ENHANCEMENT OF CUTTING SURFACE QUALITY OF ABRASIVE WATERJET BY USING MULTIPASS CUTTING STRATEGY

MUHAMMAD HAKIMI BIN

YUSRI B092010026

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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**

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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2023

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SESI PENGAJIAN: **2023-2024 Semester 1**

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Tarikh: 25/1/2024

Cop Rasmi:

TS. DR. HANIZAM BIN HASHIM
Pengurus Operasi, Kilang Pengajaran
Pejabat Timbalan Naib Canselor (Akademik & Antarabangsa)
Universiti Teknikal Malaysia Melaka

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DEDICATION

In the name of Allah, the Most Gracious, the Most Merciful, this dedication is made to the pursuit of knowledge and the advancement of science, with the blessings and guidance of Allah. This study on “Enhancement of Cutting Surface Quality of Abrasive Waterjet by using Multipass Cutting Strategy part is dedicated to all the lecturers, my supervisor, Dr Hanizam Bin Hashim, Utem assistants, and friends who are working very hard and help me towards the development of sustainable materials and technologies. Due to the advantages of multipass have drawn a lot of attention as a good method in processing hard materials. This study demonstrates the potential surface quality and the type of passes, affected the surface roughness of the aluminum alloy. This study offers the important of multipass in abrasive waterjet manufacturing process and enhancing the performance of the material. May Allah grant success to all those who participated in this research and may it be for the good of mankind. May society accept and benefit from our efforts, and may we continue to pursue excellence in all of our academic endeavors.

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ABSTRACT

This study examines the Enhancement of Cutting Surface Quality of Abrasive Waterjet by using Multipass Cutting Strategy. The goal of the study is to investigate the enhancement uses of multipass cutting strategy in the field of cutting manufacturing as well as implying it as a cutting strategy to proceeding the materials. The research methodology entails the strategy of choosing the suitable cutting strategy as 1,2 and multipass in processing the pure aluminum blocks. The study's findings show how the different choose of cutting strategy affects the surface roughness of the aluminum blocks at different thickness of 5mm, 10mm, 15mm and 20mm by using the T-test statical method to measure and compare the result obtained and deciding the significantly. The research findings can help engineers and manufacturer in adding a new cutting strategy method in their manufacturing process.

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ABSTRAK

Kajian ini mengkaji Peningkatan Kualiti Permukaan Pemotongan Pancutan Air Abrasif dengan menggunakan Strategi Pemotongan Berbilang Laluan. Matlamat kajian adalah untuk menyiasat penggunaan peningkatan strategi pemotongan berbilang laluan dalam bidang pembuatan pemotongan serta membayangkannya sebagai strategi pemotongan untuk meneruskan bahan. Metodologi penyelidikan memerlukan strategi memilih strategi pemotongan yang sesuai sebagai 1,2 dan multipass dalam memproses blok aluminium tulen. Dapatan kajian menunjukkan bagaimana pilihan strategi pemotongan yang berbeza mempengaruhi kekasaran permukaan blok aluminium pada ketebalan yang berbeza iaitu 5mm, 10mm, 15mm dan 20mm dengan menggunakan kaedah statik ujian-T untuk mengukur dan membandingkan keputusan yang diperoleh dan memutuskan secara signifikan. Penemuan penyelidikan boleh membantu jurutera dan pengilang dalam menambah kaedah strategi pemotongan baharu dalam proses pembuatan mereka.

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My utmost appreciation goes to my main supervisor, Dr Hanizam Bin Hashim, for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered.

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CHAPTER 1

INTRODUCTION

1.1 Background

Aluminum alloy is a metallic material made from a combination of aluminum and other elements, such as copper, magnesium, silicon, and zinc. These elements are added to aluminum to improve its strength, durability, and other properties, making it suitable for a wide range of applications in various industries.

Aluminum alloy is commonly used due to its light weight, low density, and ease of processing (Mrad et al., 2018c). Making them ideal materials for aircraft, automobiles, and other transportation applications. They are also used in construction, packaging, and consumer goods, among other industries. Due to the universal usage of this aluminum alloy in many sectors, many type of cutting method had been used in order to process this kind of material. Sawing is a simple and effective way to cut aluminum alloy. Saws with carbide-tipped blades are the best choice for cutting aluminum, as they will not dull quickly.

Other than that, waterjet cutting which is a precise and versatile method that can be used to cut a variety of materials, including aluminum alloy. Waterjet cutters use a high-pressure stream of water to cut through the material, and can produce very smooth cuts. Waterjet cutting uses a high-pressure stream of water to cut through materials. The water is typically pressurized to between 30,000 and 60,000 psi, and it is forced through a small nozzle that can be as small as 0.001 inches in diameter. The water stream is so focused that it can cut through a variety of materials, including steel, glass, stone, and even some plastics. Plasma cutting which is an efficient method that can be used to cut thicker pieces of aluminum alloy. Plasma cutters use a high-temperature plasma arc to cut through the material, and can produce very straight cuts. Plasma cutting cuts through electrically conductive materials by means of an accelerated jet of hot plasma. The plasma is created by ionizing a gas, such as air or argon, and then accelerating it through a small nozzle. The temperature of the plasma can reach up to 20,000 degrees Celsius, which is hot enough to melt and vaporize most metals.

Electric discharge machining (EDM) is a precise and accurate method that can be used to cut complex shapes in aluminum alloy. EDM machines use a spark to erode the material away, and can produce very smooth and burr-free cuts. Electrical discharge machining (EDM), also known as spark machining, die sinking, wire burning or wire erosion, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the tool or electrode, while the other is called the workpiece-electrode, or work piece.

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Abrasive waterjet showed a good potential in processing the aluminum alloy due to the its good cutting method and technique. Abrasive waterjet (AWJ) is one of the methods for cutting with high-power density streams. It is dependent on a high-pressure water stream to accelerate abrasive particles to sufficient velocities. It is an effective method for cutting the majority of solid, reflective, and heat-sensitive materials (Trivedi et al., 2015b). It works by using a high-pressure pump to force water through a small opening, creating a narrow stream of water that travels at speeds of up to 1,500 meters per second. An abrasive material such as garnet is then added to the water stream, which combines with the water to create an abrasive mixture.

This abrasive mixture is then forced through a nozzle, creating a powerful cutting tool that can cut through a variety of materials such as metal, glass, plastics, and composites. The nozzle is designed to focus the abrasive mixture into a fine, concentrated stream that can cut complex shapes and designs with great accuracy. Surface quality is an important aspect to consider when evaluating the abrasive waterjet cut processes (Schwartzentruber et al., 2017). Abrasive waterjet cutting can cut a wide variety of materials, including steel, glass, stone, and even some plastics. It is a very precise process, and it can be used to cut complex shapes. However, it can be a slow process for thick materials.

Here are some of the abrasive waterjets being used, manufacturing, abrasive waterjets are used to cut precision parts in a variety of industries, including the automotive, aerospace, and medical industries. Construction, abrasive waterjets are used to cut stone, concrete, and other materials in construction projects. Industrial cleaning abrasive waterjets are used to clean and deburr metal parts. Engraving, abrasive waterjets are used to create intricate engravings on metal, stone, and other materials.

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Compared to other cutting technologies, abrasive waterjet (AWJ) cutting has been shown to have a number of differentiating advantages, including no thermal distortion on the workpiece, great machining versatility to cut almost any material, high flexibility to cut in any direction, and low cutting forces (Van Luttervelt, 1989). Furthermore, abrasive waterjet also is a potential technology with advantages such as the lack of a heat-affected zone (Patel & Tandon, 2015), minimal residual stress, and relative resistance to edge damage (Bañon et al., 2021).

Despite having many pros there also cons when using abrasive waterjet as a cutting method. They can be expensive to purchase and operate. They can create a fine mist of water and abrasive particles, which can be a health hazard. The main problem that usually occur in the manufacturing process nowadays is the low quality of the cut surface and the rough surface finish of the product.

