AN ENERGY ANALYSIS OF WATER JET PROCESS USING RANDOM FOREST METHOD

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BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY WITH HONOURS

2022

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**A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology with Honours**

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "An Energy Analysis Of Water Jet Process Using Random Forest Method" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology with Honours.

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DEDICATION

To Al-Quran, the greatest source of knowledge Bring me sheets of iron" - until, when he had leveled [them] between the two mountain walls, he said, "Blow [with bellows]," until when he had made it [like] fire, he said, "Bring me, that I may pour over its molten copper."

(Al-Kahf: Verse 96)

Alhamdulillah

Praise to Allah for the strength, guidance and knowledge that was given by Allah for me to complete this study

&

To my beloved parents, Azri Bin Abdullah and Noraini Binti Che Othman for every support that was given to me

&

To my supervisor, Ts. Mohd Faizal Bin Halim for his guidance and advice in completing this research.

&

To all people who support me throughout my journey.

ABSTRACT

Modern production is faced with the challenge of reducing the environmental impacts related to machining processes. Machine tools consume large amounts of energy and, as a consequence, environmental impacts are generated owing to this consumption. Many studies have been carried out in order to minimize cutting power, cutting energy or power consumed by the machine tool. Nevertheless, the response variables mentioned before do not take into account the energy required by all the components inside the machine tool during the cutting operation. This paper presents an experimental study related to the combination of cutting parameters that influence energy consumption in cutting process of Aluminum plate. A set of experimental runs was established using an Orthogonal Array design to obtain the regression empirical model for the energy consumed during machining. The adequacy of the model was proved by Random Forest method. The relationship between cutting parameters (water pressure, feed rate, cutting speed and thickness of material) and the response variables was analyzed using main effect plots and heat map. Thickness of material and feed rate were the most significant factors for minimizing the total specific energy consumed using the right combination of parameters. Consequently, sustainability and quality of the machining process were achieved at the same time.

ABSTRAK

Pembuatan moden berhadapan dengan cabaran untuk mengurangkan kesan alam sekitar yang berkaitan dengan proses pemesinan. Mesin menggunakan sejumlah besar tenaga dan, sebagai akibatnya, kesan alam sekitar berlaku disebabkan penggunaan ini. Banyak kajian telah dijalankan untuk meminimumkan kuasa pemotongan, tenaga pemotongan atau kuasa yang digunakan oleh mesin. Namun begitu, pembolehubah tindak balas yang dinyatakan sebelum ini tidak mengambil kira tenaga yang diperlukan oleh semua komponen di dalam alat mesin semasa operasi pemotongan. Kertas kerja ini membentangkan kajian eksperimen berkaitan gabungan parameter pemotongan yang mempengaruhi penggunaan tenaga dalam proses pemotongan plat Aluminium. Satu eksperimen dilakukan telah diwujudkan menggunakan reka bentuk Tatasusunan Ortogonal untuk mendapatkan model empirikal regresi untuk tenaga yang digunakan semasa pemesinan. Kecekapan model telah dibuktikan dengan kaedah Random Forest. Hubungan antara parameter pemotongan (tekanan air, kadar suapan, kelajuan pemotongan dan ketebalan bahan) dan pembolehubah tindak balas dianalisis menggunakan plot kesan utama dan peta haba. Ketebalan bahan dan kadar suapan adalah faktor paling penting untuk meminimumkan jumlah tenaga khusus yang digunakan menggunakan kombinasi parameter yang betul. Secara langsung, kelestarian dan kualiti proses pemesinan dapat dicapai pada masa yang sama.

ACKNOWLEDGEMENTS

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

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform.

My utmost appreciation goes to my main supervisor, Ts. Mohd Faizal bin Halim, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice, and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. I would express my sincere honor for guidance, critics, and willingness in giving a helping hand and advice through this research. I deeply appreciate his hospitality, intelligence, and knowledge from the beginning of the semester until now.

Last but not least, from the bottom of my heart a gratitude to my parent Azri bin Abdullah and Noraini binti Che Othman. I recognize that this research would not have been possible without their support. Finally, thank you to all the individual(s) who had provided me the assistance, support, and inspiration to embark on my study. In advance, I wish to apologize for all other unnamed who helped me in various ways to finish my research.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	-	Carbon Dioxide
MPa	-	Mega Pascal
mm^3	-	Millimeter Cubic
mm	-	Millimeter
min	-	Minute
kg	-	Kilogram
%	-	Percent
s	-	Second
#	-	Abrasive Mesh
Ra	-	Surface Roughness
AWJM	-	Abrasive Water Jet Machine
AWJ	-	Abrasive Water Jet
AI	-	Artificial Interlligence
NCMP	-	Non-Conventional Machining Process
SOD	-	Stand-Off Distance
CNC	-	Computer Numerical Control
PA	-	Predictive Analytics
MS	-	Mild Steel
ASTM	-	America Society For Testing And Material
2-D	-	2 Dimension
3-D	-	3-Dimension
DFX	-	Drafix
OA	-	Orthogonal Array
P	-	Power
V	-	Voltage
I	-	Current

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CHAPTER 1

INTRODUCTION

1.1 Background

Energy efficiency has been ingrained in the metal production sectors as a method of improving economic and environmental performance while increasing competitiveness. Industrial machines not only consume the most energy in the industrial sector, but they are also inefficient. As a result, analyzing energy consumption by industrial is critical for understanding their complicated and dynamic energy consumption behavior. As a result, more stringent remedial actions will be implemented.

Many manufacturers are understanding the financial and environmental benefits of sustainable production processes (Haapala et al., 2013). This will contribute to advancements in energy efficiency and environmental impact reduction in the industrial sector. In the manufacturing business, new enhanced methods and production are needed to develop sustainable manufacturing energy sources and achieve cleaner production (Sáez-Martínez et al., 2016).

Abrasive water jet cutting, one of today's most popular contour cutting methods, was born out of the need to cut difficult-to-machine materials used in the aerospace, aviation, and automobile industries. In abrasive water jet cutting, high water velocity is mixed with abrasive particles such as diamond to improve the efficiency of the process in the material removal rate and making it possible to cut all the materials (Deaconescu & Deaconescu, 2021). Water with a high velocity and high pressure is mixed with small abrasive particles on the work piece, eroding the material and producing material removal due to impact.

Because there are no heat impacts, this technique is ecologically friendly and has no influence on the materials' characteristics (or internal structure). This modern machine techniques that leave no heat impacted zone or residual tension on the machined surface or work piece.

Figure 1.1 Abrasive Water Jet Cutting Machine (Cookelma, 2019).

Industries are now attempting to meet the 2030 sustainability targets. As a result, a strategic transformation from the present production paradigm to manufacturing sustainability is required (Jamwal et al., 2021). Manufacturers are now using Artificial Intelligence (AI) and machine learning to improve energy efficiency. AI algorithms may be used in real time to handle cognitive activities and make quick decisions (Giovannini et al., 2012).

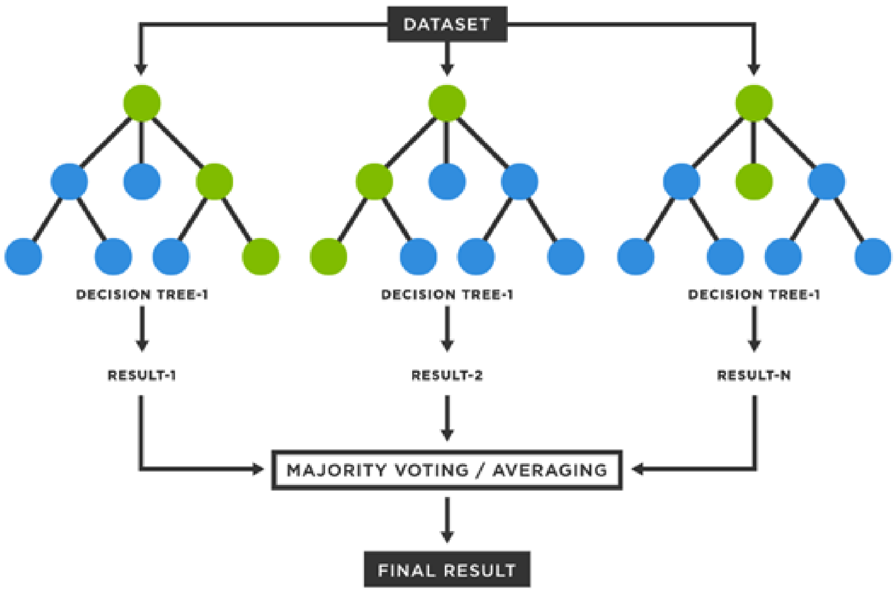


Figure 1.2 Example of Random Forest method (Ampadu, 2021).

