if you want accurate and reliable results.

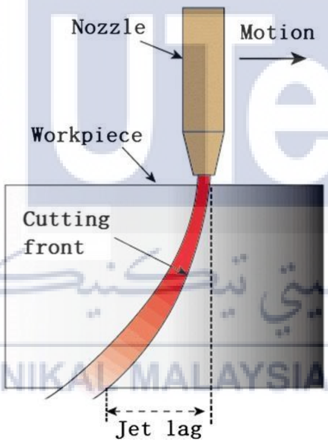

Figure 2. 1 Jet Lag

Through the AWJ process, the information is taken away in a way that seems complicated. Even though different interpretation models have been put forward in the literature, this phenomenon is still not fully known, and a model that describes it well has not yet been putforward. Also, because the results of the removal process must be judged based on both thejet's depth of entry and the quality of the cut (Micro- and macro-geometrical elements), thereneeds to be a model for each of these factors (Yuvaraj and Kumar, 2016). The efficiency of the procedure is influenced by a multitude of interrelated factors, including the velocity of the cutting head, the potency of the water jet, the water flow rate, the type and size of the abrasive material, and the abrasive flow rate. This presents one of the key challenges with modelling the results.

Overall, by providing a complete study of the predictive modelling technique for reducing jet lag, this literature reviews he individual aims to make a scholarly contribution to the existing knowledge base regarding the utilization of abrasive waterjet multi-pass cutting techniques for thick materials. The findings of this paper may aid scientists, engineers, and professionals in the field in understanding the issues associated with jet lag and may help to develop more precise and efficient cutting procedures.

2.3 Impact of jet lag issue on product process and application.

When there is a time difference between the place where a waterjet machine is set up and the location where the workpiece is being machined, a phenomenon known as jet lag may develop. This is because the waterjet machine must be set up in one time zone and the workpiece must be machined in another time zone. Inaccuracies in the cutting process are possible because of this, particularly on the radio and corners. The following is a synopsis of the effects that jet lag has on the product process and the application of the product: Jet lag may produce geometric mistakes in the machined workpiece, such as variations in the form of the cut, surface roughness, and the radius of corners. These inaccuracies can impact the accuracy of the product. This might result in issues with the product's fit and functionality, in addition to a decline in the overall quality of the product. There is a possibility that jet lag may lengthen the amount of time needed to complete waterjet machining tasks.

This is since the operator of the machine may need to alter the cutting settings to compensate for the jet lag. This may lead to trial and error, which wastes both time and resources. Application range Jet lag is another factor that might reduce the number of possible applications for waterjet cutting. For instance, because of jet lag, it may be impossible to manufacture sharp edges or tiny radios with a high degree of precision. The effects of jet lag may be reduced in a variety of different ways via the use of waterjet machining. To make up for lost time due to jet lag, the cutting settings may be adjusted accordingly. Adjusting the water pressure, abrasive flow rate, and traverse speed are all part of this process, which aims to reduce the amount of geometric error brought on by jet lag. Utilizing a waterjet machine with a high level of precision: The negative effects of jet lag on product quality may be mitigated with the assistance of a waterjet machine with a high degree of accuracy. These machines often feature cutting heads that are more stable and have improved control systems, both of which may contribute to the production of more precise cuts. It is possible to make a prediction on how the cutting process will be affected by jet lag by using a software simulation. This might be of assistance to the operator of the machine in optimizing the cutting settings and preventing geometric mistakes. If you follow these guidelines, you will be able to reduce the negative effects of jet lag on waterjet machining and create workpieces of a high quality.

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2.4 Principle of Operation Waterjet.

Abrasive water jet machining is founded on the effect of high energy impact of water jet mixed with the abrasive onto the workpiece material (Gostimirovic et al., 2019). The AWJM can machine by combining the granular abrasive with a high-pressure waterjet stream. A high-pressure pump drives the pressured water into the nozzle system. Figure 2.2 shows abrasive waterjet system. This system has an aperture, mixing chamber, focusing tube, and abrasive hopper. The water driven out of the orifice at a high rate of speed and in an extremely thin stream form (Llanto et al., 2021). The AWJ machining methods produce complicated products with a high degree of precision and accuracy (Ficko et al., 2021) In order to cut through materials with various mechanical qualities, abrasive waterjet cutting uses a high-speed waterjet with abrasive particles suspended in it (Hilmi et al., n.d.). The abrasive waterjet exits the nozzle and contacts the workpiece. Water and abrasive particles carry energy that erodes the substance and makes a cut. Depending on the material and thickness being cut, the cutting speed can vary.

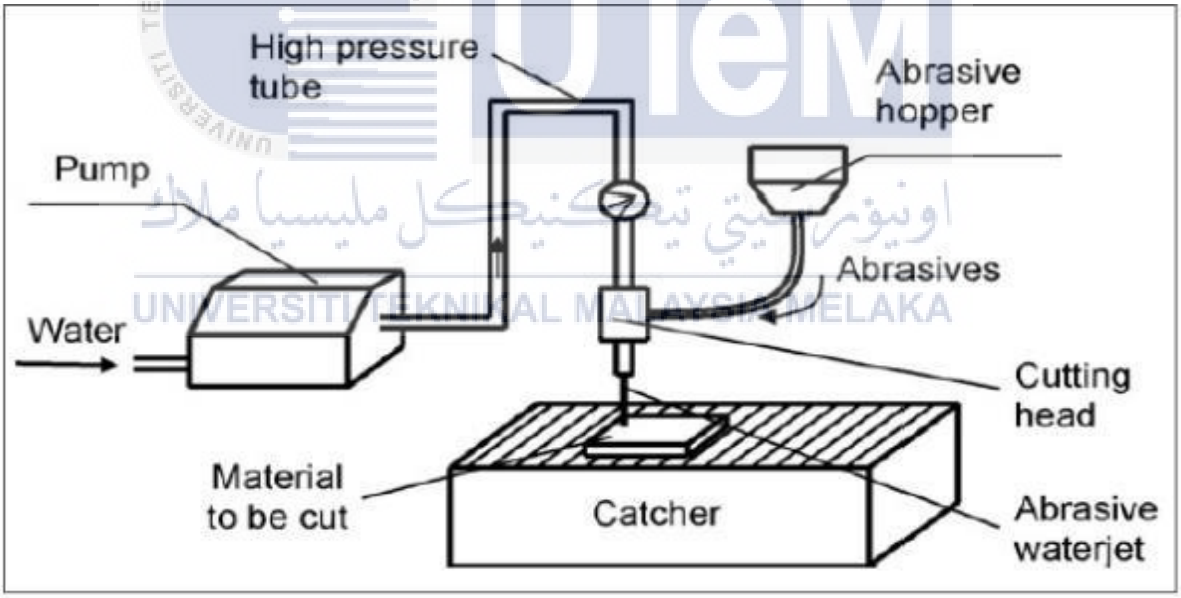


Figure 2. 2 An Abrasive Waterjet (AWJ) System.
(Babashov et al., 2015)

2.5 Abrasive Waterjet Erosion Mechanism

An erosive journey of high-velocity abrasive particles is what causes the AWJM technique of material removal, which removes material from a target workpiece. (Nguyen & Wang, 2019). Material loss rates in AWJM are managed by two main models: the cutting and deformation wear mechanism and the ploughing deformation wear mechanism. (Natarajan et al., 2020). A workpiece is either ductile or brittle. Erosion may occur in ductile materials through two different mechanisms: repeated. plastic deformation and cutting action. In general, ductile erosion refers to metals and other comparable materials that may withstand significant plastic deformation (Hlaváčová et al., 2020). The erosion of brittle materials is attributed to crack propagation and chipping, induced by contact stresses arising from the impact of abrasive particles. This phenomenon is commonly categorized as a cracking mechanism (Kowsari et al., 2014).

2.6 Advantages of Waterjet

Metals, polymers, alloys, glass, stone, and other materials can all be cut with waterjet cutting. It works with both thick and thin materials, and it can make shapes and patterns with a lot of detail. Waterjet cutting is a cold-cutting method, which means that no heat is made during the process. This makes it impossible for heat to deform, warp, or damage the material being cut in any other way. It is especially helpful for things like metals and other things that can be damaged by high temperatures. Since waterjet cutting doesn't make any dangerous gases or fumes, it's a safer choice than laser cutting or plasma cutting, which can give off dangerous gases. This means that you don't need any more air or exhaust systems. Waterjet cutting can be done with a lot of skill and precision. It can make parts with tight tolerances and smooth edges in complicated forms. Computer numerical control (CNC) technology makes it possible to control and repeat the cutting process with great accuracy. The narrow kerf width of a waterjet lets parts fit together closely, making the most of the material and cutting waste. The capability of cutting many portions from a single sheet of material contributes further to the reduction of waste. Waterjet cutting is different from other ways of cutting, like milling or drilling, in that it doesn't require special tools for each job. This saves time and money on setting up and changing tools. The process of cutting with a waterjet is good for the earth. It doesn't make any harmful waste or put. anything bad into the world. The water that is used can be returned and filtered so that it can be used again. Figure 2.3 shows that the superiority based on experimental study conducted on a range of workpieces, AWJM is preferred above other non-traditional machines (Llanto et al., 2021).

Cutting Activity	AWJM	LBM	EDM	ECDM
Heated affected zone (HAZ)	No	Yes	Yes	Yes
Material Distortion	No	Yes	No	Yes
Tool Wear	No	No	Yes	Yes
Material Removal Rate (mm^3/s)	Medium-slow (approx. ≤ 2)	Fast (approx. 2–3) for non-reflective materials only	Medium (approx.1–2)	Medium (approx.1–2)
Type of material	metals, composites, natural, electrically, non-conductive, non-reflective	metals, composites, natural, electrically, non-conductive, non-reflective surface	Only electrically conductive such as metals and composites	Only electrically conductive such as metals and composites
Material thickness (mm)	Ranging ≤ 304.8	Ranging ≤ 20	Ranging ≤ 304.8	Ranging ≤ 304.8
Type of shapes	Complex and complicated shapes	Complex and complicated shapes	Simple	Simple
Burr formation	Minimal	High	High	Minimal
Hazardous vapour	None	fumes, gases	CO & CH_4	$NaOH/NaNO_3$

Figure 2. 3 Alternatives to traditional cutting methods compared.