1.2 Problem Statement

Although abrasive waterjet showed a good potential in processing different materials due to the its good cutting method and technique, there is still a problem in conducting this process. The quality of the cut surface by using this process is still a challenge. Rough surface finish usually occurs when using abrasive waterjet due to some of the factors that result to this problem is still cannot be corrected. Results demonstrated that the material removal rate was greatly impacted by stand-off distance, flow pressure, and traverse rate, in ascending order of significance. In addition, they concluded that the traverse rate was being the main factor influencing the surface roughness (Thakur & Singh, 2020).

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However, the cutting surface quality can be further improved by using more than one or multipass cutting technique as the cutting strategy in the term of processing the materials. Using multipath cutting technique is consider new in abrasive waterjet cutting. Although, it can result in several problems including slow cutting speeds and time-consuming, some parts that are complex and require smoother surface finished and able to eliminate the secondary process such as grinding and finishing. Therefore, this study is to explore the potential of multipass cutting technique or strategy in order to improve cutting surface; number of paths vs thickness of the material.

1.3 Research Objective

Specifically, the objectives are as follows:

1. To determine the surface roughness of pure aluminum block cutting surface at 1, 2 and multipass cutting strategies.

2. To determine the best multipass cutting strategy to be used for every measured thickness on the pure aluminum block surface.

3. To analyses the means of surface roughness using the T-test statistical method.

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1.4 Scope of Research

The scope of research on the enhancement of cutting surface quality of abrasive waterjet to the Aluminum alloy by using multipass cutting strategies includes the following:

Investigation the effect of multipass cutting on the cutting surface quality of abrasive waterjet to the Aluminum alloy by using abrasive waterjet machine, Flow Mach2. Involves the evaluation of the surface finish, kerf width, and taper angle of the cut by using the abbrasive waterjet machine. Identification of the optimal cutting parameters for multipass cutting. This includes the determination of the appropriate cutting speed, abrasive flow rate, standoff distance, and number of passes. Comparison of the results of the aluminum block cutting surface at 1, 2 and multipass cutting strategies by using the T-test statical method of the obtained data. This involves the evaluation of the cutting efficiency, accuracy, and quality. Optimization of the multipass cutting strategy for specific applications. This includes the development of a decision-making tool to determine the optimal cutting strategy for a given material and application and analyses the means of surface roughness using the T-test statistical method by comparing the means of two groups. It is a parametric test, which means that it makes certain assumptions about the data, such as that the data is normally distributed.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Aluminum alloy is an alloy consisting primarily of aluminum. Aluminum alloy is an alloy of aluminum (Al) with other elements, such as copper, magnesium, manganese, silicon, tin, nickel, and zinc. The addition of these elements to aluminum improves its properties, such as strength, hardness, corrosion resistance, and conductivity. Other elements are added to aluminum in order to enhance its properties, such as its strength, stiffness, and resistance to corrosion.
There are numerous applications for aluminum alloys, including aircraft, automobiles, and construction. The properties of aluminum alloys can be further modified by heat treatment. Heat treatment can increase the strength and hardness of aluminum alloys, while also improving their corrosion resistance.

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Aluminum alloys are a versatile and widely used material. They offer a combination of strength, lightness, and corrosion resistance that makes them ideal for many applications. Aluminum also it is the second most commonly used metal after steel. By alloying with other elements, a variety of aluminum alloys with distinct properties have been developed and eventually utilized.
Aluminum alloys usually maintain their high strength-to-weight ratios and exceptional corrosion resistance. These aluminum alloys are commonly employed in the aerospace and automotive industries (Zhi et al., 2022). Their application potential in construction has also been recognized and they are also competitive in lightweight, durable, and sustainable structures, such as helideck structures,

gearbox, transmission towers constructed in mountains, and others (Wang et al., 2020). Here are some of the advantages of using aluminum alloys, they are lightweight, making them ideal for applications where weight is a concern. They are corrosion resistant, making them ideal for applications where they will be exposed to the elements. In addition, aluminum is recyclable, making them environmentally friendly and relatively inexpensive, making them a cost-effective option.

2.2 Abrasive Waterjet

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Abrasive waterjet (AWJ) as in Figure 1 is an alternative cutting technique that employs high-pressure water to generate a high-velocity stream containing abrasive particles for cutting a broad range of soft to hard materials. It is a versatile method because AWJs can be used for a variety of manufacturing applications, including cutting, milling, cleaning, and surface treatment. Unique advantages of AWJ cutting involve a low heat affected zone, a high degree of flexibility in the cutting process, and reduced machining force work (Hashish et al., 1984). In previous research, the surface quality behavior of single pass cutting for Aluminum alloy was studied (Ahmed et al., 2018).

Using single cuts in abrasive waterjet cutting can result in several problems including slow cutting speeds, cutting a single part at a time can be time-consuming, especially if the parts are complex or require multiple passes. In term of improving the cutting quality and surface roughness, multipass cutting strategies being applied. Regardless of the limitations of cutting quality for a single pass of AWJ cutting, the majority of previous study has centered on single pass cutting. Few studies studied the multipass cutting procedure. Guo, J. researched multipass cutting technique to enhance the quality of cutting (Wang & Guo et al., 2003).

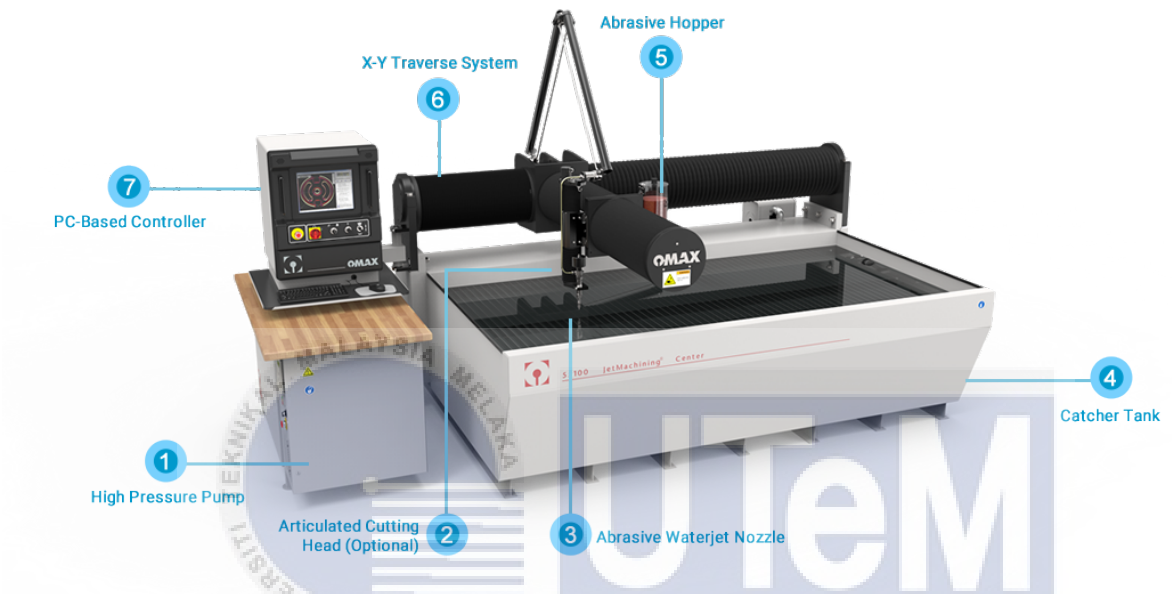

Figure 2.1 Flow Mach2 Abrasive waterjet machine

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Multipass abrasive waterjet cutting is a cutting technique that uses multiple passes of the waterjet to cut a workpiece. This technique can be used to improve the cutting quality and surface finish of the cut, as well as to increase the depth of cut. In multipass abrasive waterjet cutting, the waterjet is first used to make a rough cut of the workpiece. The second and subsequent passes are then used to refine the cut and to improve the surface finish. The number of passes that are required will vary depending on the material being cut and the desired surface finish. Multipass abrasive waterjet cutting can be a more time-consuming process than single-pass cutting.

However, it can be a more effective way to achieve a high-quality cut.