Machine Learning is an important method for achieving Artificial Intelligence. The Random Forest Method is a characteristic algorithm in the field of Machine Learning, and it is noted for its simplicity and effectiveness. The key problem in this context is the creation of a vast volume of data. Data and analytics technologies can help organize and understand created data that may be relevant for future decision-making (Jamwal, 2020). However, it is anticipated that if we can apply Machine Learning's representative such as Random Forest method to achieve sustainable manufacturing in energy consumption reduction on abrasive water jet machine.

1.2 Problem Statement

In recent years, abrasive water jet cutting is one of today's most attractive contour cutting methods, was developed in response to the challenge of cutting materials that are difficult to machine in the aerospace, aviation, and automobile sectors. It is critical to examine the influence of process parameters on performance metrics such as cutting quality, productivity, and costs for the efficient use of abrasive water jet cutting. However, from the standpoint of energy consumption, it is critical to examine the influence of these factors on the specific cutting energy, which indicates the amount of energy used on material removal per unit time (Janković et al., 2018).

Abrasive Water Jet machines typically consume about 20 KW of electricity (Schlick, 2022). Energy consumption can be minimized by changing or modifying the parameters setup on AWJ machines such as material thickness, traverse speed, and water jet pressure. The Random Forest method will be used as medium to find the possible minimization the amount of energy that can used on AWJ machine cutting process based on the data collection. Random Forest is used in this study because it can deal with binary, categorical, and numerical data. There is very little pre-processing necessary. It is not necessary to rescale or transform the data. The Random Forest technique works effectively with high-dimensional data since it works with subsets of data. It is also faster to train than decision trees since it only operates on a subset of feature models, allowing it to accommodate hundreds of features (Kho, 2018).

1.3 Research Objective

The main aim of this research is made an analysis on energy consumption of abrasive water jet cutting process using Random Forest method. Specifically, the objectives are as follows:

i. To develop empirical model for prediction using Random Forest method

ii. To identify the parameters from empirical model that influence the energy consumption on AWJM

1.4 Scope of Research

The limitations set for this research will affluence the experiment and data collection:

- The material that will be used is Aluminium.
- The experiment and data collection will take place on abrasive water jet machine in Abrasive Water Jet Laboratory, Faculty of Mechanical and Manufacturing Engineering Technology (FTKMP) in UTeM.
- The parameters that have been congregated are water pressure, feed rate, cutting speed and material thickness.
- Random Forest method will be used to predict the parameters that influence energy consumption on abrasive water jet machine based on the data collection.

1.5 Scope of Study

The study is focusing on energy consumption of water jet process using Random Forest method. The analysis is to identify the factors that influenced the energy consumption on abrasive water jet (AWJ) cutting process by modifying the machine parameters that available in the laboratory. Using Random Forest method, the final prediction result will be derived by carrying out the voting process from data sample collection.

1.6 Structure of Thesis

The format of this thesis is provided by Universiti Teknikal Malaysia Melaka (UTeM), which is based on the publication of this study. The following components comprise this study: introduction, literature review, methodology, result and discussion, and conclusion. The specifications of the structure are as follows:

Chapter 1

This chapter describes the study's purpose in detail and highlights the difficulty that prompted this investigation. This chapter elaborated on the significance and scope of study and work.

Chapter 2

This chapter justifies the total literature review conducted by previous research linked to the topic of this thesis. In addition, the research gap identified through a review of past studies is discussed in this chapter.

Chapter 3

This chapter described the technique utilized in this study for material preparation, testing procedures, and data gathering.

Chapter 4

In this chapter, the hypotheses of all tests, including experimental testing, and physical testing, will be thoroughly explored.

Chapter 5

This chapter presents the overall conclusion of the study by recommendation and improvement for further study according to An Analysis on Energy Consumption of Water Jet Process using Random Forest.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy efficiency has become a crucial engine for sustainable manufacturing growth in many nations throughout the world in today's contemporary manufacturing industry. The increased focus on mitigating climate change through greenhouse gas emissions reductions and accompanying legal obligations is poised to affect corporate practices and economies in the next years. Strategic energy management practices and energy-efficient company operations will be critical to accomplishing these objectives. Any industrial system designed for both energy efficiency and economic effectiveness may not use the exact minimum amount of energy theoretically achievable. The emphasis is on developing a cost-benefit balance that uses energy resources as effectively as possible.

2.2 Abrasive Water Jet Machine (AWJM)

Over the last few decades, there has been an increase in the industrial usage of modern materials with better qualities. The increased need for these materials' complicated and exact geometries has resulted in the creation of variety innovative machining methods known as non-conventional machining procedures (NCMP) (Debroy & Chakraborty, 2013). The emergence of innovative, predominantly fibrous, and multilayer composites in aviation and aerospace sectors demanded the development of NCMP capable of processing these materials that are sensitive to heat and pressure. The solution was discovered by adapting water jet technology, which has been used in mining for decades. Abrasives, high-speed water jets, and technological advances culminated in the creation of a tool capable of cutting almost any material. The first machine for abrasive water jet (AWJ) cutting of automotive glass was sold in 1983. New cutting technology was originally used in automotive and aerospace sector to treat materials including stainless steel, titanium, and carbon fiber reinforced composites. This method was then used to other sectors such as metal processing, construction, and shipbuilding.

When it comes to creating components with complicated 2-D shapes, AWJ processing outperforms similar processing methods. This benefit is much more obvious when processing thin sheets and foil, and materials may be cut using this approach, regardless of whether they are brittle or tough (Deaconescu & Deaconescu, 2021). The fact that there is no significant increase in temperature in the processing zone and that the cutting forces are relatively tiny is a key benefit of this technique.

The AWJ technology has undergone rapid development in recent years as a result of its remarkable advantages and its capacity to expand into new fields of application. It is capable of cutting any kind of material, cutting complex profiles, preventing thermal and mechanical damage on the material, reducing the formation of burrs, and eliminating delamination phenomena. Cutting, surface polishing, surface cleaning, and other similar operations make up the majority of the AWJ processing procedures. Erosion is always used as the processing mechanism, and AWJ machines are always used as the cutting tools in whatever circumstance. The method of grinding is the one that is most analogous to the cutting procedure. Instead of using a wheel made of solid material, water is used to move the abrasive particles through the material (Janković et al., 2018).

Water jet cutting has both benefits and drawbacks. A wide variety of machinable materials, cheap machining costs, great flexibility, simple programming, high processing productivity, and material property retention owing to the low machining temperature are all advantages that has at AWJ machine. Specific challenges arise as a result of the rather low dimensional accuracy and some machining surface defects (striations, mini-craters, and high roughness). (Deaconescu & Deaconescu, 2021)

2.2.1 Main parts for AWJM

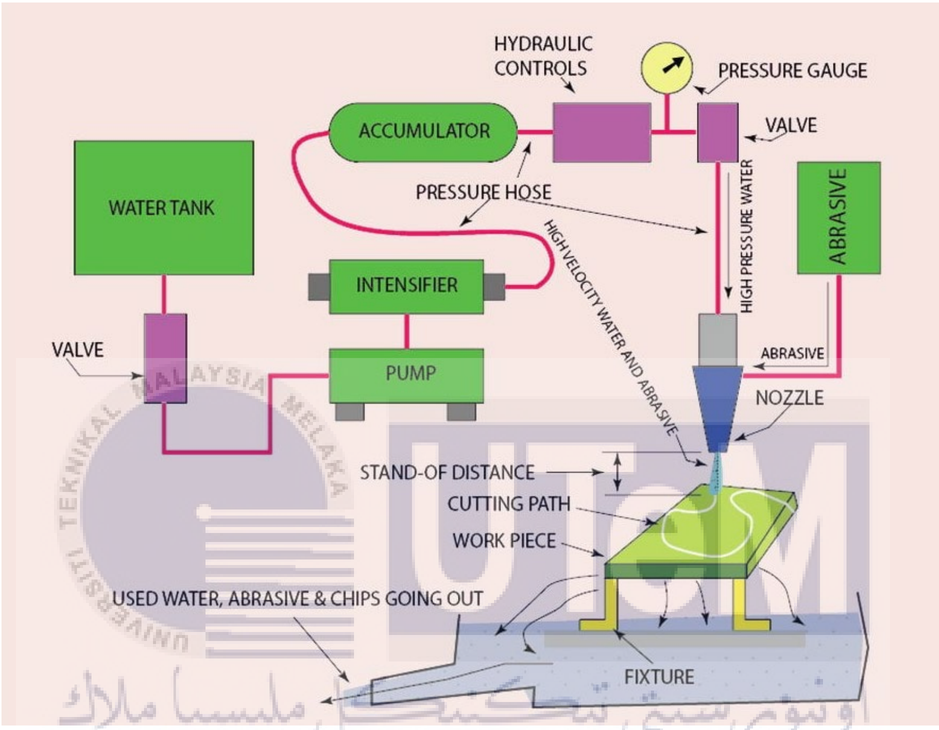


Figure 2.1 AWJM main parts (Mishra, 2017).

i. Hydraulic Pump

Water from the tank is circulated during the machining process. This low pressure is used to feed the intensifier's water supply. Boosters are also used to elevate the water's initial pressure to 11 bar before it is fed to the intensifier.

ii. Hydraulic Intensifier

To get very high-water pressure, a cylinder is inserted into a tank. Pump pressure of 4 bars is increased mostly to 3000 to 4000 bar with this device.

iii. Accumulator

It can hold high-pressure water for a short period of time. As a result, it produces a large amount of pressure energy as needed. As a result, the machining process is more consistent and predictable.

iv. **Mixing Chamber or Tube**

It is a place where abrasive particles are mixed with water.

v. **Control Valve**

It is a device to regulate the water jet's pressure and direction.

vi. **Flow Regulator or Valve**

It controls the rate at which water flows.

vii. **Nozzle**

It is a device used in water jet machining to transform the pressure energy of water into kinetic energy. The nozzle in this case turns the pressure of the water jet into a high-velocity beam of water jet. To avoid erosion, the nozzle tip is constructed with ruby or diamond.

viii. **Drain and Catcher System**

Following machining, the drain and catcher system separates the trash and machined particles from the water. It filters out the metal particles and other undesired particles from the water and returns it to the reservoir for reuse.