2.7 Jet Lag in Multi-Pass Cutting

Particle erosion is another significant factor that limits the effective depth of cut and causes jet lag when cutting thick materials in multiple passes (Hilmi et al., n.d.). This paper presents a predictive model for jet lag-integrated multi-pass cutting with appropriate cutting parameters to reduce jet lag and cutting-parameter selection in AWJ machining. In this regard, multi-pass cutting was based on a single-factor experimental strategy in which a fixed starting position was used for each cutting pass and high-speed photography was used to record the changing jet deflection (Chen et al., 2022). We hypothesize that multi-pass cutting can increase the cutting capacity and decrease the energy loss of the upper surface. In addition, it enhances surface quality and reduces machining time (Chen et al., 2022). In multi-pass cutting, it's important to use the same cutting methods all the way through. Make sure that the cutting head is parallel to the surface of the object and that the standoff distance stays the same. Jet lag can happen when the method isn't consistent, like when the cutting angle or distance between passes changes.

2.8 Abrasive Waterjet Cutting Parameter

The process of cutting with an abrasive waterjet (AWJ) involves several independent process factors that have a direct effect on how well the machine works (Llanto et al., 2021). Figure 2.4 shows The AWJM process parameters can be represented through a cause-and- effect diagram that categorizes the input process parameters into distinct groups, nozzle, hydraulic, abrasive, material, and cutting. Most of the impact on the cutting efficacy or output metrics of an Abrasive Water Jet Machining (AWJM) implementation is attributed to the process parameters that are utilized. Several factors influence the efficacy of waterjet cutting, including standoff distance, abrasive flow rate, water pressure, and nozzle shape. To get the most out of cutting while causing the least amount of damage to the machined surface, you must optimize the cutting settings and pick the right abrasive particles. (Hilmi et al.,n.d.)

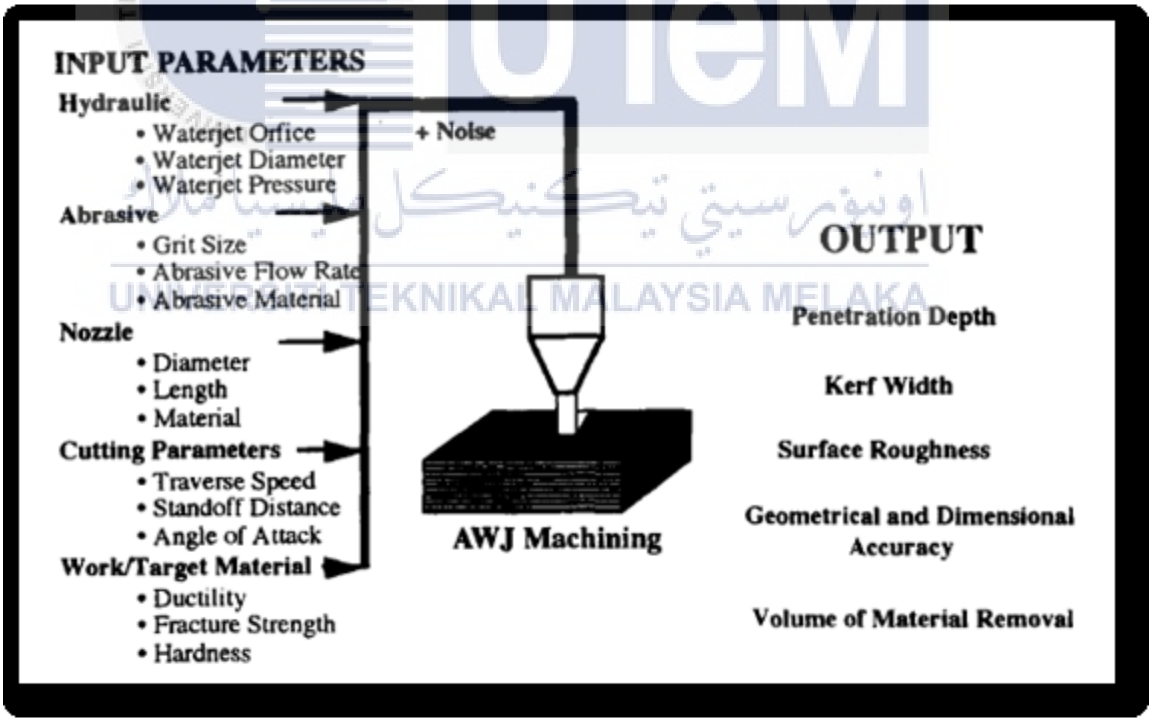


Figure 2. 4 AWJM process parameter diagram.

2.8.1 Water pressure

This is an essential step in the production of AWJs, so be sure not to skip it. The water pressure influences the amount of kinetic energy the AWJ possesses. When there is no material removal, the pressure is below the threshold range. Similarly, the critical pressure range is equal to the pressure at which the effective cutting limit is reached. The machining procedure becomes ineffectual if it is prolonged beyond this point. The rate of material removal is proportional to the water discharge pressure, the depth of penetration, and the amount of material being removed. It affects the way water and abrasive particles are distributed inside the jet. MPa, bar, and PSI are common units of measurement (Natarajan et al., 2020).

2.8.2 Transverse Rate of Focusing tube.

The condition of cut surfaces produced by AWJ is determined. During the AWJ machining process, the decision of the exposure length has the most important impact on the traverse rate. Reducing the traverse rates has been found to enhance the surface quality of the target material as it allows for a higher concentration of abrasive particulates to contact the surface. Furthermore, it has an impact on the velocity of the trimming procedure. The rate of traverse is represented in units of millimeters per minute (Natarajan et al., 2020).

2.8.3 Standoff Distance

The parameter in question pertains to the spatial separation between the substance under consideration and the aperture. Due to the enormous influence that SOD has on the kerf profile that is formed by the AWJ, the ideal distance, measured in millimeters, is normally maintained (Natarajan et al., 2020). Figure 2.5 show that effect of nozzle distance on kerf profile.

Figure 2. 5 Effect of nozzle distance on kerf profile (Natarajan et al., 2020).

2.8.4 Jet Impingement angle.

The cutting head is tilted at this angle, which corresponds to this angle. It is defined as the angle that exists between the initial flow direction of the AWJ and the surface of the substance being targeted. Any change in the angle at which the jet impinges on the target material will ultimately alter the angle at which the jet attacks the target material, which will have an influence on the mode of erosion. Figure 2.6 shows the angle of the jet's impingement in the forward direction. The use of the changing jet impingement angle has a significant effect on the AWJ cutting performance, and there are no extra expenses associated with its utilization. In the process of machining, there are two distinct kinds of jet impingement angles that are used: forward and backward orientations. (Natarajan et al., 2020).

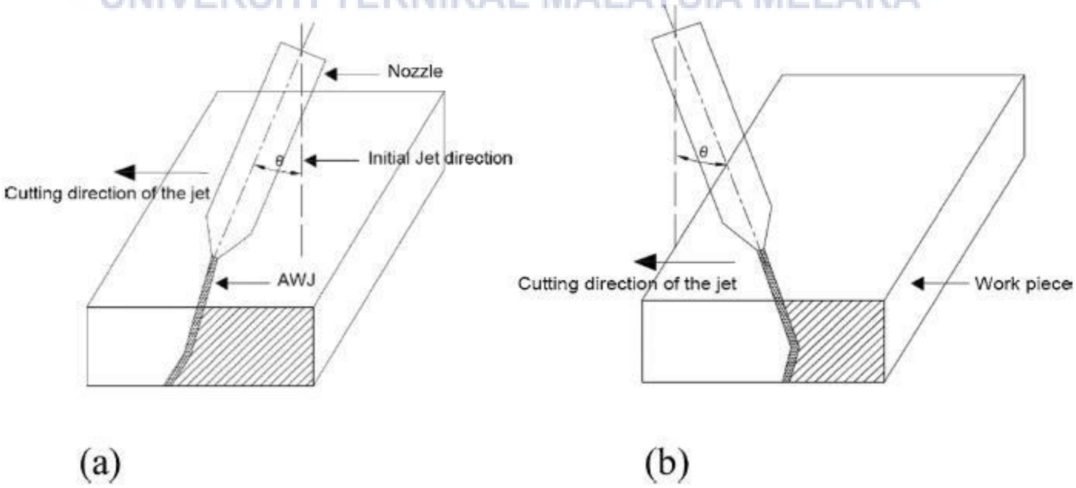


Figure 2. 6 The angle of the jet's impingement(a)in the forward direction

2.9 Application Materials

2.9.1 Alumminum

The study by Hashish (1987) used high velocity abrasive waterjets to turn a range of materials including aluminium, glass, and magnesium boron carbide. He evaluated the impact of AWJ process parameters on the waviness and roughness created on turned component using these waterjets (Manu & Babu, 2008). Several researchers have investigated the surface integrity of materials that have been processed using water jets and AWJs. The information is laid out in detail further down the page. conducted research on the impact of plain water jet cutting on the surface integrity of AA 7075 aluminium alloy. This was done by cutting the material with the jet. The creation of compressive residual stress in the aluminium alloy by a simple water jet appears to be responsible for the improvement observed in the fatigue life of the material, as shown by the research's findings. According to smooth AWJ cut surfaces were obtained on the hard materials, whereas the cut surfaces of the soft materials had severe wear tracks. The abrasive water jet peening technique was initially developed for use on tough materials such as titanium and nickel. They discovered that there was a rise in the compressive residual stress because of an increase in the jet pressure and the size of the abrasive particles. Investigated the effect that several types of water jet formation had on the surface integrity of the AA6061-T6 aluminium alloy. These types of water jet formation included a fuzzy jet, a fan jet, and a round jet. They noticed that a fuzzy jet might produce a superior surface integrity when a lower water jet pressure and a traverse rate were used. This was something that they observed. Investigated the surface topography of machined AA6063–T6 aluminium alloy by altering the ratio of theorize to the diameter of the focusing nozzle in AWJ. Their findings were presented in the form of a study. According to the findings, the effect of increasing both the orientation and the diameter of the focusing nozzle does not decrease the quality of the cut surface all that significantly. (Yuvaraj & Kumar, 2016) This paper presents the findings of an initial inquiry into how surface integrity because of plain waterjet machining influences on component fatigue life (Boud et al., 2014). The investigation was conducted by presenting the outcomes of an initial investigation. Aluminium is used for testing because it is widely employed for flight- critical airframe structural components, and aluminium alloys are the overwhelming choice for the fuselage, wing, and supporting structures (Starke & Staley, 1996). Aluminium is also used because it is lightweight and corrosion resistant. Strength and fracture toughness are offered by aluminium 7475, in addition to resistance to the propagation of fatigue cracks. To manufacture fatigue test specimens, a set of parameters that can offer an acceptable surface finish and removal rate is identified and used. These specimens are milled by waterjet using a fanjet nozzle optimized for wide area surface removal (Boud et al., 2014), and a range of different parameters are used to determine the influence that Plain Waterjet has on fatigue life. Using white light surface profiling and x-ray diffraction, respectively, measurements of surface roughness and surface stress were acquired. After obtaining these results, the overall surface integrity, and the impact it has on fatigue life are both analyzed and determined (Boud et al., 2014).