2.3 Principles of AWJ

Abrasive waterjet cutting is a non-traditional machining technique that applies a high-pressure water jet containing abrasive particles to cut through a variety of materials and is an attractive technology for machining materials that are difficult to cut (Wang et al., 1999). The water jet can typically reach velocities of up to 6,000 feet per second (fps) and can slice through materials up to 12 inches thick.

Based on the principle of erosion, abrasive waterjet cutting operates. By impacting at high velocities, the high-pressure water jet and abrasive particles erode the workpiece. Typically, the abrasive particulates consist of garnet, aluminium oxide, or silicon carbide. The type of abrasive employed is determined by the material that want to be removed.

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2.4 Parameter of AWJ

The following are the important parameters of abrasive water jet machining (AWJM):

- Jet pressure: The jet pressure is the most important parameter in AWJM. It determines the cutting speed and the material removal rate (MRR). Higher jet pressure results in higher MRR, but it can also cause surface damage.

- Standoff distance:

The standoff distance is the distance between the nozzle and the workpiece. It affects the focus of the jet and the cutting speed. A shorter standoff distance results in a more focused jet and a higher MRR, but it can also cause surface damage.

- Abrasive type and size:

The type and size of the abrasive particles used in AWJM affect the cutting speed and the surface finish. Coarser abrasive particles result in faster cutting speeds, but they can also cause surface damage. Finer abrasive particles result in smoother surface finishes, but they can also reduce the MRR.

- Abrasive flow rate:

The abrasive flow rate is the number of abrasive particles that are fed into the jet. It affects the cutting speed and the surface finish. Higher abrasive flow rates result in faster cutting speeds, but they can also cause surface damage.

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- Traverse speed:

The traverse speed is the speed at which the nozzle is moved across the workpiece. It affects the MRR and the surface finish. Higher traverse speeds result in higher MRR, but they can also cause surface damage.

The optimal values of these parameters will vary depending on the material being cut, the desired MRR, and the desired surface finish. It is important to experiment with different parameters to find the best combination for a particular application. In addition to the above parameters, the standoff distance, transverse speed, and abrasive flow rate are some of the input factors that also have a significant impact on the quality of the machining produced by the AWJM process (Olsson & Snis et al., 2007).

2.5 Parameter effect the Surface Roughness and Quality

Surface quality is an important aspect to consider when evaluating the abrasive waterjet cutting processes [3]. So, it is important to take the parameter as the main priority when processing any kind of material using the abrasive waterjet machining. In this research, it is crucial to know all the parameters that can affect when processing the Aluminum alloy block to improving the surface roughness and the surface quality.

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There are a number of parameters that can affect the surface roughness and surface quality when using abrasive waterjet. These include the water pressure, the higher the water pressure, the more powerful the waterjet will be and the smoother the surface finish will be. Abrasive type and size, the type and size of abrasive used can also affect the surface finish. Coarser abrasives will produce a rougher surface finish, while finer abrasives will produce a smoother surface finish.

Traverse speed, the faster the traverse speed, the rougher the surface finish will be. Standoff distance, the standoff distance is the distance between the nozzle and the material being cut. The closer the nozzle is to the material, the rougher the surface finish will be.

This is because the abrasive particles have less time to spread out and impact the material evenly. Nozzle type, the type of nozzle can also affect the surface finish. Conical nozzles produce a smoother surface finish than straight nozzles. Understanding the influence of the control factors (traverse speed, water pressure, and standoff distance, i.e., the distance between the nozzle and the surface of the sample) on the behavior of the AWJ process becomes essential for improving the process's cutting performance. Despite the fact that the influence of process parameters on surface roughness has been studied in the past, a comprehensive understanding and model for the influence of these parameters and their interactions on cutting quality are required [1].

2.6 Multipass Cutting Strategies

The use of machine learning and artificial intelligence to optimise multipass cutting strategies has gained popularity in recent years. This is due to the fact that these technologies can take into consideration a greater variety of factors than conventional methods, including the workpiece geometry, the tool geometry, and the cutting conditions. As a result of this research, new multipass cutting strategies that can considerably improve surface finish, reduce machining time, and enhance the productivity of machining operations have been developed.

Multipass cutting is a method of abrasive waterjet (AWJ) cutting in which the material is removed in multiple passes compared to a single pass. This can be done for a variety of purposes, including improving the surface finish, reducing the cutting forces, or preventing the workpiece from warping. Moreover, research on traditional machining processes shows that multipass cutting is more beneficial compared to single pass cutting (Aydin et al., 2011). To obtain the same total

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depth of cut in AWJ cutting, multipass cutting at high traverse rates may be prefer compare to a single pass at low traverse rates. Therefore, it is important to investigate the multipass AWJ machining procedure (Armarego et al., 1994).

The following method and technologies are applied in multipass cutting such as using computer-aided manufacturing (CAM) software, tool trajectories for multipass cutting operations can be generated. This can enhance the precision and productivity of the machining process.

The application of machine learning to optimize multipass cutting strategies is possible. Training a machine learning model on a dataset of machining data achieves this objective. The model is then capable of predicting the optimal cutting conditions for a given set of parameters.

The application of artificial intelligence to optimize multipass cutting strategies is also possible. Utilizing techniques such as genetic algorithms and neural networks, this is accomplished. These methods can be used to find the optimal cutting conditions that satisfy a set of constraints.

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2.7 T-test method and Significant Parameter

T-test, also known as the student's t-test, is frequently used as a statistical method for determining if the mean value of the data from a separate sample that follows a normal distribution is consistent with or significantly different from the mean value of a null hypothesis, or if the difference between the means of two separate samples that follow a normal distribution is statistically significant (Talavera et al., 2020).

The T-test can be classified into one-sample t-test, two independent samples t-test and two paired samples t-test (Hashimoto et al., 2004). The one-sample t-tests used when the data from the two groups are independent, showing that the data from one group cannot be used to predict the data from the other and the two paired samples t-test, which is used when the data from the two groups are

dependent, showing that one group's data is related to the data from the other group. The null hypothesis is denied and the alternative hypothesis is accepted if the t-statistic is greater than the critical value. This shows that there is a difference between the means of the two categories that is statistically significant.

The null hypothesis is not rejected if the t-statistic is less than or equal to the critical value. This shows that there is insufficient evidence to conclude that the difference between the means of the two categories is statistically significant by using the Minitab software or the Excel software.

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2.8 Summary or Research Gap

For the summary on this chapter, it is known that there are some of the parameters and things that crucial and need to be taken as the priority and investigation because of it affects the outcome of the case study. For an instant, these parameters like the water pressure, abrasive type and size, traverse speed, standoff distance and nozzle type. Understanding the influence of the control factors (traverse speed, water pressure, and standoff distance, i.e., the distance between the nozzle and the surface of the sample) on the behavior of the AWJ process becomes essential for improving the process's cutting performance.

Despite the fact that the influence of process parameters on surface roughness has been studied in the past, a comprehensive understanding and model for the influence of these parameters and their interactions on cutting quality are required [1]. It essential to know that by doing adjustment towards all these parameters will affects the outcome of the data obtained through the experiments.

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CHAPTER 3

METHODOLOGY

3.0 Introduction

This experimental configuration calls for the use of an abrasive waterjet machine capable of single-pass cutting of aluminum block with a different thickness. Appropriate cutting heads, nozzles, and abrasive delivery systems must be installed on the machine. In addition, safety measures are implemented to secure the workplace.

Important step in the methodology is the selection of parameters, material, equipment, and also characterization. Important process parameters are outlined, including water pressure, traverse speed, abrasive flow rate, standoff distance, and nozzle size. These parameters have a significant effect on the AWJ surface quality and roughness. Establishing a range of values for each parameter in order to investigate their influence on the cutting surface roughness and determine the suitable cutting strategy for different thickness of the aluminum block.

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The method of experimentation applies a systematic approach, such as a Design of Experiments (DoE) methodology, to investigate the parameter and the multipass cutting strategy for in term of obtaining the surface roughness of the pure aluminum block. Each investigation run in a series is assigned a unique set of parameter values.