2.3 Abrasive Water Jet Machine (AWJM) Process

Transverse speed, standoff spacing abrasive flow rate, water pressure, abrasive grit size, and other machining factors influence the exhibition parameters in the AWJM operation such as decrease edge, kerf top width, surface quality and material evacuation rate. To achieve the desired quality, the perfect parameter setting for the machining process must be obtained. Few experts have studied the influence of procedure parameters on the AWJM presentation quality. Using the pressure of a liquid stream, abrasive jet machining removes material from the outside of the action.

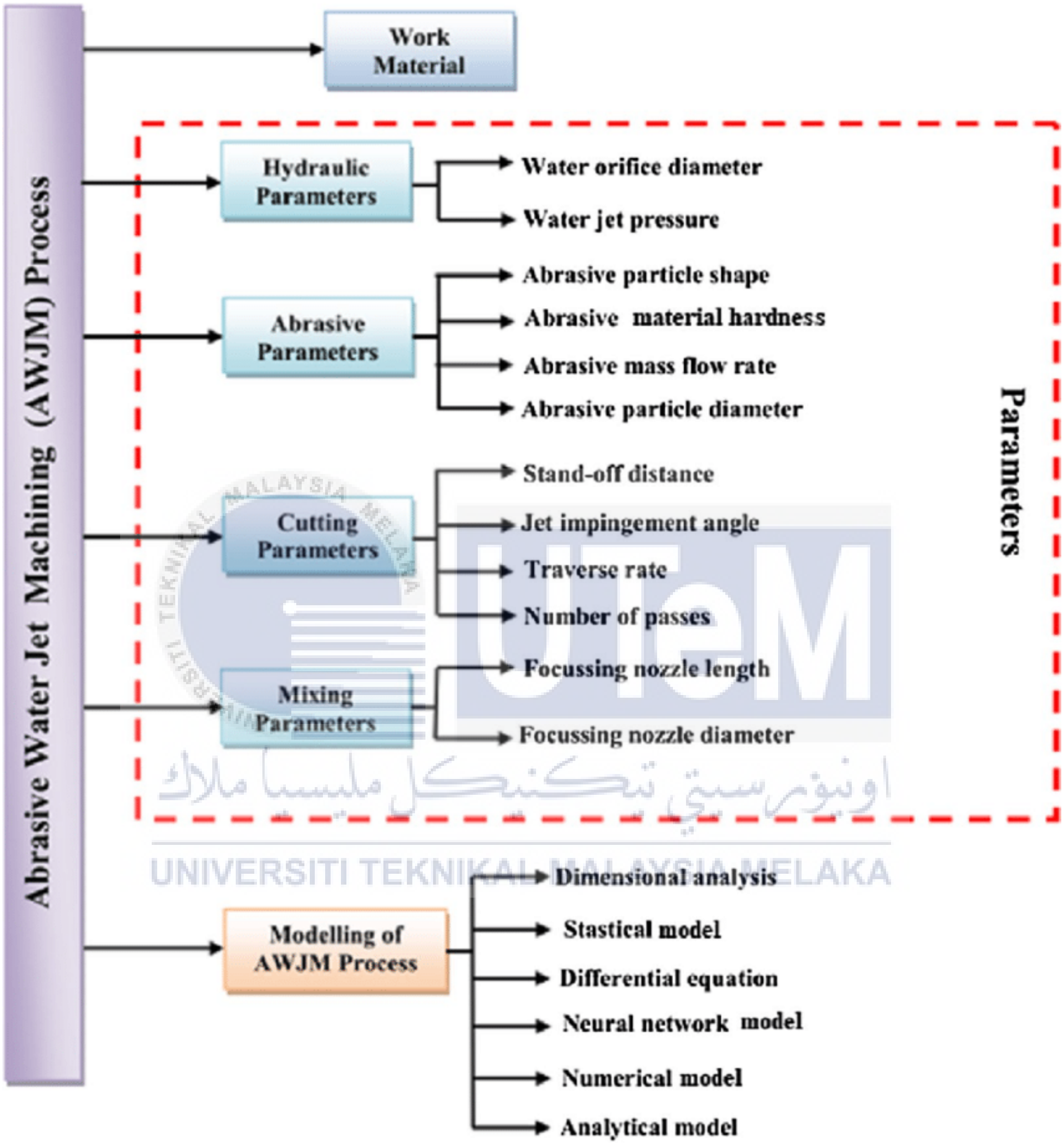


Figure 2.2 AWJM Parameters (Anu Kuttan et al., 2021)

For a broad variety of materials, including both soft and hard ones, AWJM employs high-pressure water to generate a high-velocity stream entrained with abrasive particles. With its tiny heat affected zone, great mobility, and low force exertion, it is a flexible technique that may be utilized in several industrial applications, including cutting and surface treatment. It also offers various benefits (Azmir & Noor, 2007). Manufacturers that want to be on the leading edge of technology will appreciate the revised AWJM technology. Only a few industrial companies use AWJM for material evacuation in hard-to-hard materials.

The pressure of a liquid stream is used to remove material from the action of abrasive jet machining. Abrasives and air are impinged on the work surface at speeds between 200 and 400 m/s generally when employing an air-based media, and the high-speed rough particles damage the work material. Standoff distance is roughly 0.7–1.0 millimeters, and the nozzle diameter is around 0.04 millimeters (Kale et al., 2019).

2.4 Factors influencing the AWJ machining process

AWJ process performance characteristics such as depth of penetration, rate of material removal, taper angle, kerf taper ratio, and surface roughness, as well as surface integrity characteristics (surface topography and surface metallurgy), are discussed in the following section considering research findings. Figure 2.3 shows the parameters that influence the AWJ machining process (Natarajan et al., 2020).

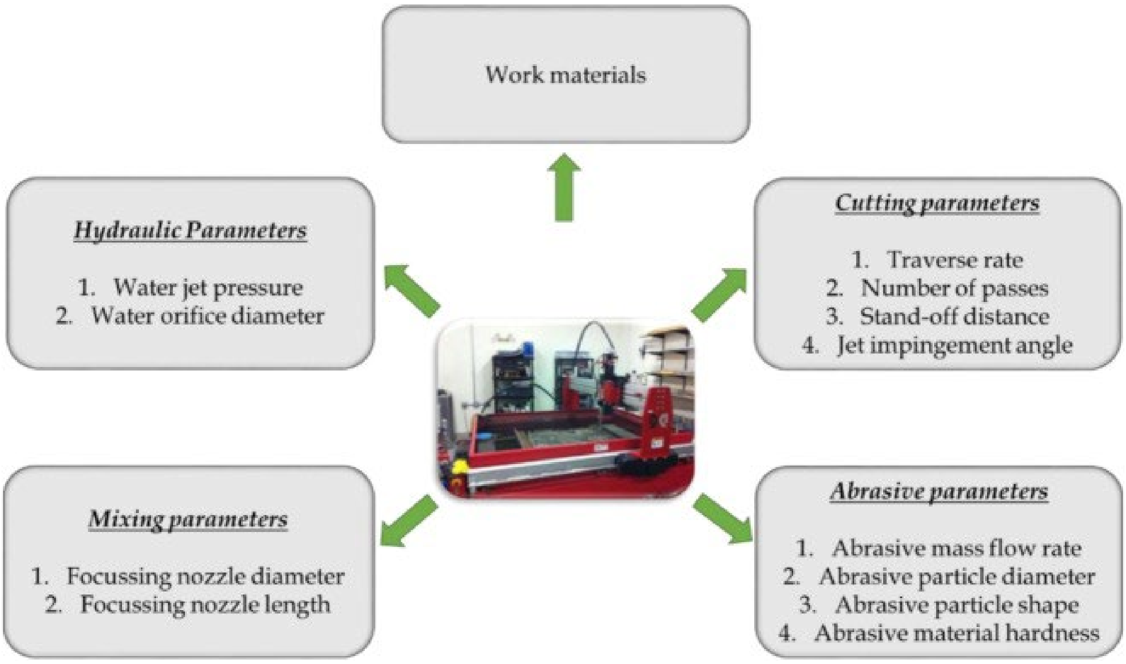


Figure 2.3 Factors which are influence in the AWJ machining process (Natarajan et al., 2020).