2.10 Abrasive Waterjet Cutting Application Limitations and Challenges

Although the AWJ machining process is well-established, it has some limitations. These include the generation of a greater quantity of secondary waste following machining, the development of heat at the primary impact zone, abrasive contamination, taper and striation formation, a rough quality surface, and a low energy transfer efficiency from the nozzle to the workpiece, which results in a shallow depth of penetration, a low material removal rate, etc. Due to these restrictions, the industrial application of this method has been extremely restricted (Natarajan et al., 2020). Figure 5 shows some of the effects of the AWJ manufacturing process on work materials. In addition, it is exhaustively discussed in the following sections (Natarajan et al., 2020). Figure 2.7 shows the results of AWJ machining on work materials.

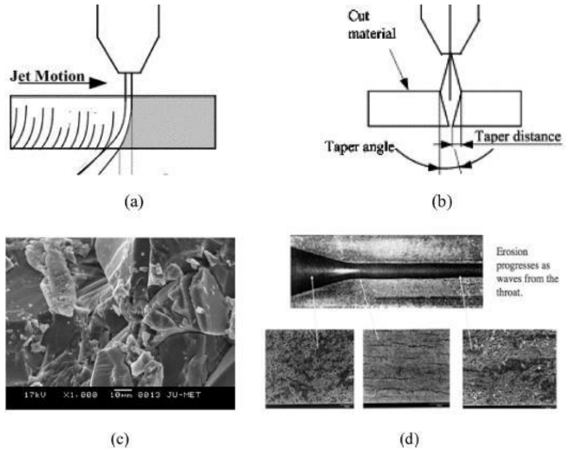


Figure 2. 7 The results of AWJ machining on work materials (a) Deflected jet striation.

(b) Taper shape (c) Abrasion contamination (d) Various nozzle wear (Natarajan et al., 2020).

2.11 Modelling And Optimization of The Direction of The Abrasive Waterjet.

Evolutionary modelling and optimization are gaining popularity as a technique for resolving critical issues in pervasive intelligent systems(Vikram and Babu, 2002). The objective of evolutionary optimization is toutilize the powerful capabilities of intelligent tools to solve predominantly problems thatcannot be optimized using conventional methods (Rao, n.d.). The development and application of genetic programming and the optimal control problem methodology are discussed in this case. The ability of their mathematical modelling of objective functionto approximate optimize the abrasive water jet trajectory curvature is their defining characteristic.

2.12 Taguchi Method.

Utilizing Taguchi approach and evolutionary optimization methodologies, Shukla and Singh carried out an empirical analysis regarding the AA631-T6 material being machined and theAWJM process's kerf top width and taper angle. (Chen et al., 2022). The design ofexperiments as well as the choice of quality attributes level of process parameters in the ECMM process have been described in the current part (*Surface Treatments*, n.d.). The Taguchi method is a statistical technique to design optimization that seeks to improve process performance by discovering the best combination of input parameters or factors. Inthe context of reducing the jet lag effect by adjusting the abrasive waterjet process parameters for cutting thick materials.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides a detailed explanation and description of the methodology employed to attain the stated objective. Furthermore, this paper aims to examine the methodology employed to determine the optimal parameter and the steps taken to accomplish this investigation. The primary methodology of the study, which optimization of abrasive waterjet process parameters for thick material cutting to reduce jet lag effect that will be subsequently discussed. The experiments were carried out using a machine that was a model Abrasive waterjet machining FLOW Mach 2. An abrasive material consisting of garnet with a mesh size of 80 mesh was used, the jet impingement angle was set to 90 degrees in every scenario, the diameter of the waterjet nozzle was 1.0 mm. The pure aluminium workpiece measurements were 100m x 30 mm x 33 mm.

3.2 Research Design

The comprehensive diagram depicting the sequence of this investigation is presented in Figure 3.1. The purpose of a flowchart is to visually represent the sequential steps involved in a process, from its initiation to its completion. The study's methodology will commence with the preparation of materials, followed by equipment utilisation, data collection includes Taguchi method orthogonal array setup using Minitab software, and data analysis procedures. However, the obtained result is satisfactory, the process will continue for the testing phase utilizes empirical modelling and statistical approach. Subsequently, Figure 3.1 shows the methodology flowchart of this thesis.

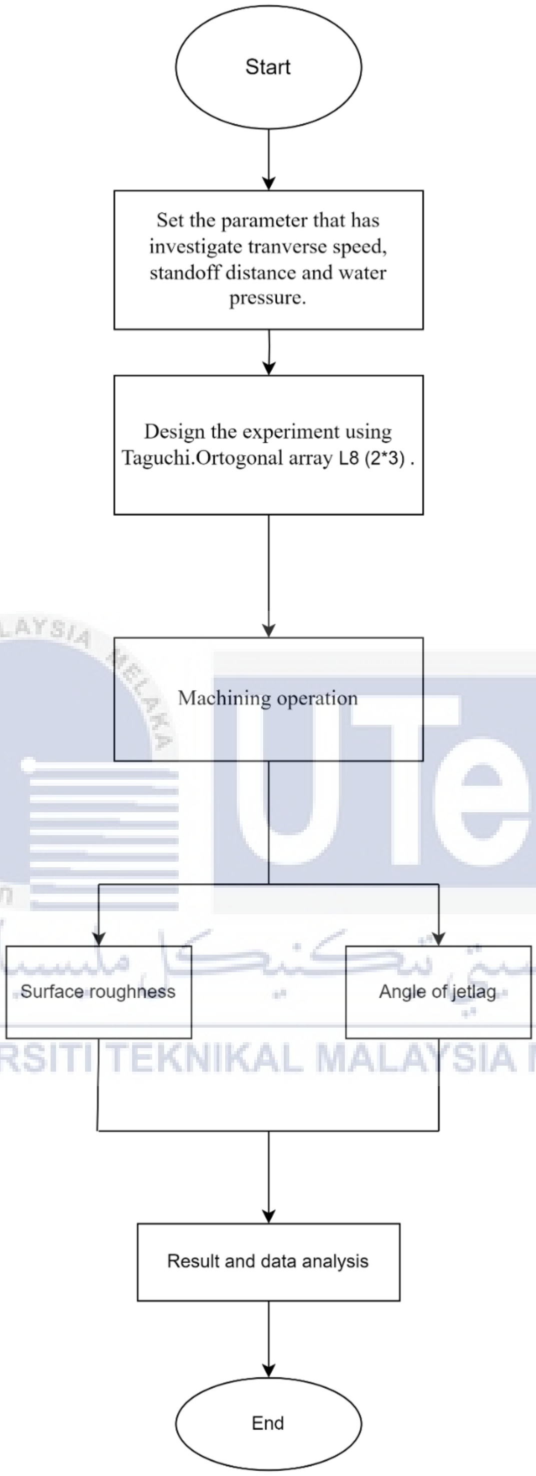


Figure 3. 1 Methodology Flowchart

3.3 Material

3.3.1 Pure Alumminium

This research used pure aluminium a material known for its ductile behaviour. Pure aluminium is regarded challenging to cut because to its strong resistance to corrosion and heat, as well as its strength, durability, minimal maintenance requirements, ease of manufacture, flexibility, and high hardness. Aluminium is the third most prevalent element in the earth's crust, making about 8% of it. After steel, aluminium is the most popular metal due to its flexibility. It is not possible to get a high tensile strength from pure aluminium. On the other hand, the incorporation of alloying elements like as manganese, silicon, copper, and magnesium may enhance the strength qualities of aluminium and result in the production of an alloy that has features that are specifically adapted to certain uses. Aluminium is an excellent material for use in cold conditions. It has an advantage over steel in that its tensile strength rises with decreasing temperature while maintaining its toughness. Furthermore, it is more durable than steel. The opposite of steel is that it becomes brittle when exposed to low temperatures. The AWJ machining process is hindered by the high alloy content of the material, making it challenging to cut. A total of 8 block of pure aluminium measuring 100 mm x 30 mm and 33 mm thickness were used in this investigation. Figure 3.2 shows the pure Aluminium block.

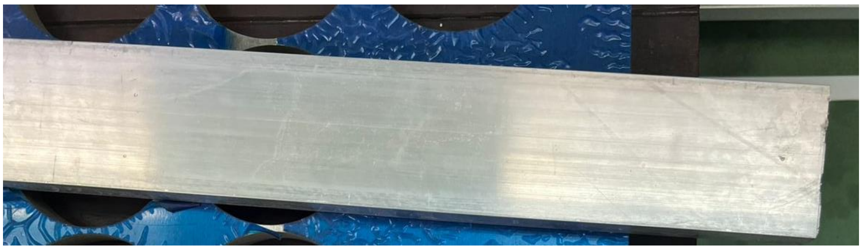


Figure 3. 2 Pure Aluminium Block

3.3.2 Abrasive

This research used the IMG garnet which is Mesh 80. IMG Garnet is a naturally available, abrasive mineral that is free of metallic components. It is mined from sources of the Almandine mineral deposit, including as mines in the Indian River and coastal bed. The Almandine Garnet is the hardest and densest variety of all the garnet varieties that make up its own category. This makes it a great option for use in a range of industrial applications as an abrasive grain. IMG Garnet is a real almandine garnet belonging to the gem family. Garnet is nature's most highly efficient, effective, and safe abrasive for both wet and dry blasting applications because of its high density and other physical characteristics. The most widely used abrasive grade in the world, 80 mesh garnet offers the ideal combination of cutting speed and precise edge. Mesh 80 is often used in steel plates and marbles because it can cut through tougher materials more quickly. Although the most common grade for waterjet cutting is Mesh 80, this method can cut through any material, including steel, aluminium, marble, granite, glass, rubber, plastic, and more. Because it is the only type of cold cutting that doesn't alter the surface, the properties of the cut edges remain unchanged. Figure 3.3 show 80 Mesh garnet abrasive.