In the procedure, the pure aluminum blocks are being cut using the multipass cutting strategies at 1, 2 and multipass based on the its thickness. The pure aluminum block is secured in fixtures or work holding devices to ensure precision and stability during the cutting process. To determine the surface roughness of thick aluminum, the selected parameters, precise and consistent surface quality and measurements are conducted.

List of materials also make a big impact during the cutting process as the type of material need to be considered before the cutting process and also type of abrasive that being used for the waterjet machine to making sure for achieving the right outcome.

The determination and the evaluation of the surface quality and roughness of the pure aluminum block, measuring with appropriate instruments such as surface roughness machine stereo microscope and more. To representative the results, the measurements are collected at multiple locations along the cut surface.

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The obtained data being analyze by using the techniques such as the T-test statistical method. Examining the relationship between the number of the cutting strategy and the effect on the surface roughness and quality and determining the best multipass cutting strategy to use for the pure aluminum block.

3.1 Research Design

All the values that obtained were based on the flow circle followed by the process flow chart from the starting point until the recommended cutting pass. This methodology provides a method for systematically enhancing surface quality and determining the best cutting strategies using abrasive waterjet cutting for the pure aluminum blocks.

The diagram below shows the sequence of this research presented in Figure 1. The purpose of a flowchart is to illustrate each step of a process, from its initiation to its conclusion. The methodology of the study will begin with the preparation of materials, followed by the use of equipment, gathering information, surface testing and data analysis. If the parameter result does not meet the desired objective, the procedure will be repeated with the previous result improved. The process will continue for the testing phase if the result obtained satisfied.

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3.2 Material

For this research, there are two materials that need to be considered during experimental session for getting the result that suits with the main objectives of this research. There are some aspects and factors that were very crucial as the types of the material, usage, details manufacturer and sizing.

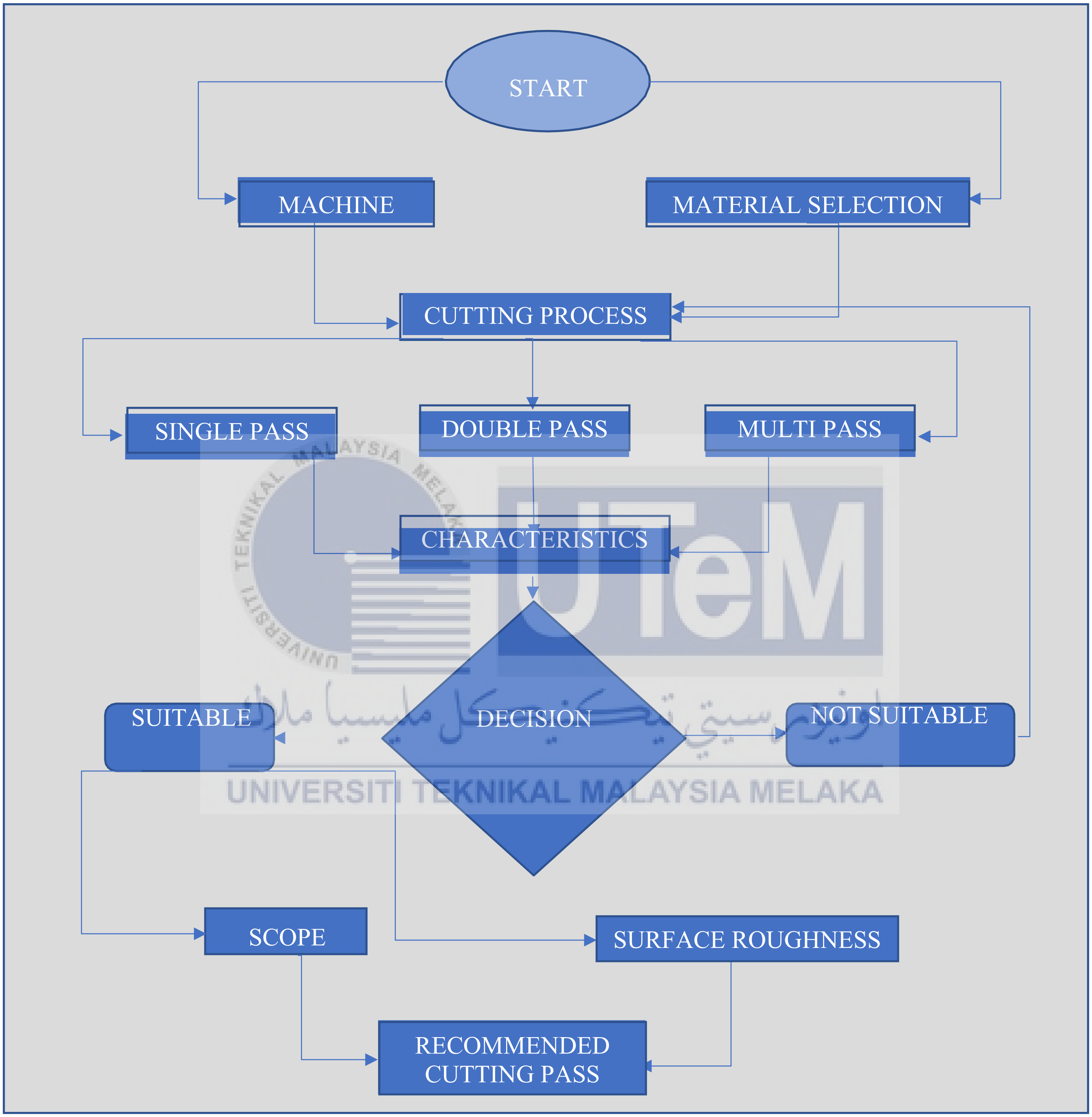

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Figure 3.2: Flowchart of the progress

3.3 Pure Aluminum Block

Pure aluminum blocks, also known as 1060 aluminum blocks, are essentially made from one thing which is aluminum and it is highly refined form with a very specific composition of Aluminum (Al): 99.6% or higher and a trace element that less than 0.4% total of other elements, such as iron, silicon, copper, and manganese. Pure aluminum is a lightweight metal with silvery-white that often described as having a matte finish and also a versatile. It has a density of 2.7 grams per cubic centimeter (g/cm^3), one-third the density of steel. Pure aluminum has a low melting point compare to other metal which is 660°C (1220°F). Because of the low melting point, aluminum is easy to be melt and casting. It also has a boiling point as high as 2467°C (4473°F) that not suitable for most application.

For the strength of this material, it relatively low compared to other metals meaning that, pure aluminum can be easily bent and shaped without breaking. This pure aluminum can be shaped into a wide variety of forms and very useful for a variety of manufacturing techniques, including rolling, extrusion, and forging. Pure aluminum also is an environmentally friendly as it is highly recyclable material. Despite to its advantages, pure aluminum also has some limitations as it is low in strength, requiring high structural integrity and have vulnerability to scratching as it can be easily scratched and dented due to its softness.

In this research, pure aluminum block as shown in figure 3.1 with a length of 72mm with 32mm height and 100mm width are being used tested in term of obtaining the value of the its surface roughness after being cut by the waterjet machine as using the multipass technique.

		Numerical values
Yield stress	(MPa)	280
Ultimate tensile strength	(MPa)	327
Strength coefficient	K (MPa)	447
Strain hardening exponent	n	0.095
Young's modulus	(GPa)	68
Percent elongation	A (%)	12
Hardness	Hv50	95

Figure 2.2 Material Properties of Aluminum alloy

Figure 3.1: Pure Aluminum Block

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3.4 Abrasive

In this experimental, parameters being a main thing to be considered in term of achieving the purpose of this study which is to determine the surface roughness of thick aluminum block cutting surface and the best multipass cutting strategy that suitable for each thickness by using the T-test statistical method. The optimal cutting parameters for multi-cutting techniques depend on the characteristics of the material being cut, according to their findings. A

Waterjet machining is made possible by the use of abrasives, which turn the process from a tool for soft materials like foam and rubber into a flexible technology that can cut through almost any material, including meterial like steel, aluminum, copper, titanium, granite, marble, concrete, float glass, tempered glass, bulletproof glass, fiberglass, carbon fiber and Kevlar.