2.5 Importance of AWJ machining parameters

The section that follows focuses at the four main factors that impact the AWJM process, such as mixing parameters, hydraulic parameters, mixing parameters, and abrasive parameters (Mahdi Abdulkareem & Mohsin Abdulazeez, 2021).

2.5.1 Water Jet Pressure

In the AWJ machining relies heavily on water jet pressure for successful completion of the task at hand. The AWJ's kinetic energy is affected by water pressure. When no material is removed, the pressure is lower than the threshold pressure range. The critical pressure range, on the other hand, determines the maximum cutting pressure. After this stage, the machining process is rendered useless. The pace at which material is removed and the depth to which it penetrates are both influenced by the water jet pressure. How the water and the abrasive particles are spread is affected by this adjustment. MPa, bar, or PSI are the most frequent units of measurement (Llanto et al., 2021).

2.5.2 Traverse rate

Quality of cut surface is influenced by the AWJ procedure. During the AWJ machining process, the exposure time has the biggest influence on the traverse rate. By enabling more abrasive particles to hit the surface of the target material, slowing down the traverse rate improves surface quality. It also influences the cutting pace of the procedure. mm3/ min represents the traversal rate.

2.5.3 Abrasives

The AWJ machining process employs both natural garnet and synthetic abrasives such as oxide, silicon carbide and aluminum. Figure 2.4 shows an example of a garnet abrasive used in the AWJ machining process. Abrasive particle size, shape, and hardness all have a significant impact on AWJ cutting performance. The tougher the work material, the harsher the abrasives should be used. As the abrasive particle size increases, so does the rate of particle disintegration. Reduced impingement frequency on the target material surface causes a reduction in penetration depth and removal rate as the abrasive particle size limit rises. Mesh size (#) uniformly indicates the abrasive size range (Ramaswamy Pillai et al., 2019).

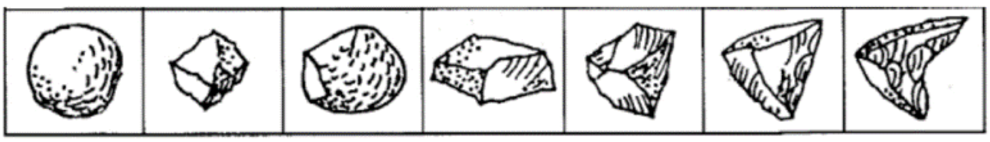


Figure 2.4 Garnet abrasive forms (Natarajan et al., 2020).

2.5.4 Abrasives mass flow rate

The material removal rate is influenced by the abrasive flow rate as well as the pressure of water jet. A good supply of abrasives leads to better cutting performance and surface quality. The abrasive flow rate is determined by the diameter of the focusing nozzle used in the AWJ machining process. Jet momentum must be converted into abrasive mass flow rate acceleration in order to offer efficient acceleration. The rate of abrasive mass flow is typically given in kg/min.

2.5.5 Stand-off distance (SOD)

The distance between the target material and nozzle is determined. Given the considerable effect of stand-off distance (SOD) on the kerf profile produced by the AWJ, it is normally an appropriate amount of distance of nozzle and material is in mm. Figure 2.5 depicts the variance in kerf profile.

Figure 2.5 The kerf profile is affected by nozzle distance (Natarajan et al., 2020).

2.5.6 Jet impingement angle

The inclination of the cutting head is tied to this angle in some way. Calculations are made to determine the angle that is created when the initial flow direction of the AWJ meets the surface of the target material. Any change in the angle at which the jet impinges on the material also changes the angle at which the jet attacks the material, which in turn affects the erosion process. The use of the switching jet impingement angle has a considerable influence on the AWJ cutting performance and doing so does not incur any extra expenditures. The process of machining utilizes both forward and backward jet impingement angles, as may be shown in Figure 2.6. The ability to machine highly delicate and sensitive materials is one of the benefits, along with a decreased creation of kerf taper, less striation development, a smaller contaminated zone, and less contamination overall.

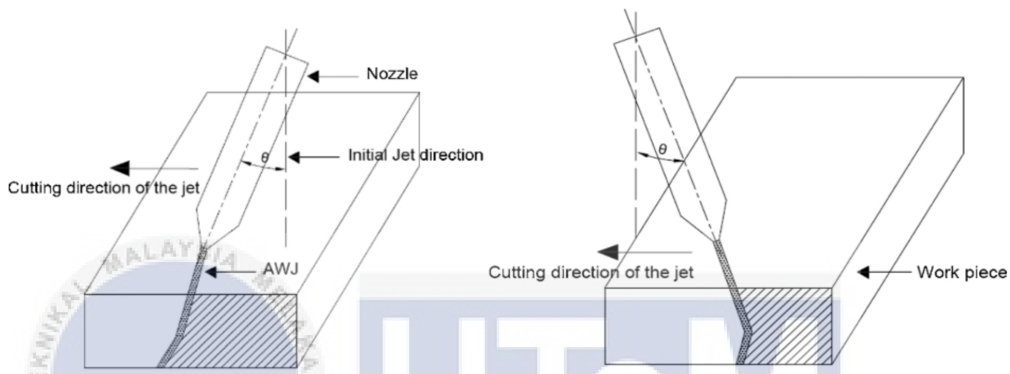


Figure 2.6 Jet impingement angle in forward direction and backward direction (Natarajan et al., 2020).

2.5.7 Work material

In the AWJ machining process, the work material required may be of any size or shape. The AWJ method utilizes hard materials such as titanium alloy, tungsten carbide, stainless steels, composites, and ceramics. Two of the most typical post-machining events are abrasive contamination and striation development. The abrasive contamination of soft materials is greater than that of hard materials due to the hardness of the work materials. When it comes to striation generation, striations are more common on the hard material cut surface than on the soft material cut surface. The abrasive attack angle rises with increasing cutting depth as the kinetic energy of the abrasive particles diminishes. Machining at a lower cutting depth reduces the amount of cutting energy required.

2.6 Materials for water jet machining

2.6.1 Metal

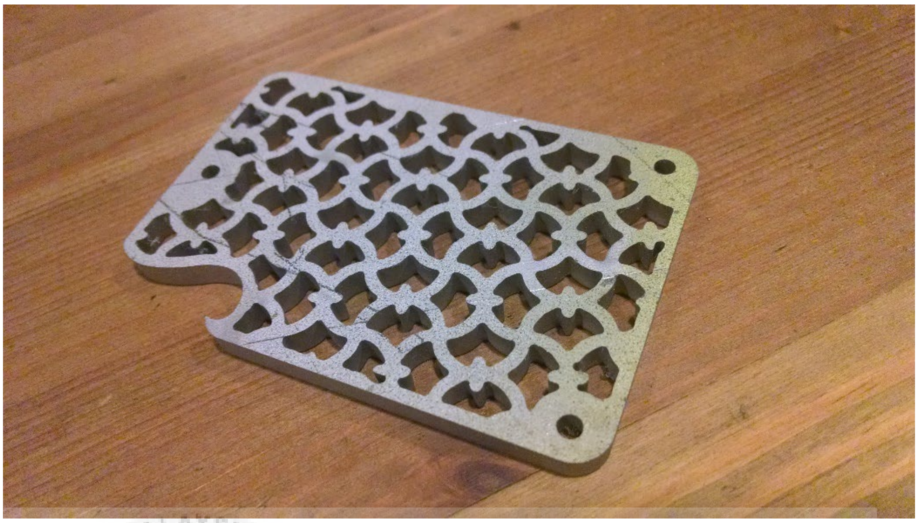


Figure 2.7 Metal plate (tinkertinker, 2016).

Any kind of metal, including hardened tool steel, aluminium, titanium, and a range of unusual metals that are difficult to cut with traditional equipment or methods, may be cut by machines that use water jet technology. Cutting using a water jet result in a perfect edge that is free of burn scars, cracking, and unnecessary burrs. In addition, seeing as how cutting with a water jet is a cold procedure, there are no heat-affected zones present.

2.6.2 Naturals

Figure 2.8 Glass cutting using AWJ (Goldberg, 2018).

With water jets, practically everything is possible, from glass to stone to wood. Techniques like water-only cutting and vacuum assist may be used to correctly mill a broad variety of natural materials.