Figure 3. 3 80 Mesh garnet Abrasive

3.3.3 Properties and Dimension Tools.

A waterjet is a type of cutting instrument that slices through a variety of materials using a high-pressure stream of water that is occasionally combined with an abrasive substance. The dimensions and characteristics of a waterjet can change depending on the model that is being used and the manufacturer. Waterjets often operate at high pressures which is 50 000 psi (max). This range of pressures is referred to as "psi." When the pressure is increased, cutting speeds can be increased along with the ability to cut through materials that are harder the measurements of the nozzle The waterjet system is dependent on the nozzle, which is a crucial element. It is responsible for determining the width of the water stream as well as the accuracy of the cutting. The diameter of nozzles is 1.0 mm.The cutting bed is the designated surface where the material to be cut is placed. hence the size of the cutting bed is important. The cutting bed's dimensions are highly susceptible to change based on the specific waterjet machine that is being used. Some machines have cutting beds that are quite narrow, allowing for precise cutting, while others have cutting beds that are rather large, allowing for the cutting of larger sheets or materials. Waterjets are renowned for their precision and accuracy in a variety of applications. Depending on the equipment and the task at hand, the permissible amount of departure from the specified dimensions, also known as the tolerance, might be as little as 0.001 inches (0.025 millimetres). Material Compatibility Waterjets can cut through a broad variety of materials, such as metals, composites, polymers, stone, glass, and ceramics, among other things. However, the appropriateness of a waterjet for a particular material may vary depending on the thickness of the material, its level of hardness, and other parameters. It is essential to keep in mind that the precise measurements and capabilities of a waterjet tool can change based on the manufacturer and the model. Table 3.1 show the properties and dimensions of tool.

Equipment	Abrasive waterjet machining FLOW Mach 2
Working area	1.3 m (X-direction) and 1.3 m (Y-direction)
Water cutting pressure	50 000 psi (max)
Nozzle	1.0 mm (diameter)
Software	• Flow Path – design software • Flow Cut – machine cutting software
Abrasive	Garnet Sand
Mesh	80
Work piece	Aluminium

Table 3. 1 Properties and dimensions of tool

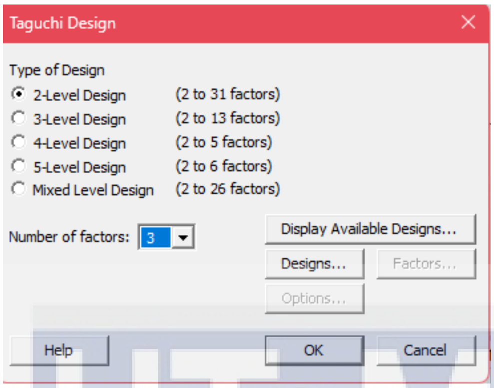
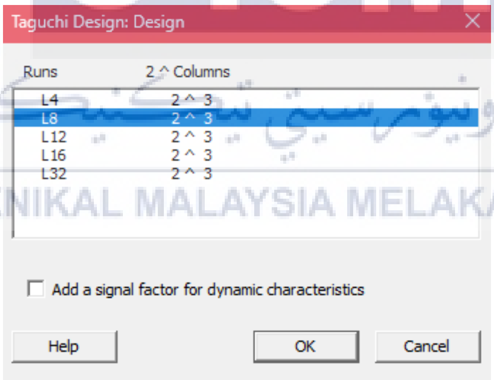
3.4 Machine Setup

Figure 3.4 presents the experimental configuration used for the AAWJ cutting. Abrasive waterjet machining was used in the trials that were conducted on the FLOW Mach 2. Tests involving AWJ machining were performed in this study on a pure aluminium workpiece. The tests involved the creation of non-through, straight slots under a variety of various process settings. To be more specific, a total of 8 trials were conducted using three distinct degrees of traverse speed, stand-off distance, and water pressure. Figure 3.4 show the machine waterjet setup.

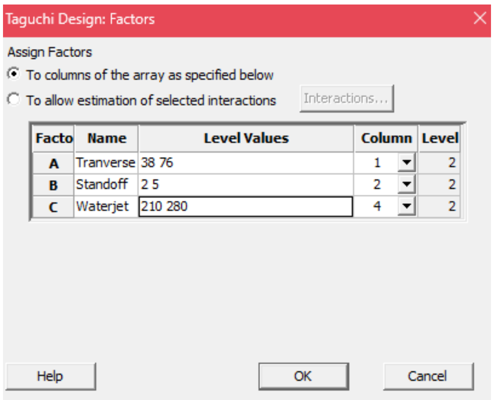
Figure 3. 4 Machine Waterjet Setup

3.5 Experimental Setup (Taguchi Method)

In the present study four process parameters were selected as control factors. Taguchi experimental design was used to construct the DOE. Three process parameters, i.e., water pressure, traverse speed, and standoff distance each varied at two levels, an L8 (2*3) orthogonal arrays table with 8 rows corresponding to the number of experiments was selected for the experimentation. Procedure is shown in Table 3.2 .

Procedure	Picture
Identify Factors and Levels	
Select Taguchi Array L8(2^3)	

Assign Factors to Columns:

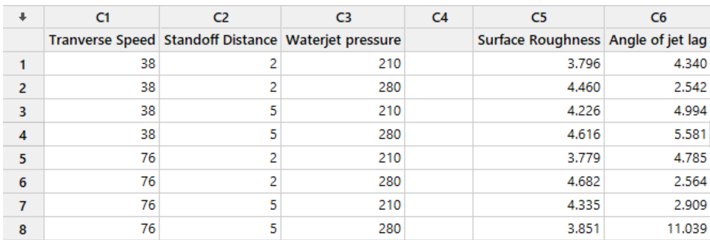


Facto	Name	Level Values	Column	Level
A	Tranverse	38 76	1	2
B	Standoff	2 5	2	2
C	Waterjet	210 280	4	2

Conduct Experimental Runs

	C1 Tranverse Speed	C2 Standoff Distance	C3 Waterjet pressure
1	38	2	210
2	38	2	280
3	38	5	210
4	38	5	280
5	76	2	210
6	76	2	280
7	76	5	210
8	76	5	280

Collect Data



	C1 Tranverse Speed	C2 Standoff Distance	C3 Waterjet pressure	C4	C5 Surface Roughness	C6 Angle of jet lag
1	38	2	210		3.796	4.340
2	38	2	280		4.460	2.542
3	38	5	210		4.226	4.994
4	38	5	280		4.616	5.581
5	76	2	210		3.779	4.785
6	76	2	280		4.682	2.564
7	76	5	210		4.335	2.909
8	76	5	280		3.851	11.039

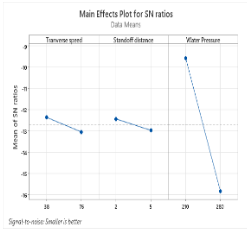
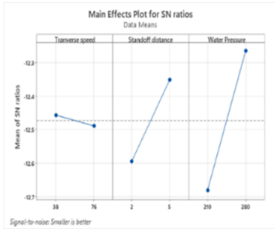
Analyze Results	 

Table 3. 2 Experimental Setup

Design Summary

Taguchi Array	L8(2^3)
Factors:	3
Runs:	8

Table 3. 3 Design of Orthogonal Array

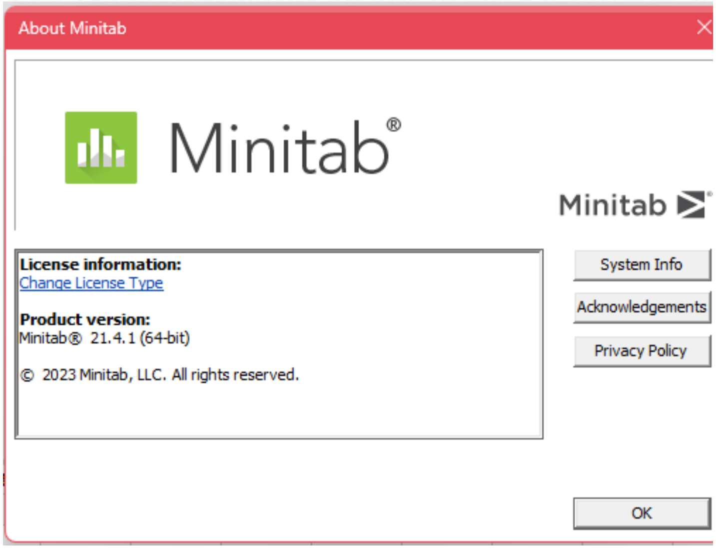


Figure 3. 5 Minitab Version

Variable factors are inputs that change in quantity when output changes. This implies that fewer variable factors are utilised when production decreases, and more variable factors are used when production increases. The reason for this is because variable factors are subject to change. The independent variables for this study are the transverse speed, water pressure, and standoff distance. A fixed factor of production refers to an input that is not readily adjustable in quantity. The fixed factors used in this study are the abrasive flow rate, abrasive size, and nozzle diameter. Table 3.4 show the orthogonal array.

Experiment	Transverse speed mm/min	Standoff distance mm	Water pressure Mpa	Surface Roughness (Ra) (µm)	Angle of jet lag (°)
1	38	2	210	3.796	4.340
2	76	2	210	4.46	2.542
3	76	2	280	4.226	4.994
4	38	2	280	4.616	5.581
5	38	5	280	3.779	4.785
6	38	5	210	4.682	2.564
7	76	5	210	4.335	2.909
8	76	5	280	3.851	11.039

Table 3. 4 Orthogonal Array

3.6 Waterjet Process

Activate the machine. Once all the levers and switches have been actuated in the right order, you must then hit the "reset" button on the machine. Note that failure to activate the machine correctly may result in its damage. Elevate the water level around the machine to ensure that the cutting occurs below the surface. Please initiate the file transfer and ensure its prompt readiness. To upload the dxf file, use the import file technique and insert a flash drive. To access, just initiate a double-click action on the provided hyperlink. This command will initiate the execution of a computer code called "Layout". Ensure that the file is prepared. Commence by selecting any issues with the drawing by choosing the "clean" button situated on the right side of the screen. Retain the settings in the pop-up box without making any changes; just choose "remove any superfluous dots," followed by "start," and ultimately "ok."To choose "all," right-click on the "quality" button at the bottom of the screen and choose the option from the drop-down menu that displays. Terminate the conversation box by closing it. Firstly, locate the left side of the screen and proceed to choose the "lead IO" button. Subsequently, choose the option labelled "auto path advances and configure," and last, choose for "go." Insert a tab. To pick "lead IO," use the right-click menu of your mouse, and thereafter go below to "create tab."To establish the starting point, right-click on "path" and pick "automatically generate" from the context menu. Click the "save" button. To access a new menu, just do the action of right-clicking on "path" and choosing "open ORD path" from the "Make" menu many times. Choose the material from the dropdown menu labelled "material". Input the dimension of the material's thickness into the designated "thickness" field. Merely touch the "OK" button. Once the water level in the water jet has been reduced, proceed to securely insert the cutting piece into the water jet. Clamps and weights may be used to secure the ceramic tile. Engaging in the necessary arrangements for the waterjet. Utilise the arrow keys to manipulate the nozzle's position, aligning it towards the initial location. To use the "make" programme, locate the "path home" section inside the interface and choose the "zero" option. Set the values of x, y, and z heights to their corresponding initial values. Once the nozzle is positioned at the correct z height, go back to the "make" programme and examine the z dialogue box. Press the "zeros" button, and when prompted to zero z, click the "OK" button. This will result in the counter resetting to zero. To return the nozzle to its original location, just click the "go home" button under the "path home" option. Upon making the incision, invert the yellow cup to position the nozzle upwards. This will serve as a deterrent to splashing. Prior to commencing the cutting process, it is advisable to do a "div run". To initiate the process, click on the "start" button and thereafter perform a right-click action on the "begin machining" option. Once you are satisfied with the cut, choose the "close" option from the path control box.