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Figure 3.12: Garnet Sand Abrasive

In this research, we used Garnet Sand, figure 3.12 as our abrasive material with a mesh size of 80 in the waterjet machine for cutting the workpiece, pure aluminum block. Garnet sand abrasive is a reddish-brown wonder that occurs naturally made up of garnet grains of almandine. It has a strong crystalline structure that highly resistant to impact and wear which leading to a longer lifespan and reduced costs. Garnet sand has a high more effective hardness of 7-7.5Mohs that make it effectively at cutting abrade and hard surfaces.

For the density, garnet sand has high density that allows a faster cutting and cleaning compared to lighter abrasives and also boosting its productivity. Garnet sand abrasive is suitable to be used in waterjet cutting material as it provides a fast and precise cutting method for various materials, from metals and ceramics to composites and concrete.

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3.5 Equipment

In this case study of Enhancement of Cutting Surface Quality of Abrasive Waterjet by using Multipass Cutting Strategy, the equipment that take part is abrasive waterjet cutting machine.

Abrasive waterjet cutting is a precise and versatile method that can be used to cut a variety of materials, including pure aluminum. Abrasive waterjet cutting is a non-traditional machining technique that applies a high- pressure water jet containing abrasive particles to cut through a variety of materials and is an attractive technology for machining materials that are difficult to cut. The water jet can typically reach velocities of up to 6,000 feet per second (fps) and can slice through materials up to 12 inches thick. Abrasive waterjet cutting works with a high-pressure pump working to force water through a small opening, makes a narrow stream of water that travels at speeds of up to 1 ,500 meters per second. An abrasive material such as garnet is then added to the water stream, combines with the water to create an abrasive mixture.

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Abrasive water jet (AWJ) is one of the methods for cutting wit high-power density streams. It is dependent on a high-pressure water stream to accelerate abrasive particles to sufficient velocities. It is an effective method for cutting the majority of solid, reflective, and heat sensitive materials.

Compared to other cutting technologies, abrasive water jet (AWJ) cutting has been shown to have a number of differentiating advantages, including no thermal distortion on the workpiece, great machining versatility to cut almost any material, high flexibility to cut in any direction, and low cutting forces. Furthermore, abrasive waterjet also is a potential technology with advantages such as the lack of a heat -affected zone, minimal residual stress, and relative resistance to edge damage. In this case study of Enhancement of Cutting Surface Quality of Abrasive Waterjet by using Multipass Cutting Strategy the equipment that take part are abrasive waterjet cutting machine, Flow Mach2, aluminum alloy blocks with different thickness as the material that being processes and the T-test statical method as the review and to collect the obtained data.

A relatively lower cutting velocity is required for brittle/harder materials, and the abrasive mass flow rate appears to be a significant parameter. While cutting brittle/softer materials, a higher cutting velocity and abrasive mass flow rate are required [19]. El-Hofy reported that the surface roughness value Ra for the AWJ single-cutting strategy is between 3.8 and 6.4 m. This process has multiple interacting control parameters. The most important control parameters for the AWJ cutting process are water pressure, traverse speed, and standoff distance (distance between the jet orifice and the sample surface) (Natarajan et al., 2020). Furthermore, the optimal center line average value was 3.46 m (Ra). According to previous investigations for the AWJ cutting process, the average surface roughness values ranged from 3.46 to 8.24 m. Manufacturing research is perpetually challenged by the possibility of enhancing the surface quality based on the results of previous investigations (Natarajan et al., 2020b).

The method for performing abrasive waterjet cutting on Aluminum alloy to enhance cutting surface quality and surface roughness. This is the standard for establishing an experiment during the cutting process:

• Material Preparation: Obtain the Pure Aluminum blocks samples with the required dimensions and ensure that the samples are properly cured and free of defects.

• Cutting Tool Selection: Choose an appropriate cutting tool based on the desired cutting method, material thickness, and desired cutting precision and cutting strategy.

• Cutting parameter: Determine the cutting parameters, such as cutting speed, feed rate, and depth of cut, traverse speed, based on the specific cutting method and the material.

• Set up for Experiment: Establish the cutting machine or workbench in a well-ventilated area, observing to all applicable safety guidelines.

• Data collection and Analysis: Throughout the process of cutting, capture vital data and analyze it to determine the effectiveness of the parameters and method of cutting strategy. Examine the results of the required cutting quality specifications or reference values.

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In this research, we use an Abrasive waterjet machine, Figure 3.13 named Flow Mach 2 located at Factory 2 to cut our material, pure aluminum block.

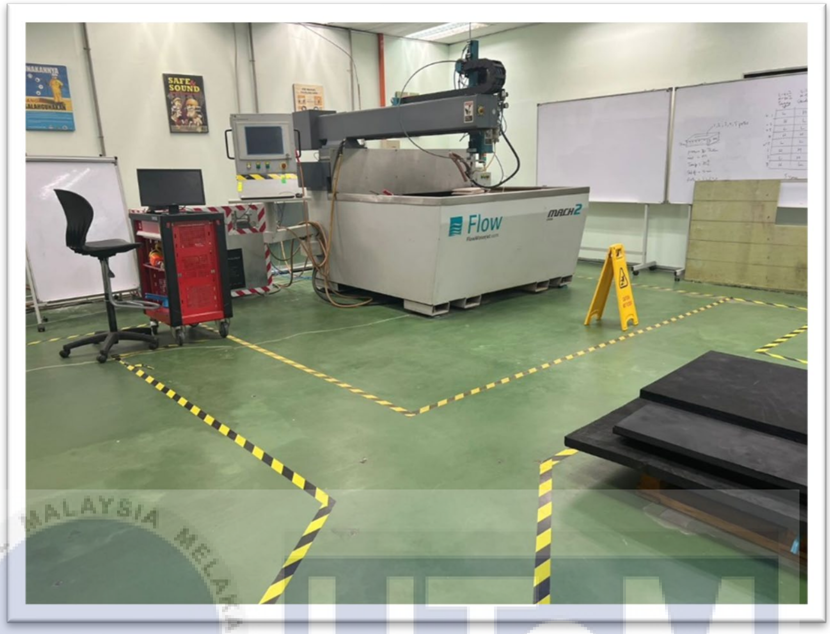

Figure 3.13: Abrasive Waterjet Machine

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3.6 Experimental Setup (T-Test method)

An experimental is a procedure that carried out to test a hypothesis or theory or to obtaining certain objective. It involves making a prediction about what will happen if a certain variable is changed, and then testing that prediction by manipulating the variable and observing the results of the outcome.

During the experimental session, there are some procedure and steps that we take in term of achieving the objective and providing the outcome of this research which is determining the surface roughness of the pure aluminum blocks.

As first, we are given a pure aluminum block with a parameter of 60mm length with 32mm height and 100mm width as the material to conduct the experiment. The suitable parameter then was set into the abrasive waterjet machine to being read. After finished setting up the coding, the material which is pure aluminum block being placed to the specific area of the cutting. The material being cut by the abrasive waterjet machine with using the single, double and multipass technique.

After finishing the process of the cutting, the workpiece then being tested at the measurable lab by using the specific measurable machine which is surface roughness machine to obtain the value of the surface roughness for each of the workpieces. The data and the outcome then being collected and reviewed.

The collected data then being compared and analyze by using the T-test method. T-test method a statistical method for determining if the mean value of the data from a separate sample that follows a normal distribution is consistent with or significantly different from the mean value of a null hypothesis, or if the difference between the means of two separate samples that follow a normal distribution is statistically significant.

The T-test can be classified into one-sample t-test, two independent samples t-test and two paired samples t-test. The one-sample t-tests used when the data from the two groups are independent, showing that the data from one group cannot be used to predict the data from the other and the two paired samples t-test, which is used when the data from the two groups are dependent, showing that one group's data is related to the data from the other group. The null hypothesis is denied and the alternative hypothesis is accepted if the t-statistic is greater than the critical value. This shows that there is a difference between the means of the two categories that is statistically significant.