2.6.3 Composites

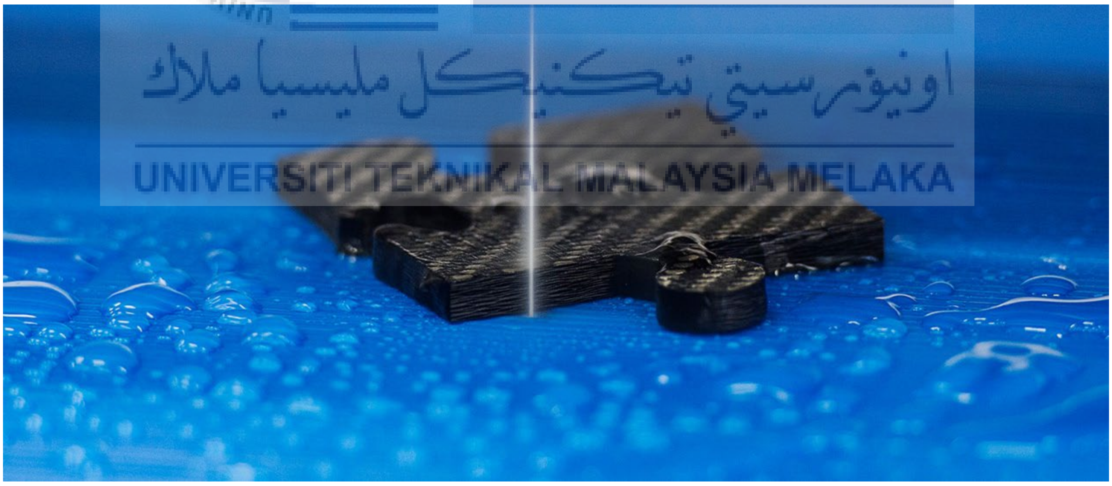


Figure 2.9 Carbon fiber cutting (Wallstrom, 2015).

When cutting carbon fiber, an abrasive water jet offers significant advantages. There is no need to replace the tooling. There are no specific concerns or limitations owing to heat accumulation. There is no melting. There are no harmful gases that necessitate the purchase of expensive air handling equipment. Any fiber-reinforced material, including Kevlar reinforced personnel armor, may be cut swiftly and cleanly without the limitations of traditional machining.

2.6.4 Plastics and Rubber

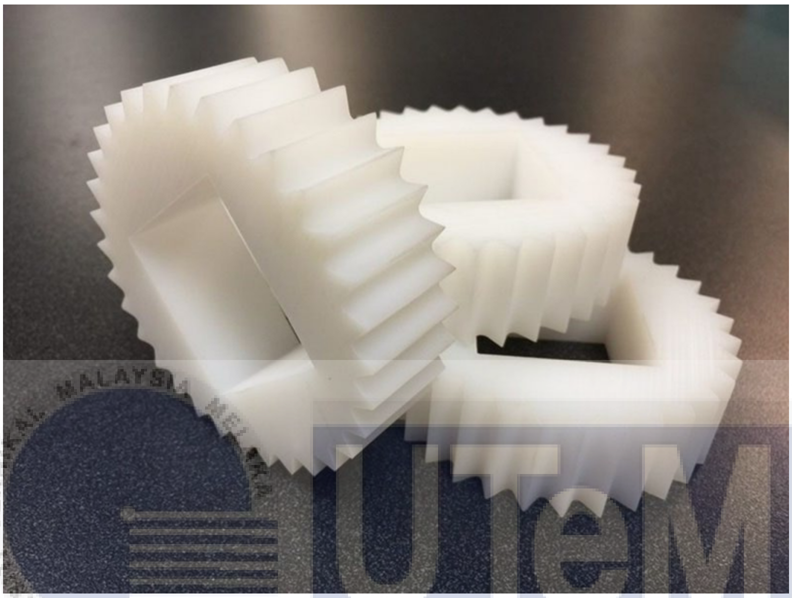


Figure 2.10 Plastic product using AWJ cutting (Devine, 2014).

When using the cold cutting technique of a water jet, the material distortions that are normally seen when milling plastic on standard computer numerical control (CNC) machines are no longer an issue. The fact that water jets can readily machine foam, rubber, and acrylic in addition to all of the materials that have been discussed before offers them an advantage as a multi-use tool that adds value. Because of its wide range of applications, a water jet is an essential tool in every kind of machine shop.

Abrasive waterjets are capable of penetrating a depth of 12 inches through the majority of materials. There have been several reports of people successfully cutting material considerably thicker than that. The majority of abrasive waterjet cutting, on the other hand, is done in materials with a thickness of little more than three inches. When cutting material that is thicker than that, the tolerance that can be maintained is often reduced, and the amount of time it takes to cut a component rises(Janković et al., 2018).

2.7 Artificial Intelligence

Artificial intelligence is the emulation of human intelligence processes by technology, particularly computer systems (Burns, 2018). Applications of artificial intelligence include things like expert systems, processing of natural languages, voice recognition, and machine vision. As interest in artificial intelligence (AI) has increased, businesses have been rushing to demonstrate how their goods and services use technology. What people often refer to as artificial intelligence (AI) is only one aspect of AI, such as machine learning. Artificial intelligence is dependent on the foundation of specialized hardware and software in order to create and train machine learning algorithms. Python, R, and Java are just a few of the programming languages that stand out, despite the fact that there is not one programming language that is associated with artificial intelligence. In general, the operation of AI systems entails the consumption of vast quantities of labelled training data, the examination of such data in search of correlations and patterns, and the application of these patterns to the prediction of future states (Liu et al., 2012). A chat bot that is given samples of text conversations may learn to create realistic interactions with humans by analyzing millions of instances, while an image recognition coder can learn to identify and describe things in images by reviewing millions of examples.

For a broad variety of businesses and organizations, such as gambling, banking, retail, commercial, and government, to mention a few of the more prominent ones. The use of artificial intelligence (AI) is quite widespread and is rapidly becoming more common in the manufacturing business; this helps with the automation of industrial processes. Robots that are powered by artificial intelligence are helping to pave the way for the future by delivering a plethora of advantages. These benefits include new opportunities, higher production efficiency, and a better match between human and machine interaction. The Fourth Industrial Revolution is defined by the automation of knowledge-based employment; by inventing new methods to automate occupations, we may be able to rebuild the way people and machines live, interact with one another, and cooperate, which will result in a better, stronger digital economy (Cao et al., 2020). AI makes it easier to overcome many of the internal hurdles that have persisted in the sector for a long time, including a lack of available knowledge, the complexity of decision making, problems linked to integration, and an abundance of information. The use of AI systems in production facilities allows enterprises to effect a fundamental change in their operations.

2.7.1 The AI Affects in the Manufacturing Industry

The industrial sector has never been resistant to the introduction of cutting-edge equipment. Since the 1960s, the manufacturing sector has been using industrial robots and drones to do various tasks (Sihag & Sangwan, 2020). The next breakthrough in automated processes is just around the corner. It is projected that the Manufacturing Industry would see an empowering development if businesses were able to maintain inventories tight and cut expenditures by implementing AI. After that, the manufacturing industry needs to start getting ready for well-organized manufacturing facilities. These facilities will have a supply chain, design team, production line, and quality control that are all well-coordinated into an intelligent engine that generates significant knowledge insights (G, 2019).

2.7.2 AI Methods and Techniques

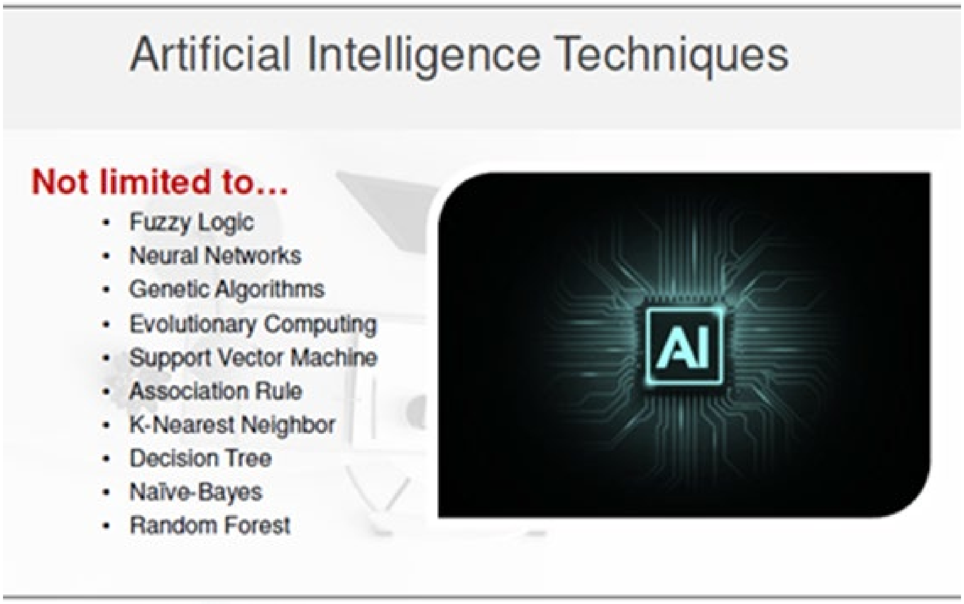


Figure 2.11 Ai Methods

The technological advancement known as artificial intelligence (AI) is altering every facet of being alive today. It is a flexible tool that enables users to reconsider how they integrate information, assess data, and apply the insights that result from doing so in order to arrive at better conclusions.