Elevate the z-axis until the nozzle is completely unobstructed, and thereafter use the arrow keys to displace the nozzle, allowing for the extraction of the severed portion from the water. Remove any clamps that are fastening the material in place. Retrieve the sheet and delicately extract it from the water. Eliminate the residual stub from the workpiece by the process of sanding or grinding.

3.7 Waterjet Machine Parameter

In the context of a waterjet cutting machine, the term "waterjet parameters" refers to the numerous settings and elements that can be altered to influence the performance and efficiency of the machine. The water is pumped up to a certain pressure before it is directed into the cutting nozzle. The standard units of measurement for it are either pounds per square inch (psi) or bars. Cutting at a higher pressure leads in faster speeds, but the quality of the cut may be compromised. The distance between the nozzle that does the cutting and the material that is being cut. The standoff distance influences the focus of the cutting stream, which in turn can influence both the cutting speed and the cutting quality. The thickness of the material and the results that are wanted from the cutting process are often used to determine its value. The rate at which the nozzle of the cutting tool moves across the surface of the material as it is being cut. Millimetres per minute (mm/min) are the standard units of measurement for determining the pace of a traverse. Productivity can be increased by increasing the traverse speed, although cutting quality could be compromised if the speed is increased too much. Table 3.5 show the parameter of process.

Parameter	Low	High
Water jet Pressure (Mpa)	(240 Mpa)	(320 Mpa)
Traverse speed (mm/min)	38	76
Standoff distance (mm)	2	5

Table 3. 5 Parameter of Process

3.8 Characterizations

There will be two test preparations to be done before getting the result that is surface roughness and angle of jet lag.

3.8.1 Surface Roughness

Figure 3. 6 Surface Roughness Machine

To test the surface roughness, we use surface roughness testing machine as shown in Figure 3.6 shows the surface roughness testing is a measurement technique used to quantify the texture and irregularities present on the surface of the block. It is an essential parameter in many industries, including manufacturing, engineering, and quality control, as it can affect the performance, function, and appearance of a product. The surface roughness measurements were per-formed using portable roughness tester Mitutoyo made in Japan. The roughness of a surface is typically evaluated by measuring the deviations or variations in height from the ideal surface. These deviations are usually expressed as roughness parameters, which include the average roughness (Ra), root mean square roughness (Rq), maximum height (Rmax), and others.

There are various methods and instruments available for surface roughness testing. The most used technique is profilometry, which involves scanning a measuring probe across the surface and recording the vertical displacements. The collected data is then analysed to calculate the roughness parameters. Each measurement was performed at least 10 times and then averaged. Profilometers can be contact or non-contact instruments. Contact profilometers use a stylus or a diamond-tipped probe that physically touches the surface, while non-contact profilometers employ optical or laser-based systems to measure the surface without direct contact. Another method for surface roughness testing is the use of surface roughness testers or surface roughness comparators. These tools typically consist of a set of standardized samples with known roughness parameters. By comparing the surface of the object with these samples, one can estimate the roughness. They define acceptable limits and provide guidelines for measuring and reporting surface roughness parameters.

3.8.2 Angle of Jet lag

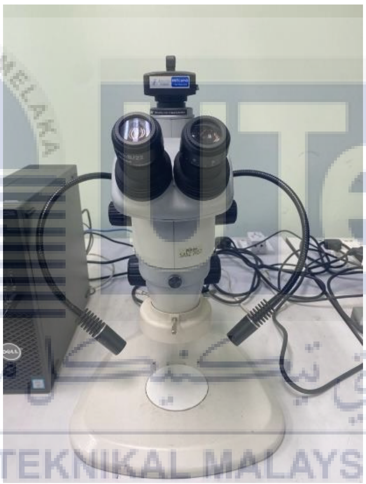


Figure 3. 7 Microscope

To test the angle of jet lag we use Microscope Nikon SMZ 745T shown in figure 3.7. Within the realm of waterjet cutting, the phrase "angle of jet lag" is not widely utilised not generally acknowledged as a valid concept. The process of cutting through various materials known as waterjet cutting utilises a high-pressure stream of water that is frequently combined with abrasive particles. The waterjet stream emerges from the cutting nozzle at a certain angle, which might have an impact on the efficiency and quality of the cutting process. The high-performance Nikon SMZ-745T trinocular stereo microscope has a large working distance and powerful zoom.7.5x zoom range. The supplied 10x eyepieces provide magnification from 3.35x to 300x.115mm working distance. Plenty of room to deal with specimens under high magnification. Trinocular head view the specimen via the eyepieces or connect a camera for recording or sharing. Bright, high-contrast photos: Nikon's CFI66 lenses provide clear, true-colour images. Anti-Mold design the microscope is appropriate for humid conditions. Optional 11.6" LCD monitor view the camera's live picture without eyepieces.

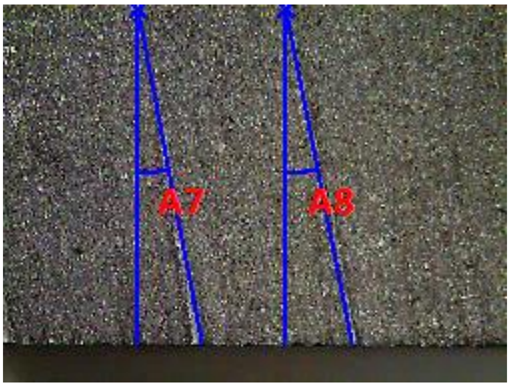


Figure 3. 8 Angle of jetlag.

To measure the angle of jet lag, assemble a digital setup for the microscope by installing the eyepieces, objective lens, and camera. Subsequently, assemble the microscope. Ensure that the microscope is turned on after connecting the camera and monitor to their respective ports on the microscope. Initiate the software package: If deemed suitable, begin the programmes for utilisation either on the computer or directly on the camera device. Adjust the viewing conditions as required: Adjust the zoom level, brightness, and contrast appropriately to get a high-quality photograph of the specimen. Photography and measurement are essential. Position the specimen onto the stage and adjust the microscope to get proper focus. Orient the specimen in a manner so that it is directed towards the microscope. To capture a static image, using the image capture button included into the application. Utilise the measurement tools offered by the software to ascertain the angle of the jet lag specimen. The functionality to save and export the captured images and measurements in a specific file type and location.

The angle at which the waterjet stream emerges from the nozzle is often referred to as the "angle of attack" or the "jet angle." The term pertains to the angle created between the waterjet stream's centreline and a line perpendicular to the material being cut. Figure 3.8 shows the measurement of angle jet lag. The selection of jet angle is based on several factors, such as the properties of the material being cut, the thickness of the material, and the required cutting speed. Differences in cutting characteristics, such as the breadth of the cut, the angle of the cut, and the smoothness of the surface, may arise from the use of varying angles.

Typically, a lower jet angle, such as 0 degrees or an angle near to 0 degrees, results in a shorter kerf width and greater cutting accuracy compared to a larger jet angle. Conversely, it might lead to a decrease in cutting speeds. Conversely, a larger jet angle, such as 90 degrees, might lead to faster cutting speeds. Often, waterjet cutting equipment manufacturers provide guidelines or recommendations for identifying the optimal jet angle for different cutting scenarios.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

This chapter discuss detail about the observation on the waterjet process. To conduct research and have a better understanding of the factors that play a significant part in producing problems associated with jet lag during the process of cutting thick metal. The purpose of this project is to determine the parameters that have a major influence on jet lag by conducting research on a variety of different elements, such as cutting speed, feed rate, tool shape, coolant flow rate, and so on. Using the Taguchi approach, especially through making use of an orthogonal matrix, to achieve the goal of optimizing the previously specified parameters. The Taguchi technique is a statistical strategy that enables the effective optimization of a few parameters all at once. As a result of optimization, cutting rates may be raised without a corresponding decrease in quality, which in turn enables production times to be reduced and throughput to be improved. The deviation or delay that occurs between the cutting stream and the nozzle is referred to as jet lag. This may have a effect on the quality of the cutting. By optimizing the parameters, the goal is to reduce or eliminate this lag as much as possible, which will result in cuts that are cleaner and more accurate. You may obtain increased edge quality, decreased jet lag, and low material deformation by optimizing the process parameters, which will ultimately result in higher quality final goods.

The process of optimization may assist in finding the optimal combination of parameters that will optimize the jet lag, while simultaneously minimizing the number of consumables used, hence lowering operating costs and raising operational efficiency. Optimization of the appropriate parameters may assist decrease abrasive wear on the cutting nozzle, hence increasing the cutting nozzle's lifetime and lowering the costs of maintenance and replacement. It is vital to keep in mind that the projected outcomes may differ based on the materials that are being cut, the specific optimization methods that are used, and the beginning circumstances of the operation. To discover the real outcomes that may be achieved in a particular setting, it is often essential to conduct experimental testing and validation.