For analyzing the data and value, we use the Minitab Statistical application in Figure 3.14 to use the T-test method to calculate and determining the significant of the surface roughness value obtained. The data that obtained were classified as 3 types which are for 1 pass cutting, 2 pass cutting and multipass cutting where there are 4 different thickness measured level for each of the category.

Figure 3.14: Minitab Statistical Application

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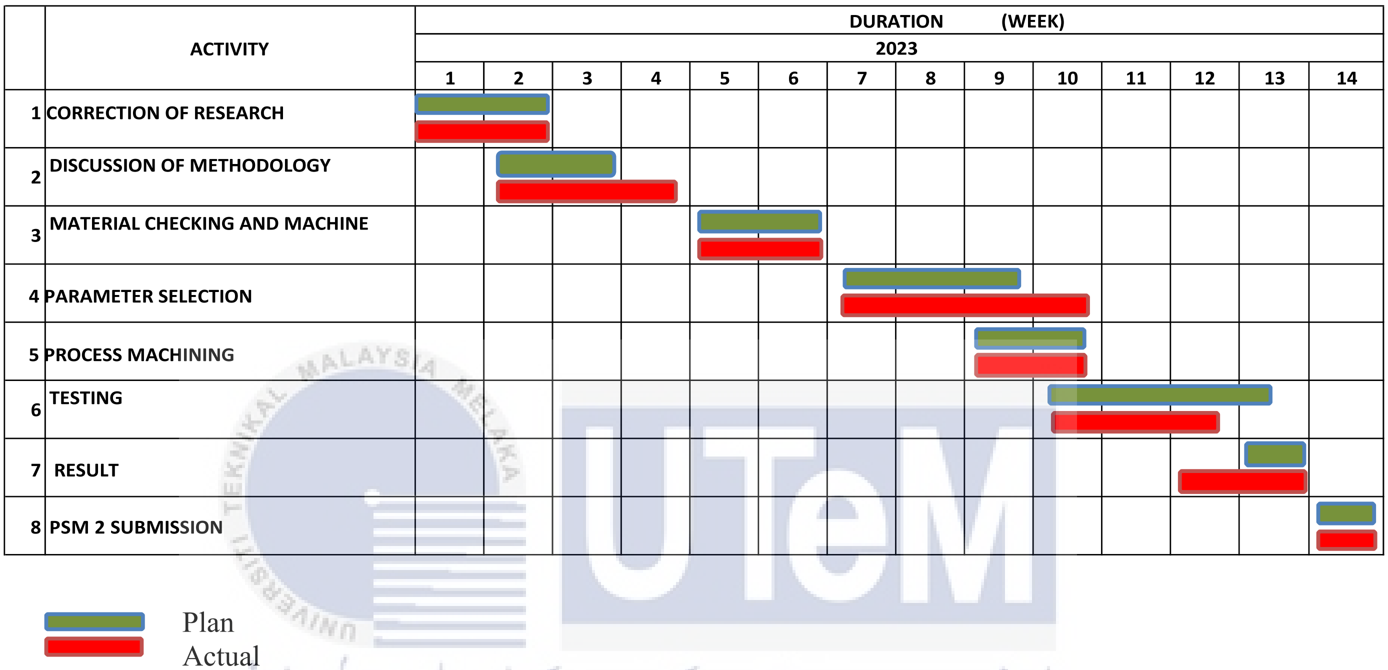
3.7 Waterjet Process

This is the planning and the actual activity during this study case



APPENDIX A The Ghantt chart of the activity

3.8 Characterization

For getting the final results for this research which is surface roughness, we need to use the surface roughness machine in Figure 3.15 to be able to obtain the value of the surface roughness for the aluminum pieces.

A surface roughness machine is a tool used for measuring the surface roughness. It is used in a variety of areas, including as engineering, manufacturing, and quality assurance, to guarantee that surfaces fulfil the necessary requirements.

A pointed probe which stylus is dragged over the surface to be measured. The stylus travels up and down as it encounters the peaks and valleys of the surface. These movements are recorded by a sensor, which converts them into a digital signal and then processed by a computer, which calculates the surface roughness parameters.

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Figure 3.15: Surface Roughness Machine

The procedure for using the surface roughness machine:

Steps	Details
Preparation	• Clean the surface • Choose the appropriate stylus • Calibrate the machine • Set measurement parameters (measuring length (cutoff), evaluation length, number of sampling lengths, roughness parameters (Ra, Rz, Rq))
Positioning the Workpiece	• Secure the workpiece • Align the measurement direction
Operating the Machine	• Lower the stylus • Initiate measurement • Maintain stability
Reviewing Results	• Analyze the results • Repeat measurements

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3.9 Waterjet Parameter

The following are the important parameters of abrasive water jet machining (AWJM):

- Jet pressure: The jet pressure is the most important parameter in AWJM. It determines the cutting speed and the material removal rate (MRR). Higher jet pressure results in higher MRR, but it can also cause surface damage.

- Standoff distance: The standoff distance is the distance between the nozzle and the workpiece. It affects the focus of the jet and the cutting speed. A shorter standoff distance results in a more focused jet and a higher MRR, but it can also cause surface damage.

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- Abrasive type and size: The type and size of the abrasive particles used in AWJM affect the cutting speed and the surface finish. Coarser abrasive particles result in faster cutting speeds, but they can also cause surface damage. Finer abrasive particles result in smoother surface finishes, but they can also reduce the MRR.

- Abrasive flow rate: The abrasive flow rate is the number of abrasive particles that are fed into the jet. It affects the cutting speed and the surface finish. Higher abrasive flow rates result in faster cutting speeds, but they can also cause surface damage.

- Traverse speed: The traverse speed is the speed at which the nozzle is moved across the workpiece. It affects the MRR and the surface finish. Higher traverse speeds result in higher MRR, but they can also cause surface damage.

The optimal values of these parameters will vary depending on the material being cut, the desired MRR, and the desired surface finish. It is important to experiment with different parameters to find the best combination for a particular application. In addition to the above parameters, the standoff distance, transverse speed, and abrasive flow rate are some of the input factors that also have a significant impact on the quality of the machining produced by the AWJM process.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the development of a set of surface roughness and the best cutting strategy that need to be applying for every circumstance such as customer demand or specific dimension and also in avoiding secondary process. The value and data obtained will be reviewed by the set of the T-test statical method in order to improving the value of the surface roughness obtained. Case studies also are performed to demonstrate the multipass cutting strategy through the pure aluminum blocks. It is to obtained the most possible cutting strategy that need to be applying for each of the pure aluminum blocks. It is important to note that, these case study aims in illustrating the proposed methodology, regardless of the multipass cutting strategy used in abrasive waterjet machining. The results are validated based on the time series simulation results of the surface roughness provided by the experiments.

4.2 Parameter Used

There are some parameters that are very significant and need to be considered during this research for running the experiment such as water pressure, standoff distance and traverse speed. In this experiment, traversal speed was expressed as a percentage which is 80% for high level. The percentage need to be converted into value which can get after the material being cut which is 76mm/min for the traverse speed. For the water pressure value, we use a material thickness 30 mm which the water pressure shows a value of 210 MPa. The value of standoff distance the cutting is 4mm respectively

variables / level	Water pressure (MPa)	Standoff distance(mm)	Traverse speed (mm/min)
High	210	4	76

Table 1: Parameter Value

4.3 Cutting process based on parameter

Based on the value of the parameter inserted into the abrasive waterjet machine, below is the value results of the number of cutting pass used with each of its parameter.

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Number of cutting pass used	Water pressure (MPa)	Traverse speed (mm/s)	Standoff distance (mm)
1	210	76	4
2	210	76	4
multipass	210	76	4

Table 2: Number of cutting pass with parameter

4.4 Experimental Result

Experimental result on the surface roughness

Surface roughness is an important factor in the fields of manufacturing that influences the performance, function and quality of machined parts and components. It has a big impact in various properties like friction, wear resistance, light scattering, and adhesion. In this research, surface roughness of each of the workpiece that have been cut by using the multipass cutting method is the main focus.