2.8 Random Forest Method

Random Forest is a well-known machine learning algorithm that uses the supervised learning method. In machine learning, it can be utilized for both classification and regression applications (Mbaabu, 2020). It is based on ensemble learning, which is a method of mixing multiple different classifiers to solve a difficult problem and increase the performance of a model. A Random Forest is a kind of classifier that improves the accuracy of a dataset's predicted results by taking the average of several decision trees applied to various subsets of the dataset in question. The random forest method does not rely on a single decision tree but rather compiles the predictions from all the trees into a single set and bases its estimate of the outcome on the projections that get the greatest number of votes. If there are a greater number of trees in the forest, then the accuracy will be better, and there will be less of a chance that the model will be overfit.

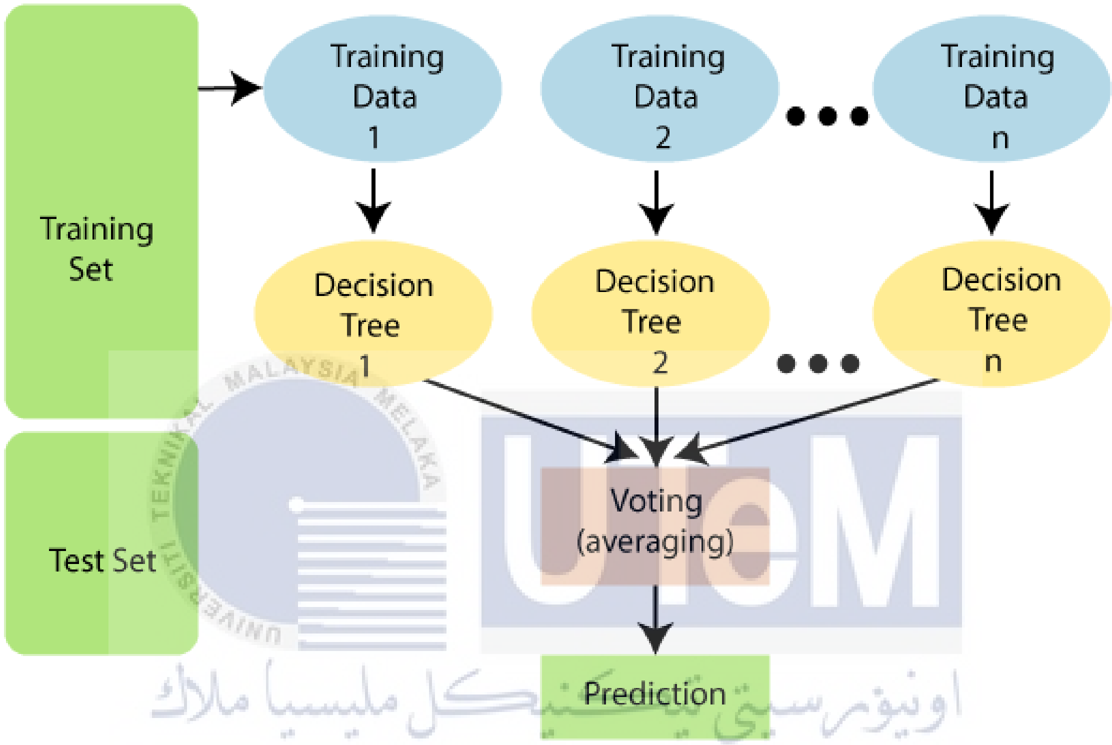


Figure 2.12 Working of the Random Forest algorithm

Because the random forest combines numerous trees to forecast the dataset's class, some decision trees may correctly predict the output while others may not. However, when all the trees are combined, the proper result is predicted. As a result, two assumptions for a better Random Forest classifier are as follows:

i. The predictions from each tree must have very low correlations.
ii. There should be some actual values in the feature variable of the dataset so that the classifier can predict accurate results rather than a guessed result.

2.8.1 Difference between Decision Tree and Random Forest

Random forest is a collection of decision trees; still, there are a lot of differences in their behavior.

Decision tress	Random Forest
Decision trees normally suffer from the problem of overfitting if it is allowed to grow without any control.	Random forest are created from subsets of data and the final output is based on average or majority ranking and hence the problem of overfitting is taken care of.
When a data set with features is taken as input by a decision tree it will formulate some set of rules to do prediction.	Random forest randomly selects observations, builds a decision tree and the average result is taken. It does not use any set of formulas.
A single decision tree is faster in computation.	It is comparatively slower.

Figure 2.13 Difference berween Decision Tree and Random Forest (Talari, 2022).

Thus, Random Forests are much more successful than decision trees only if the trees are diverse and acceptable.

2.8.2 Data Analytics in Machine Learning and Artificial Intelligent

To cope with huge volumes of data and to make predictions and suggestions based on data sets, two promising technologies are emerging: machine learning and artificial intelligence (AI). They are often used interchangeably, despite their shared characteristics.

ML is sometimes referred to as a subfield of artificial intelligence (AI) since it is predicated on the idea that people can teach computers to learn by supplying them with a large quantity of information. According to AI, technology is capable of doing tasks intelligently, a widely held and growing view (Mahdi Abdulkareem & Mohsin Abdulazeez, 2021). When it comes to the next generation of communication systems, applied AI, rather than generalized AI (which, in principle, can perform any job), is more suited. While ML models are unable to adapt to changes in their environment, AI models can do so. Artificial intelligence (AI) extends beyond forecasts to prescribe real strategies and ideas, while machine learning is vital for predictive analytics (PA) (Kibria et al., 2018).

In 2021, (Adams, n.d.) stated that each has its own set of applications, subsets, and specializations, making them highly distinct areas. However, there are certain locations where they do overlap. Below, are just some of the ways in which machine learning, data analytics, and AI is overlap:

i. Data-driven.

Each of these fields relies on the analysis of massive volumes of data. They are more successful at providing outcomes when there is more information available. Managing such massive data sets frequently necessitates a significant amount of computer processing power.

ii. Insights.

Data analytics, artificial intelligence, and machine learning may all be applied to generate deep insights in certain domains. Each may uncover patterns, highlight trends, and give important and actionable results by analyzing data.

iii. Predictive models.

Based on current data, these technologies can also assist in the creation of forecasts and predictions. Again, this method may assist organizations of all sizes in planning for the future and making sensible decisions.

2.9 Energy Improvement and Measurement

Abrasive water jet cutting is gaining popularity across the world as a modern and revolutionary cutting process. The machining parameters are one of the primary elements influencing the power consumption on an AWJ machine during the cutting or machining operation. By modifying the parameters, the power consumption can be minimized but still not affected the quality of machining quality. The power consumption of AWJ machine is measured by taking the reading of voltage using clamp meter for each parameter that has been setup. This study will be investigating the impacts of machining parameters such water pressure, pierce time, cutting speed and thickness of material in order to reduce energy consumption by using Random Forest Method (Triebe et al., 2018).

In industrial application currently are in use water jet cutting machines with high and ultra-high-pressure pumps of 150 to 400 MPa and hyper pressure pumps of 600 to 650 MPa. Ultra-high-pressure pumps of 350 to 400 MPa are standard. However, their operation is essentially the same: water flows from an ultra-high or hyper pressure pump, through tubing, out of a cutting head as pure water jet or abrasive water jet and cut material. Basic components of typical abrasive water jet cutting machine are water pump, tubing system, cutting head, abrasive hopper with abrasive metering, X-Y motion table and controller. Each of these components is vital for the water jet cutting machine to function properly. Comparison of abrasive water jet cutting for various water pressure with motor power of 37 kW (50 HP) is shown in Figure 2.14.