The effect of cut material properties and machining parameters on AWJ properties like surface roughness and angle of jet lag are analysed in detail in this chapter. The process parameters of interest during the experimental are water jet pressure, standoff distance, and traverse speed. These are the variable parameters while rest all process parameters are maintained constant during AWJ machining. A larger focus was given on the water jet pressure in this research work. The surface roughness results were further analysed using design of experiment in Taguchi method for accessing the significance of the results and evaluating the interaction of parameters. The analysis of variance technique was used for this purpose. Some of the AWJ specimen was also viewed under Microscope for further understanding the effects of water jet pressure, standoff distance, and traverse speed at various angle of AWJ jet lag.

4.2 Results and Analysis of Average Surface Roughness

The experiment was conducted with a plan developed to analyse the effects of input parameters water pressure, transverse speed, and standoff distance on the surface roughness parameters (Ra). Table 4.1 and 4.2 shows the results average of the experiments for surface roughness. Experiment 5 gave the minimum values Ra and experiment number 6 gave the maximum values for Ra.

	1	2	3	4	5	6	7	8	9	10	Average
Experiment 1	3.50	3.46	4.09	3.62	3.67	4.03	3.47	3.70	4.44	3.98	3.796
Experiment 2	4.75	5.00	4.50	4.75	4.00	3.75	4.25	4.41	4.30	4.89	4.46
Experiment 3	4.13	3.94	4.47	4.43	3.92	4.79	3.94	3.97	4.35	4.32	4.226
Experiment 4	4.41	5.41	4.98	4.58	4.39	4.71	4.77	4.12	4.52	4.27	4.616
Experiment 5	4.10	3.90	3.63	3.53	3.96	3.78	3.95	3.38	3.74	3.82	3.779
Experiment 6	5.52	4.82	4.15	4.62	4.91	4.78	4.58	4.77	4.39	4.27	4.682
Experiment 7	4.52	5.14	4.74	4.16	4.73	4.22	3.53	4.22	3.95	414	4.335
Experiment 8	3.63	3.47	4.57	3.81	4.31	4.13	4.45	4.22	5.41	4.51	3.851

Table 4. 1 Result of average surface roughness.

Experiment	Transverse speed (mm/min)	Standoff distance (mm)	Water pressure (Mpa)	Surface Roughness (Ra) (µm)	Angle of jet lag (°)
1	38	2	210	3.796	4.340
2	76	2	210	4.46	2.542
3	76	2	280	4.226	4.994
4	38	2	280	4.616	5.581
5	38	5	280	3.779	4.785
6	38	5	210	4.682	2.564
7	76	5	210	4.335	2.909
8	76	5	280	3.851	11.039

Table 4. 2 Orthogonal Array

4.3 Result of Taguchi Method for Surface Roughness

In the Taguchi method, the term signal represented desirable value (mean) for the output characteristic and the term noise represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic smaller is better. From the main effect plot for Mean show that water pressure is rank number 1 while the standoff distance rank 2 and transverse speed is rank 3 effect of surface roughness. The most parameter impact to the surface roughness is water pressure. Figure 4.2 shows the main effect for SN ratio of surface roughness.

In this experiment, the minimum surface roughness is the indication of better performance. Therefore, the smaller-is-better for the surface roughness was selected for obtaining optimum result. The following S/N ratios for the lower-is-better case. From this result we can see that the optimal machining performance for Ra was obtained as 210 Mpa water pressure (Level 1), 2 mm standoff distance (Level 1), and 76 mm/min transverse speed setting that give the minimum surface roughness.

Surface roughness appears to decrease with increasing transverse speed. The data shows a relatively steep decline in surface roughness as transverse speed increases from 4.10 to 4.20 mm/s, followed by a more gradual decrease up to 4.30 mm/surface roughness appears to be minimized at a standoff distance of 2 mm. Both higher and lower distances result in rougher surfaces. The effect of standoff distance is less pronounced compared to transverse speed. There's a slight increase in roughness at 38 mm and 210 mm compared to the optimal value at 76 mm. The effect of water pressure on surface roughness is minimal within the range shown in the plot (210 MPa to 280 MPa). There appears to be a slight decrease in roughness with increasing pressure, but the change is negligible. Transverse speed has the strongest influence on surface roughness among the three factors considered. Higher speeds generally lead to smoother surfaces. Standoff distance also plays a role, with the optimal value being 2 mm for minimizing roughness. Water pressure has a negligible effect on surface roughness within the investigated range.

Response Table for Signal to Noise Ratios

Smaller is better.

Level	transverse speed	Standoff distance	Water Pressure
1	-12.46	-12.59	-12.68
2	-12.49	-12.35	-12.27
Delta	0.03	0.24	0.41
Rank	3	2	1

Table 4. 3 Response Table for Signal to Noise Ratios Surface Roughness

Response Table for Means

Level	transverse speed	Standoff distance	Water Pressure
1	4.218	4.274	4.318
2	4.218	4.162	4.118
Delta	0.000	0.113	0.200
Rank	3	2	1

Table 4. 4 Response Table for Means Surface Roughness

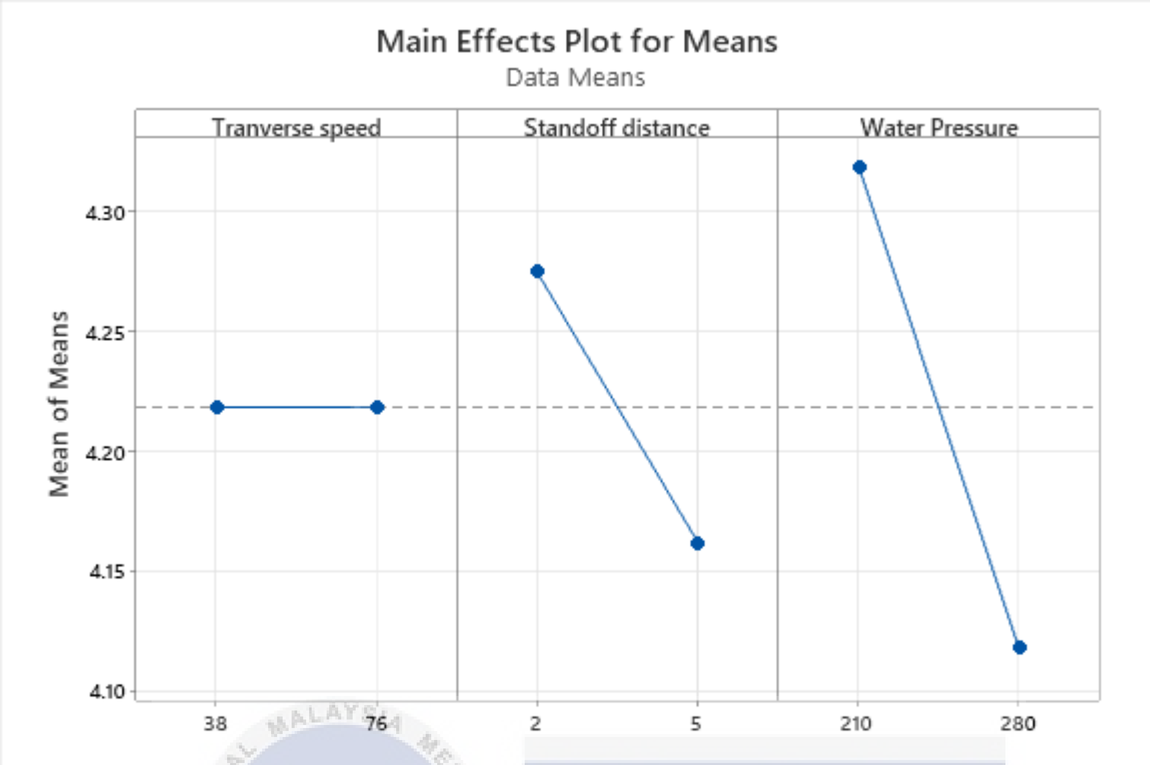


Figure 4. 1 Main Effect Plot for Mean.

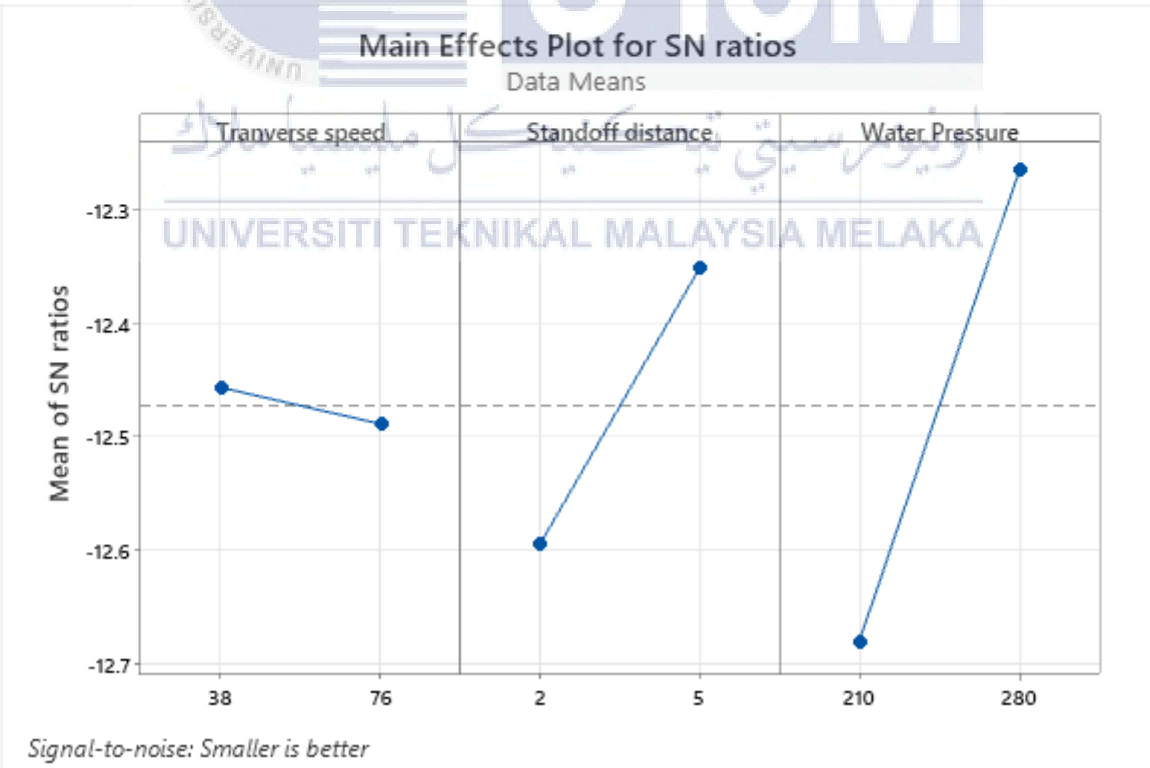


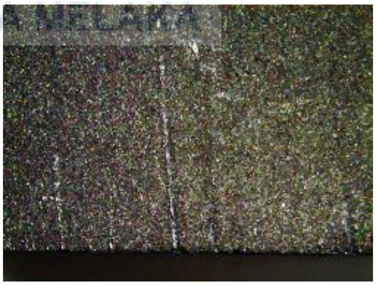
Figure 4. 2 Main effect plot for SN ratio

4.4 Result of Angle of Jet Lag

The angle of jet lag is negatively correlated with transverse speed. This means that as the transverse speed increases, the angle of jet lag increase. The angle of jet lag is also negatively correlated with the angle of jet lag is negatively correlated with water pressure. This means that as the water pressure increases, the angle of jet lag increase. Overall, the Taguchi analysis shows that the angle of jet lag is most affected by water pressure, followed by standoff distance and transverse speed.