The blocks of pure aluminum have been cut by using 3 different types of cutting pass which are 1 pass, 2 pass and also multipass by using the same parameter setting for the abrasive waterjet machine. The experiment also includes the determination of average values generated from each of the measured thickness which are 5mm, 10mm, 15mm and 20mm for each type of cutting pass. The option selection was made to use many trials for every sample in order to adjust for the potential natural variation in surface quality within the same material.

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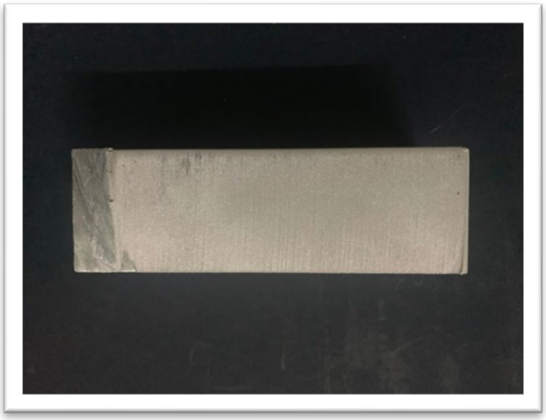

1 pass cutting result

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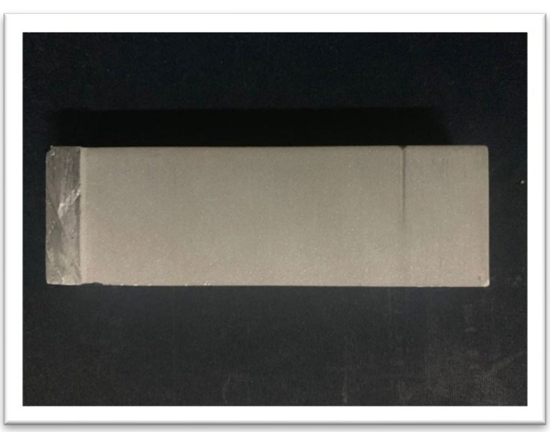
2 pass cutting result



Multipass cutting result

By reducing the effects of problems and providing that the estimated average surface roughness is a more reliable and precise measurement of the actual surface quality, this technique is particularly useful. Make an average from several trial measures increase the data's statistical stability and provide a more accurate and detailed surface roughness value. The value for the surface roughness 5 trial for 4 different thickness for 3 types of cutting pass sample are shown in table below.

Number of passes	Surface Roughness for 1 Pass (µm)			
Thickness (mm)	5	10	15	20
1	4.40	5.17	5.33	4.94
2	5.22	4.79	4.98	5.11
3	4.67	4.45	4.67	5.22
4	4.45	5.20	5.24	5.40
5	5.11	4.99	5.14	4.87
Total	23.85	24.6	25.36	25.54
Average	4.77	4.92	5.07	5.12

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Number of passes	Surface Roughness for 2 Pass (µm)			
Thickness (mm)	5	10	15	20
1	3.36	3.60	3.48	3.47
2	3.40	3.62	3.35	3.32
3	3.65	3.44	3.34	3.65
4	3.34	3.32	3.40	3.31
5	3.50	3.48	3.47	3.46
Total	17.25	17.46	17.04	17.21
Average	3.45	3.49	3.41	3.44

Number of passes	Surface Roughness for multipass (µm)			
Thickness (mm)	5	10	15	20
1	2.97	3.24	3.20	3.12
2	3.24	3.16	3.17	2.94
3	2.99	3.12	3.06	2.99
4	3.21	3.18	2.93	3.20
5	2.98	2.99	3.04	3.16
Total	15.39	15.69	15.4	15.41
Average	3.07	3.14	3.08	3.08

Table 3: Average value of surface roughness

From the average value obtained, the value was insert to MINITAB software as shown in table below to analyses the result using T-Test method. To analyses the data, click stat then choose basic statistic and find the paired T column. Then after that, select any two of the columns from the data and make the comparison.

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No of pass / Thickness (mm)	1 cutting pass	2 cutting pass	multipass
5	4.77	3.45	3.07
10	4.92	3.49	3.14
15	5.07	3.41	3.08
20	5.12	3.44	3.06

Table 4: Average value inserted in MINITAB

4.4.1 T-Test method analysis on surface roughness

Surface roughness is one of the most important factors in determining the cleanness and the roughness of the workpiece material after being cut or processed during manufacturing or any works. The T-test statical method from the MINITAB can ensure to make a comparison and determining the significancy of the value for the surface roughness of the tested material after processed.

To be able to tell if there are any significant different between the 2 group of data, the P value need to be lower than the value of 0.05 so that we can see the different between the two items that we want to compare.

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Paired T-Test and CI: 1 pass, 2 pass

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
1 pass	4	4.9700	0.1581	0.0791
2 pass	4	3.4475	0.0330	0.0165

Estimation for Paired Difference

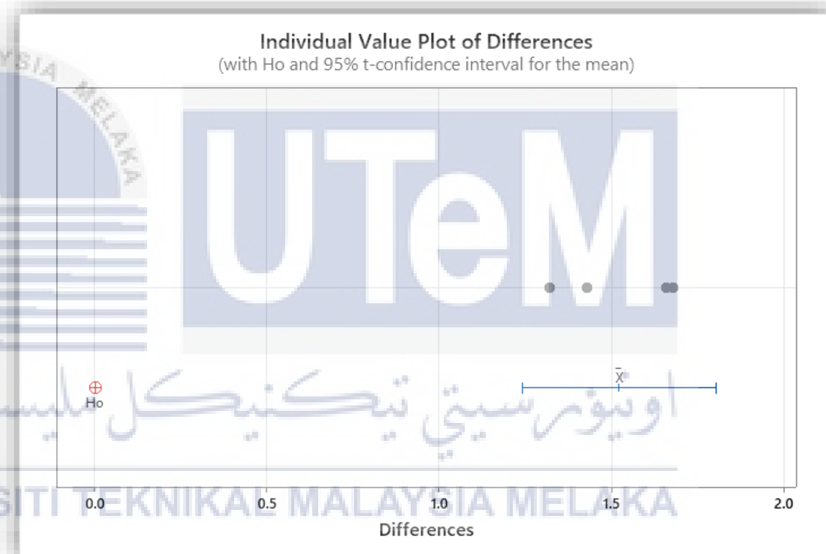
Mean	StDev	SE Mean	95% CI for μ_difference
1.5225	0.1763	0.0882	(1.2419, 1.8031)

μ_difference: population mean of (1 pass - 2 pass)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
17.27	0.000



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- The value of confident level, P for the Paired T-test between 1 cutting pass and 2 cutting pass is 0 which is lower than the value of 0.05, means that we can tell that the value between them is significantly different.

Paired T-Test and CI: 2 pass, multipass

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
2 pass	4	3.4475	0.0330	0.0165
multipass	4	3.0875	0.0359	0.0180

Estimation for Paired Difference

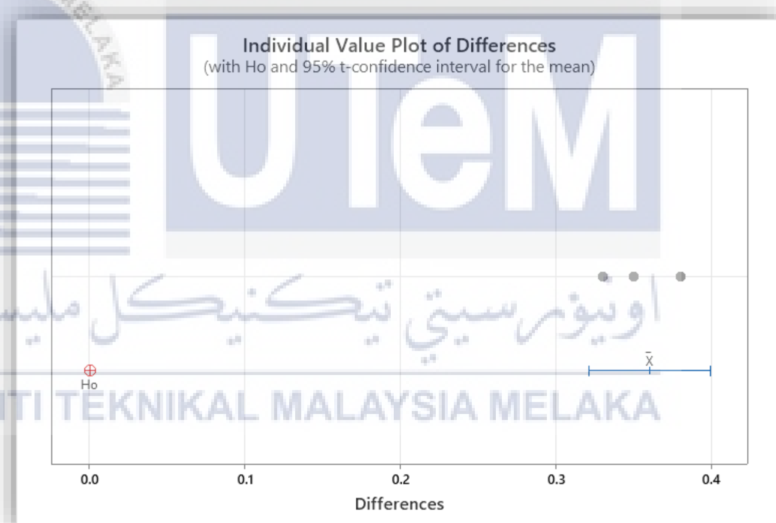
Mean	StDev	SE Mean	95% CI for μ_difference
0.3600	0.0245	0.0122	(0.3210, 0.3990)

μ_difference: population mean of (2 pass - multipass)

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference ≠ 0

T-Value	P-Value
29.39	0.000



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- The value of confident level, P for the Paired T-test between 2 cutting pass and multipass cutting is 0 which is lower than the value of 0.05, means that we can tell that the value between them is significantly different.