Pump	SL-V 50 Classic (KMT)	SL-V 50 Plus (KMT)	XP90-50 (Jet Edge)	HyperJet S (Flow)
Motor power	37 kW (50 HP)	37 kW (50 HP)	37 kW (50 HP)	37 kW (50 HP)
Operating pressure	380 MPa (55000 psi)	413.7 MPa (60000 psi)	520 MPa (75000 psi)	600 MPa (87000 psi)
Water flow rate	3.8 L/min (1.00 gpm)	3.5 L/min (0.92 gpm)	2.6 L/min (0.7 gpm)	2.44 L/min (0.64 gpm)
Hydraulic power	24.06 kW	24.13 kW	22.53 kW	24.4 kW
Water jet velocity	854 m/s	891 m/s	999 m/s	1073 m/s
Orifice diameter	0.356 mm (0.014 in)	0.330 mm (0.013 in)	0.279 mm (0.011 in)	0.254 mm (0.010 in)
Water jet flow rate	3.63 L/min	3.27 L/min	2.58 L/min	2.28 L/min
Nozzle diameter	1.067 mm (0.042 in)	0.991 mm (0.039 in)	0.838 mm (0.033 in)	0.762 mm (0.030 in)
Orifice/nozzle size	14/42	13/39	11/33	10/30
Abrasive size	Mesh 60 - 80	Mesh 60 - 80	Mesh 80 - 120	Mesh 80 - 120
Abrasive mass flow rate	0.530 kg/min	0.470 kg/min	0.370 kg/min	0.330 kg/min
Abrasive water jet velocity	522 m/s	544 m/s	610 m/s	656 m/s
Abrasive jet power	1.20 kW	1.16 kW	1.15 kW	1.18 kW
Power density	1.11 kW/mm^2	1.24 kW/mm^2	1.72 kW/mm^2	2.14 kW/mm^2
Traverse speed	650 mm/min	680 mm/min	810 mm/min	930 mm/min
Machining time	1.54 min	1.47 min	1.23 min	1.08 min
Abrasive consumption	0.816 kg	0.691 kg	0.455 kg	0.356 kg
Machining cost	1.28 EUR	1.22 EUR	1.02 EUR	0.90 EUR

Figure 2.14 Comparison of abrasive water jet cutting with motor power of 37KW (50HP) (R. Radovanović, 2017)

2.10 Electric Current Measurement

For the present study, the type of electricity that will be measured at AWJ machine is electric current. Electric current is the movement of electrons through a wire. Electric current is measured in amperes (amps) and refers to the number of charges that move through the wire per second (Vancouver, 2018). A current clamp meter is an electrical device with jaws which open to allow clamping around an electrical conductor. This allows measurement of the current in a conductor of AWJ machine without the need to make physical contact with it, or to disconnect it for insertion through the probe.

2.11 Measuring Device

A clamp meter is a clothespin-shaped device that measures the current carried by a live wire by clamping it around it. The standard multimeter must be connected in series with the circuit being measured, which requires that it be terminated first. Clamp meters, on the other hand, can detect the magnetic field created by the current and so measure the current flowing through the wire around which they have been clamped.

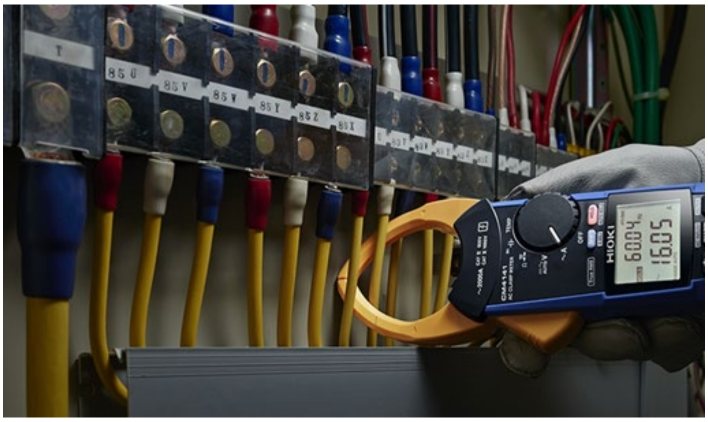


Figure 2.15 Measuring using clamp meter. (Rivers, 2022)

In short, a clamp meter may measure the current flowing to a machine or electrical equipment while it is still operating. Clamp meters come in a variety of configurations; however, they may be classed based on what they measure as follows:

i. DC current measurement
ii. AC current measurement
iii. Leakage current measurement
iv. Starting current measurement
v. Voltage measurement
vi. Continuity checks, resistance measurement, and diode measurement
vii. Capacitance measurement, temperature measurement

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, methods involved in the experiment are discussed including the preparation method and how the research was conducted. Chapter three contains Project Planning and Process Flow. The project should adhere to the criteria to ensure that the work put into this project does not deviate from the goals that have been established. The focus in this chapter is on project planning and testing. In this chapter, we also learned about the research methods used in the study.