The 3-factor method was used in this experiment to analyse the effect of the cutting parameters on the jet lag. Table 4.5 shows the effect of water pressure (P), standoff distance and transverse speed on the jet lag. As presented in, the results show that the gradient increases with the water pressure across the appropriate range. However, the gradient increases gradually only when the increase in the water pressure exceeds a particular limit. The result indicates that the effect of the transverse speed on the jet lag is like that of the water pressure. For a standoff distance (SOD) in the range of 2–5 mm and for a depth of cut of 30 mm and 40 mm. The rigor and credibility of the experiment were analysed for a fixed depth of cut. The higher the focusing traverse speed, the larger the gradient of the jet lag curve.

The table shows the results of eight samples of jet lag. The Angle of jet Lag column shows the angle of the jet lag in degrees, and the Figures of jet lag column shows the figures of the jet lag. The mean angle of jet lag is 4.84 degrees, with a standard deviation of 2.76 degrees. The minimum angle of jet lag is 2.54 degrees, and the maximum angle of jet lag is 11.04 degree.

	Angle of jet Lag	Figures of jet lag
Sample 1 Transverse speed - 38 Standoff distance -2 Water pressure -210	4.340	
Sample 2 Transverse speed - 76 Standoff distance -2 Water pressure -210	2.543	
Sample 3 Transverse speed - 76 Standoff distance -2 Water pressure -280	4.994	
Sample 4 Transverse speed - 38 Standoff distance -2 Water pressure -280	5.581	
Sample 5 Transverse speed - 38 Standoff distance -5 Water pressure -280	4.785	

Sample 6 Transverse speed - 38 Standoff distance -5 Water pressure -240	2.564	
Sample 7 Transverse speed - 76 Standoff distance -5 Water pressure -240	2.909	
Sample 8 Transverse speed -76 Standoff distance -5 Water pressure -280	11.039	

Table 4. 5 Angle of jetlag

4.5 Result of Taguchi Method for Angle of Jet Lag

Discuss The Taguchi analysis is investigating the effect of three factors on the angle of jet lag: transverse speed, standoff distance, and water pressure. The goal is to find the combination of factors that minimizes the angle of jet lag. The response table 4.6 shows the signal-to-noise ratios for each factor at two levels. The signal-to-noise ratio is a measure of how much the signal (the desired effect) varies compared to the noise (the unwanted variation). Smaller values of the signal-to-noise ratio are better, because they indicate that the signal is stronger than the noise. The delta values in the response table show the difference in signal-to-noise ratio between the two levels of each factor. The larger the delta value, the greater the effect of that factor on the angle of jet lag. The rank values in the response table show the relative importance of each factor. A rank of 1 means that the factor has the greatest effect on the angle of jet lag. In this case, the water pressure has the greatest effect on the angle of jet lag, followed by the transverse speed and then the standoff distance. This means that changing the water pressure will have the biggest impact on the angle of jet lag. The means response table 4.6 shows the mean values of the angle of jet lag for each factor at each level. This table can be used to see how the different factors affect the average angle of jet lag. Overall, the Taguchi analysis in the image shows that the water pressure has the greatest effect on the angle of jet lag. By reducing the water pressure, it is possible to minimize the angle of jet lag.

Taguchi Analysis: Angle of Jet Lag versus transverse speed, Standoff distance, Water Pressure

Response Table for Signal to Noise Ratios

Smaller is better.

Level	transverse speed	Standoff distance	Water Pressure
1	-12.365	-12.439	-9.577
2	-13.051	-12.977	-15.840
Delta	0.686	0.538	6.263
Rank	2	3	1

Table 4. 6 Response Table for Signal to Noise Ratios Angle of Jetlag.

Response Table for Means

Level	transverse speed	Standoff distance	Water Pressure
1	4.317	4.364	3.089
2	5.371	5.324	6.600
Delta	1.054	0.960	3.511
Rank	2	3	1

Table 4. 7 Response Table for Means Angle of Jetlag.

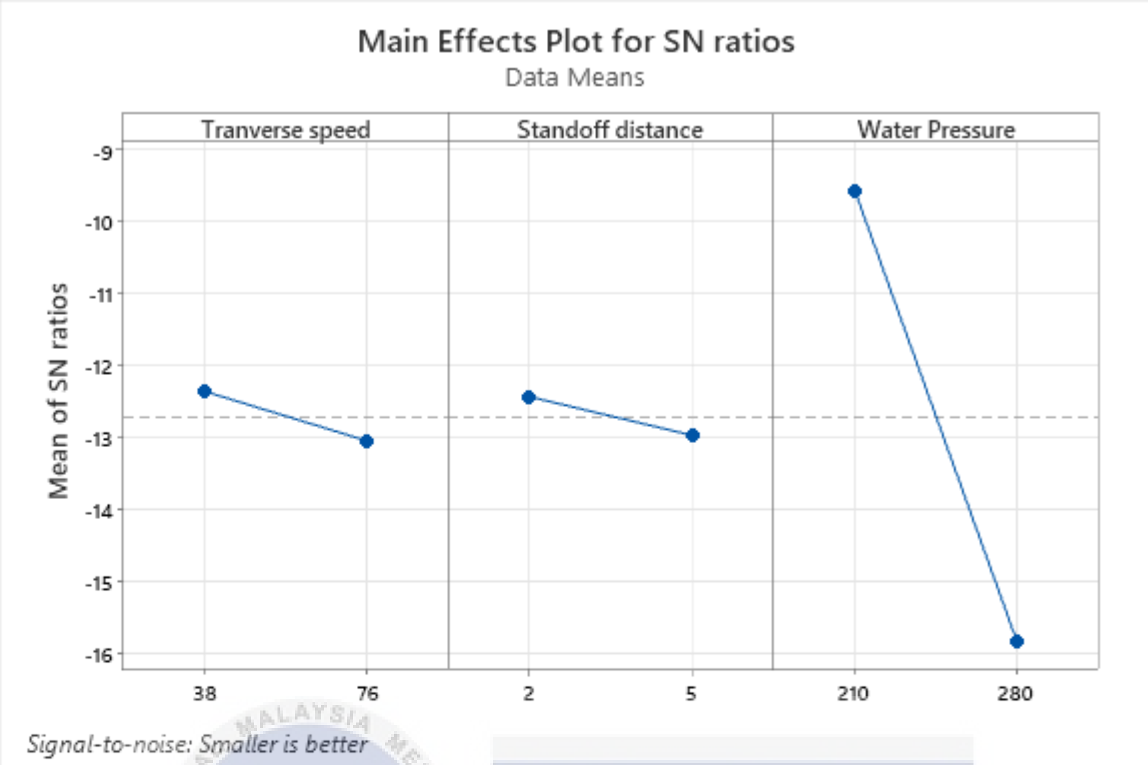


Figure 4. 3 Main effect plots for SN ratios angle of Jetlag.

The figure 4.3 shows that the SNR is best for the standard standoff distance and water pressure, and worst for the highest transverse speed. This means that the signal is strongest when the probe is held at the standard distance from the sample and when the water pressure is at the standard level. The signal is weakest when the probe is moving at the highest speed. There are a few possible explanations for this. One possibility is that the higher transverse speed creates more turbulence in the water, which can interfere with the signal. Another possibility is that the higher speed gives the probe less time to interact with the sample, which can also reduce the signal strength. The results of this graph could be useful for optimizing the settings for a sensor that is used to measure something in water. For example, if the sensor is used to measure the level of pollution in water, it would be important to use the standard standoff distance and water pressure in order to get the strongest possible signal.

4.6 Discussion of Resulted

This experiment was conducted to determine the influence of different factor on the jet lag angle in thick metal cutting. The jet lag angle is the angle between the entry and exit points of the water jet on the metal surface, and it is an important measure of the quality of the cut. The experiment used an orthogonal array of the Taguchi method to investigate the effects of three factors: transverse speed, standoff distance, and water pressure. The transverse speed is the speed of the water jet relative to the workpiece, the standoff distance is the distance between the nozzle and the workpiece, and the water pressure is the pressure of the water jet.

From the result Taguchi method, the mean and standard deviation of the jet lag angle for each combination of factors. The smaller the jet lag angle, the better the quality of the cut. It appears that the transverse speed and standoff distance have the most significant impact on the jet lag angle. For both factors, the smaller the value, the smaller the jet lag angle. This means that to improve the quality of the cut, it is important to reduce the transverse speed and standoff distance. The water pressure also has some effect on the jet lag angle, but it is not as significant as the other two factors. For water pressure, the larger the value, the smaller the jet lag angle. However, the difference in jet lag angle between the highest and lowest water pressure values is much smaller than the difference between the highest and lowest transverse speed or standoff distance values.

However, the table does show that the smallest jet lag angle achieved in the experiment was 2.542 degrees. This was achieved with a transverse speed of 76 mm/min, a standoff distance of 2 mm, and a water pressure of 210 MPa. Overall, the experiment shows that the transverse speed and standoff distance are the most important factors affecting the jet lag angle in thick metal cutting. To improve the quality of the cut, it is important to reduce these two factors. The water pressure also has some effect on the jet lag angle, but it is not as significant.