Paired T-Test and CI: 1 pass, multipass

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
1 pass	4	4.9700	0.1581	0.0791
multipass	4	3.0875	0.0359	0.0180

Estimation for Paired Difference

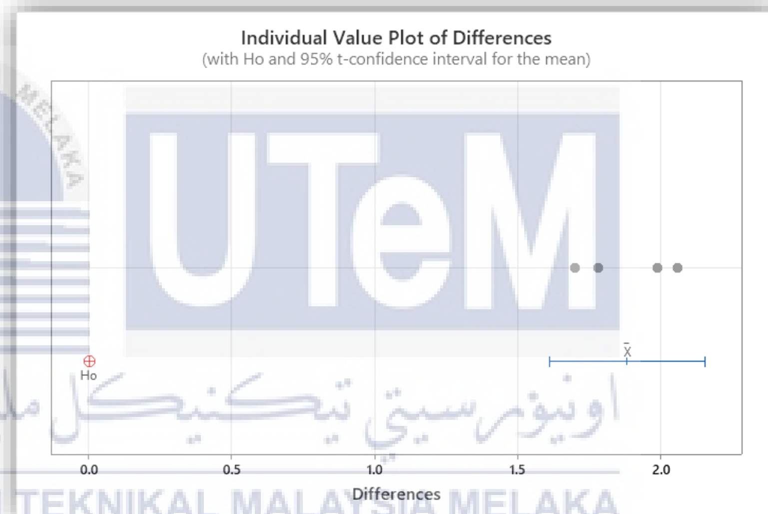
Mean	StDev	SE Mean	95% CI for μ_difference
1.8825	0.1702	0.0851	(1.6117, 2.1533)

μ_difference: population mean of (1 pass - multipass)

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference ≠ 0

T-Value	P-Value
22.12	0.000



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- The value of confident level, P for the Paired T-test between 1 cutting pass and multipass cutting is 0 which is lower than the value of 0.05, means that we can tell that the value between them is significantly different.

4.5 Result Discussion

The experiment of obtaining the surface roughness of the pure aluminum block by using different type of cutting pass method have produced interesting results. By understanding the parameter and the use of cutting pass method we were able to see a difference value and pattern in each of the workpiece's surface roughness.

Using T-test statical method, we successfully be able to compares the means of two related (paired, repeated, or matched) samples to determine if there's a statistically significant difference between them. This method enables us to measure the same variable twice under different conditions or on the same subjects at different times. The small different in the value of the surface roughness between the pure aluminum workpieces can be seen by using the t-test statical method. The organized character of the T-test method approach allowed for a thorough investigation of the surface roughness value, which resulted in enhanced machining results.

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We discovered the optimum surface roughness from the 3 types of cutting pass on pure aluminum blocks by using the scope analysis. This step was important in proving that the T-test method approach's improved parameters achieved, in actually, result to enhanced machining performance and results. The study providing an estimate of possible ways in improving the surface quality for future optimization for abrasive waterjet cutting process on pure aluminum.

4.6 Summary

These predicted outcomes might be different based on factors including the aluminum block's properties, the cutting equipment being applied, and the required cutting parameters. In order to optimize the process and get the required surface quality. It's often critical to perform experimental testing and optimization. In addition, it is very important to making sure considering all the crucial factors that may affects the results before start conducting the experiment.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

As we already come to the end phase of the research for the topic of types of cutting pass affects the surface roughness quality of the pure aluminum block, this part provided a chance to delivers an opportunity to generate a variety of ideas and findings that have developed during the course of our research. The focus on surface roughness of the pure aluminum block has leading us to the affects of the number of passes with the results of the surface roughness quality.

5.2 Conclusion

In this conclusion, the ability to machine and process the pure aluminum block material is experimented for desired machining quality and specification. The key parameters such as water pressure, traverse speed, and standoff distance which are controlling the surface roughness quality are studied. In conclusion, the main objectives that leading our research and the progress of our understanding of surface quality improvement. This study's results provide insight on the effectiveness of abrasive waterjet cutting on processing the pure aluminum block, they also have higher effects for the manufacturing and material processing sectors.

Through a systematic investigation and research, the important factors that have a significant effect on surface quality and the applying of the suitable cutting passes during abrasive waterjet cutting of aluminum blocks has been determined. Our results demonstrate a complex connection between machining functions, process parameters, the cutting pass method and also analyses the means of surface roughness using the T-test statistical method. The multipass have provided the best surface roughness value as compared to the 1 and 2 cutting pass due to the effectiveness of the cutting process.

We effectively improved the identified significant different between the cutting passes and the parameters using the T-test statical methods of experiments tool. The T-test statical method from the MINITAB can ensure to make a comparison and determining the significancy of the value for the surface roughness of the tested material after processed. We also be able to tell any significant different between the 2 group of data, as the P value need to be lower than the value of 0.05 to see the different between the two items that we want to compare. Our findings demonstrate the T-test method's usefulness in achieving the significant different, thus increased efficiency and precision in abrasive waterjet cutting operations for the surface roughness effectiveness.

In conclusion, achieving each of these objectives advances our knowledge of the complex physics of abrasive waterjet cutting on pure aluminum blocks and provides useful information for optimizing surface roughness and achieving better machining outcomes. This work's effective strategy for parameter discovery, optimization, surface roughness improvement and validation make it a valuable addition to the industries of accurate machining and materials processing.

5.3 Recommendation

In many applications, achieving good surface quality using abrasive waterjets might be important. The whole research produces several recommendations in optimizing the surface roughness quality during the process of implying multipass method on abrasive waterjet machining.

Firstly, provide more study about the relationships between cutting passes impacting surface quality and is required to improve our understanding of abrasive waterjet cutting processes specification. Studying the complicated connections between different components and materials can improve the overall improvement strategy and increase the precision of abrasive waterjet cutting processes.

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Secondly, use different the type of material such as aluminum and composite, for example. For this reason, in order to gain a deeper understanding of how various materials respond to waterjet cutting, researchers need expand the scope of their investigation and explore beyond a specific aluminum alloy. The detailed investigation will enable cutting processes to be modified to the unique characteristics of different materials, offering a versatile and adaptable approach for a variety of applications.

Next, expand studies in implementing a multipass strategy requires and consideration of several factors such as material properties because different materials will respond differently to multipass cutting. Harder materials may benefit from more passes, while softer materials might require fewer. Nozzle selection, choosing the right nozzle size and type is crucial for optimizing the cutting process for each pass and abrasive flow rate and pressure. Adjusting the abrasive flow rate and pressure for each pass ensures efficient material removal while minimizing surface damage.

Additionally, take into consideration various alternatives such laser cutting. Although abrasive waterjet cutting is an effective technology, considering other cutting techniques such laser or plasma cutting may offer significant knowledge on the benefits and limitations of each technique. Comparisons provide an in-depth analysis of modern technology, helping researchers in selecting the optimal approach for certain applications.

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In conclusion, the recommendation about the study and improvement of the application of abrasive waterjet machining operations on pure aluminium block brings up the details of this machining approach. This recommendation will enhance for the future study in the paths of precision, versatility, sustainable development, and continual improvement of machining processes and also to have an impact regarding the way machining technologies grow throughout the more general materials processing industry.

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