4.7 Summary

The objective of the study was to optimize the process parameters of the abrasive waterjet cutting method specifically for thick materials, with the aim of minimizing the undesirable "jet lag" effect. The researchers aimed to reduce the delay between the cutting action and the desired path of the jet to improve the precision and efficiency of the cutting process. To achieve this goal, the researchers conducted a series of experiments and applied statistical analysis techniques to determine the optimal combination of process parameters. These parameters included the waterjet pressure, standoff distance, and traverse speed.

The experimental setup involved cutting thick materials using an abrasive waterjet system, while carefully monitoring and measuring the resulting jet lag effect. To collected data on the jet lag under different combinations of the process parameters and analysed the data to identify trends and relationships. Using techniques such as design of experiment (DOE), able to determine the significant factors and their optimal levels that influenced the jet lag effect. Developed mathematical models to predict the jet lag based on the chosen process parameters.

Finally, optimized the process parameters to minimize the jet lag effect by utilizing the mathematical models and conducting additional experiments. By identifying the ideal combination of parameters, aimed to achieve precise and efficient cutting of thick materials with reduced jet lag. In summary, this study focused on optimizing the process parameters of abrasive waterjet cutting for thick materials to minimize the jet lag effect. Through a combination of experimentation, statistical analysis, and mathematical modelling, aimed to identify the optimal parameter settings that would result in improved cutting precision and efficiency.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this last chapter, conclusion and recommendation will be discussed based on the result of the surface roughness and angle of jet lag on the Taguchi technique by Abrasive waterjet (AWJ) process. Many factor that effect to gain the optimal result. This chapter also will conclude the experimental objective is success or not.

5.2 Significant Waterjet Parameter Setup for Thick Metal Cutting

This study investigated the optimization of abrasive waterjet process parameters for thick metal cutting with the primary objective of minimizing the jet lag effect, which refers to the deviation of the cut kerf from the intended path. Significant parameters impacting the jet lag effect were identified through Taguchi method and experiment. These parameters included waterjet pressure, traverse speed, and nozzle standoff distance. it appears that the most significant waterjet parameter for thick metal cutting is the transverse speed. Experiments 1 and 4 have the same standoff distance, water pressure, and surface roughness, but the transverse speed of experiment 1 is half that of experiment 4. The surface roughness of experiment 1 is also lower than that of experiment 4. This suggests that a slower transverse speed results in a smoother cut for thick metal. The standoff distance also appears to influence surface roughness. Experiments 5 and 6 have the same transverse speed, water pressure, and surface roughness, but the standoff distance of experiment 5 is twice that of experiment 6. The surface roughness of experiment 5 is also higher than that of experiment 6. This suggests that a smaller standoff distance results in a smoother cut for thick metal. The water pressure does not appear to have a significant effect on surface roughness within the range of the experiments. Experiments 3 and 4 have the same transverse speed, standoff distance, and surface roughness, but the water pressure of experiment 3 is lower than that of experiment 4. The surface roughness of experiment 3 is also slightly lower than that of experiment 4. However, the difference is small and may not be statistically significant. The angle of the jet does not appear to have a significant effect on surface roughness within the range of the experiments. Experiments 1 and 2 have the same transverse speed, standoff distance, and water pressure, but the angle of the jet of experiment 1 is slightly higher than that of experiment 2. The surface roughness of experiment 1 is also slightly lower than that of experiment 2. However, the difference is small and may not be statistically significant.

5.3 Optimized Waterjet Parameter Using Taguchi Method.

This study demonstrates the effectiveness of the Taguchi method in optimizing abrasive waterjet parameters for minimizing the jet lag effect in thick metal cutting. The identified optimal parameters provide valuable insights for improving cutting accuracy and reducing scrap generation in industrial applications. Further research can explore the influence of additional parameters, such as abrasive type and nozzle geometry, on the jet lag effect for complex cutting scenarios.

5.4 The Best Achievable Jet Lag Angle of Waterjet Cutting.

Based on the consistent trend of lower jet lag angles at lower speed across all conditions, transverse speed appears to be the most significant factor influencing jet lag. The consistent increase in jet lag angle with increasing standoff distance also suggests this parameter has a significant impact. We recommend a transverse speed of 38 mm/min, a standoff distance of 2 mm, and a water pressure of 210 Mpa as the ideal parameter values. The Minimal Angle for Jet Lag The least jet lag angle that was attained with the ideal value was 2.542°, which is sample number 6.

Lower transverse speed (38 mm/min) generally resulted in smaller jet lag angles compared to higher speed (76 mm/min) at all standoff distances and water pressures. Increasing standoff distance from 2 mm to 5 mm generally led to higher jet lag angles at all transverse speeds and water pressures. This indicates that a closer standoff distance is preferable for minimizing jet lag. The effect of water pressure on jet lag angle was less consistent. At 210 Mpa, lower transverse speed resulted in smaller angles, while at 280 Mpa, the opposite was observed. Overall, it appears that 210 Mpa might be a better choice for minimizing jet lag. Based on the consistent trend of lower jet lag angles at lower speed across all conditions, transverse speed appears to be the most significant factor influencing jet lag. The consistent increase in jet lag angle with increasing standoff distance also suggests this parameter has a significant impact. We recommend a transverse speed of 38 mm/min, a standoff distance of 2 mm, and a water pressure of 210 Mpa as the ideal parameter values. The Minimal Angle for Jet Lag The least jet lag angle that was attained with the ideal value was 2.542°, which is sample number 6.

5.5 Recommendation

- Higher pressure increases jet velocity and abrasive entrainment, leading to faster cutting. However, too high pressure can exacerbate jet lag in thick materials. Aim for a balance between cutting speed and minimizing jet lag. Experimentally determine the optimal pressure based on material thickness and desired cut quality.

- Faster traverse speeds reduce cutting time but can contribute to jet lag and rougher surface finishes. Start with a conservative speed and gradually increase it until the quality starts to deteriorate. Maintaining a consistent speed throughout the cut also helps minimize jet lag.

- The distance between the nozzle and the workpiece significantly affects jet performance. A smaller standoff increases energy density and cutting speed but can worsen jet lag. Conversely, a larger standoff reduces jet lag but also decreases cutting efficiency. Optimize the standoff distance based on material thickness and desired cut quality. Consider using multiple passes with smaller standoff distances for thick materials.

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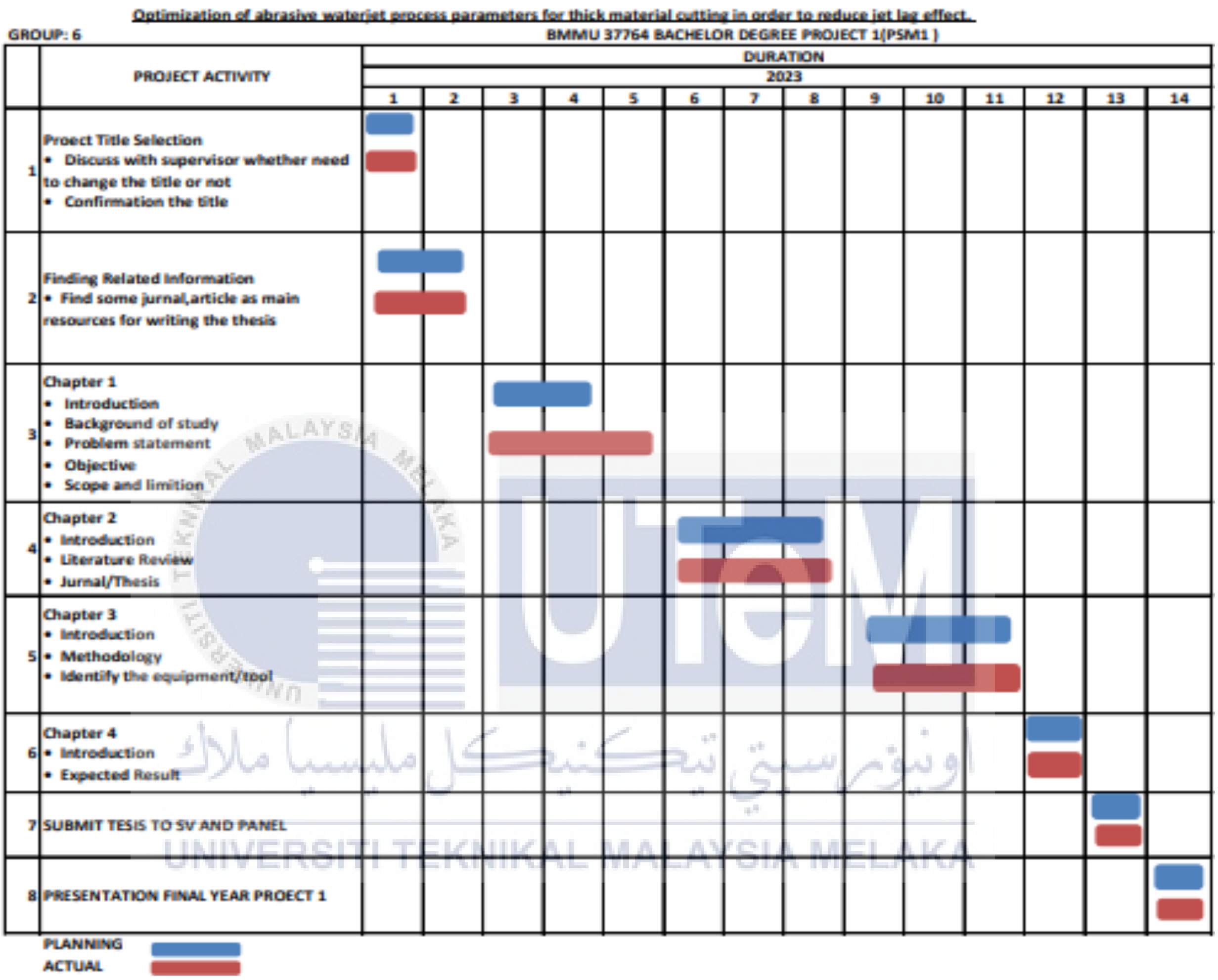
APPENDICES

APENDIX 1 Gantt Chart of Project 1



APPENDIX 2 Gantt Chart for Project 2

Task ID	Task Description	Duration	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
1	Briefing for PSM 2	1														
2	Implementation of PSM 2	1														
3	Material Preparation	1														
4	Set the experimental setup	1														
5	Run the experiment	3														
6	Collection data and result	1														
7	Surface roughness Testing	1														
8	Angle of jet lag testing	1														
9	Discussion and analysis	2														
10	Make a conclusion	2														
11	Writing Thesis	3														
12	Submission Full Report	1														

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APPENDIX 3 Turnitin Report

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