3.2 Process Flow Chart

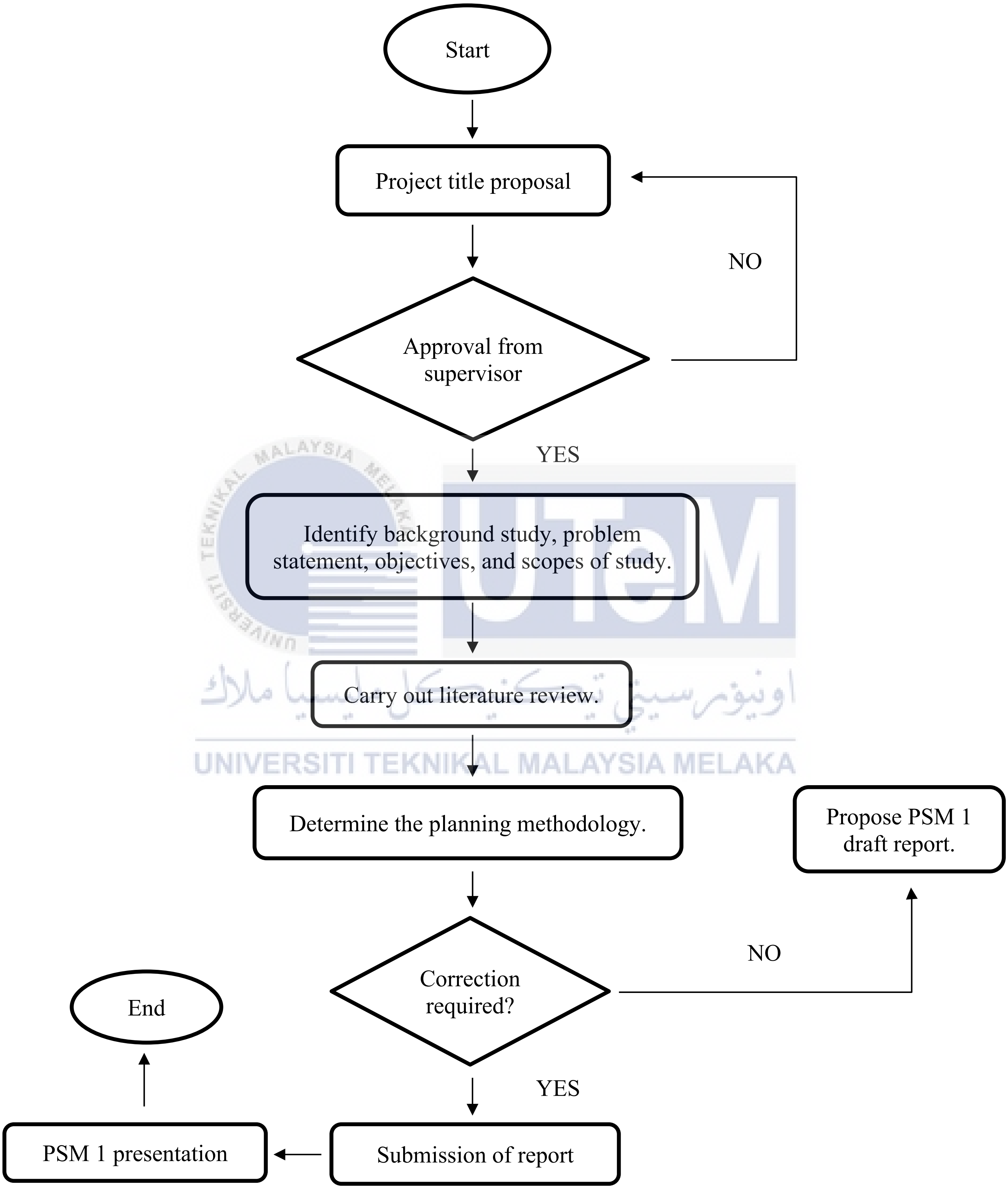


Figure 3.1 PSM 1 process flow

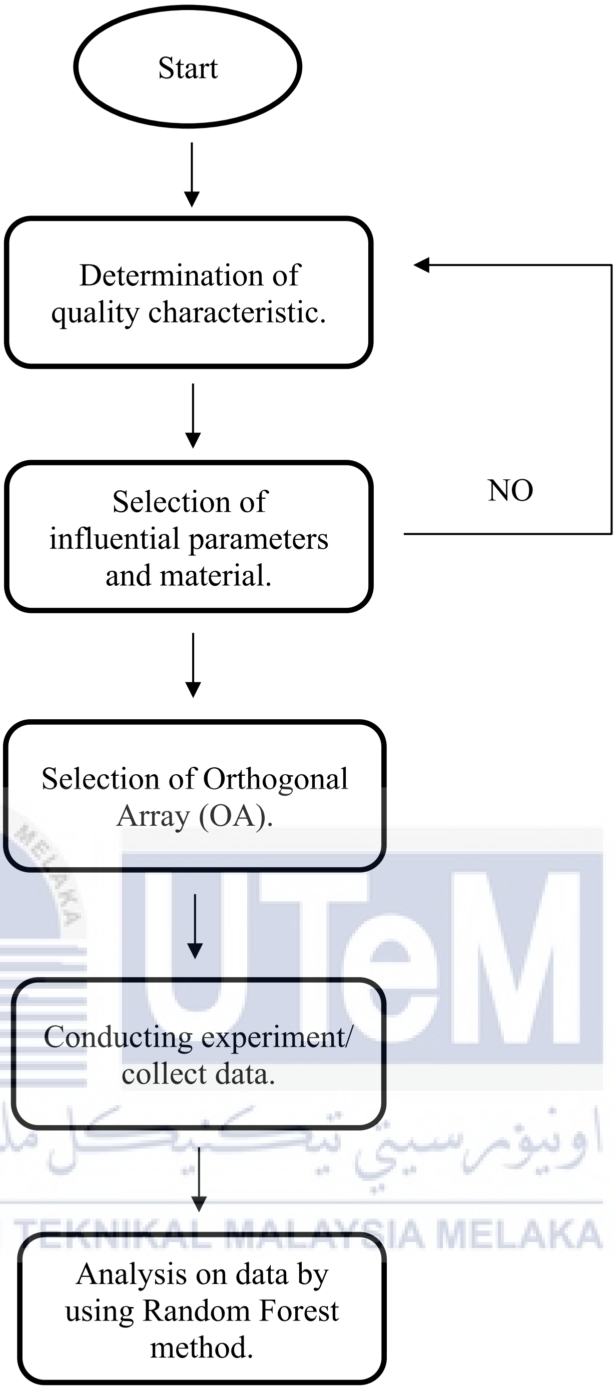


Figure 3.2 PSM 2 process flow

3.3 Determination of quality characteristic of AWJ machine

For material processing, AWJM is a non-traditional technology that has several benefits, including the absence of heat-impacted zones and minimum tool wear, low response force and a wide variety of applications. Abrasive water jets are employed in this process. High-pressure pump, abrasive flow control system and cutting head, computer-based controller, and water-filled tank are the four major components of the water jet system in general. The cutting head generates the cutting abrasive water jet, and the cutting head is controlled by a computer-based controller that monitors the cutting head's activity.

An AWJM nozzle system includes a water nozzle, a mixing/vacuum chamber, and a focusing tube or inserts. To remove the abrasive particles, a water jet stream is used in the vacuum chamber, where they are transported to and given to the cutting head. With the help of high-pressure water and abrasive particles, the abrasive water jet is formed. The abrasive water jet nozzle system and its settings are shown in Figure 3.0 (Llanto et al., 2021).

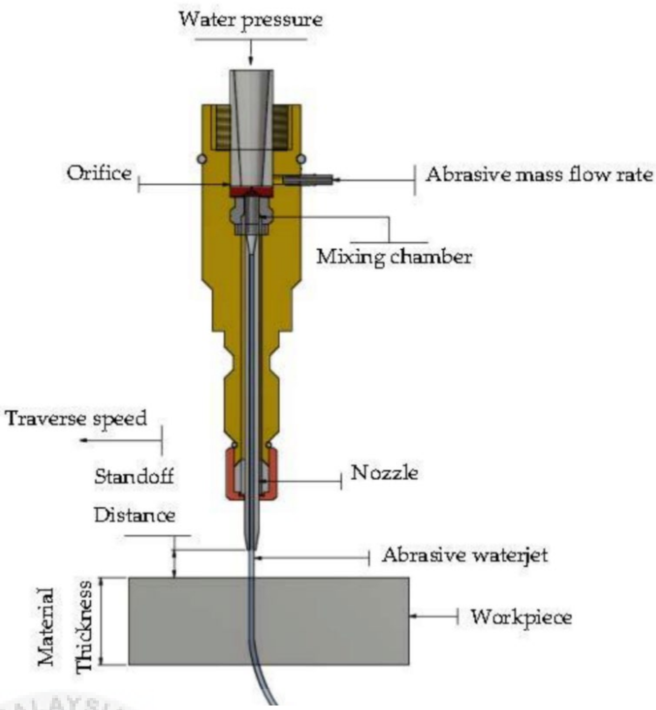


Figure 3.3 Schematic representation of AWJM cutting (Llanto et al., 2021).

As a result, an optimization approach is required because AWJM faces uncertainty in selecting the best parameter combination to optimize energy and productivity in terms of surface roughness and material removal rate. AWJM incorporates several independent input factors that have a direct impact on machine efficiency and quality. AWJM input parameters are divided into four categories: hydraulic parameters, cutting parameters, abrasive parameters, and mixing and acceleration parameters. Since the introduction of abrasive water jet applications in the 1980s, researchers have been investigating material reactions and behaviors like as surface roughness, material removal rate, and kerf taper angle to AWJM.

3.4 Selection of influential factor and material

The material used for this research is Aluminum plate. In this section the description on type and size of materials will be explained thoroughly.

3.4.1 Influential parameters

The parameters chosen for this study are water jet pressure, feed rate, cutting speed and thickness of material. The parameters of AWJ machine and levels were selected primarily based on the condition of the AWJ machine and available parameters that has on AWJ machine in Abrasive Water Jet Laboratory, UTeM. All these parameters can be modified in FLOWCUT software that is being used on AWJ machine as shown at Figure 3.1.

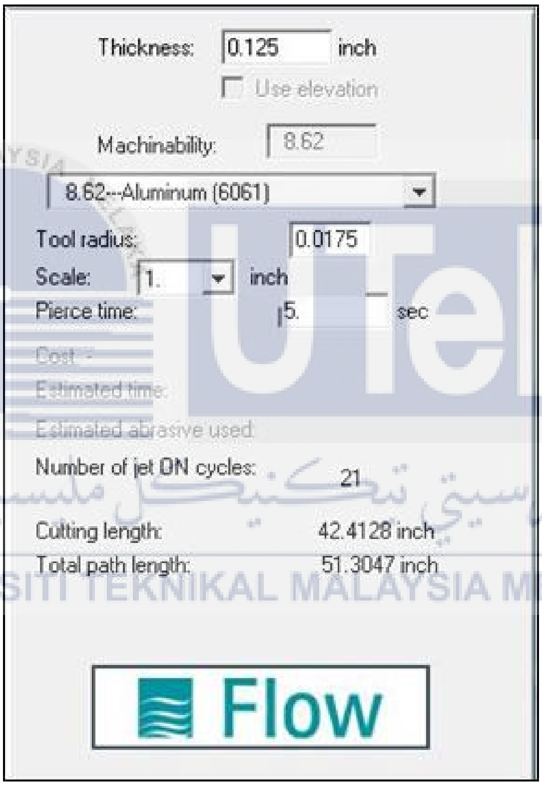


Figure 3.4 FlowCut sofware parameters setting

3.4.2 Material

In present study, Aluminium (Al) is used as material. Aluminium has a density lower than those of other common metals, at approximately one third that of steel. It has a great affinity towards oxygen and forms a protective layer of oxide on the surface when exposed to air. Most technical applications may benefit from its cheap cost and versatile features. One of Aluminium's special properties is that it can resist corrosion, which makes it a suitable material in present study. (Jr, 2016). Aluminium will be used at varied thickness of 2 mm, 3 mm, and 4 mm that are available at the laboratory. The thicknesses of the selected materials were chosen in order to evaluate the influence of AWJM behavior and energy usage on the cutting process. The chemical composition and properties of Aluminium are given in Table 3.1 and 3.2.

Table 3.1 Chemical composition in % of Aluminium (Ilayaraja et al., 2011).

Elements	Chemical composition, %	Elements	Chemical composition, %
Aluminium	98.570	Ferrous	0.243
Magnesium	0.499	Beryllium	0.004
Copper	0.007	Manganese	0.025
Zinc	0.004	Plumbum	0.001
Titanium	0.028	Silicon	0.474

Table 3.2 Mechanical Properties of Aluminium (Kubasad, 2018).

Properties	Values
Young's Modulus	68 GPa
Poisson's ratio	0.31
Density	2660 Kg/ m3
Tensile Yield Strength	125 MPa
Tensile Ultimate Strength	275 MPa

3.4.3 Shape and Size of Material

The shape of the material was processed as dog bone shaped. The specimen was made from various levels of thickness in order to measure the energy consumption that is produced by AWJ machine. The dimension, except the thickness of the dog bone specimen is using American Society for Testing and Materials (ASTM) D-638 standard.

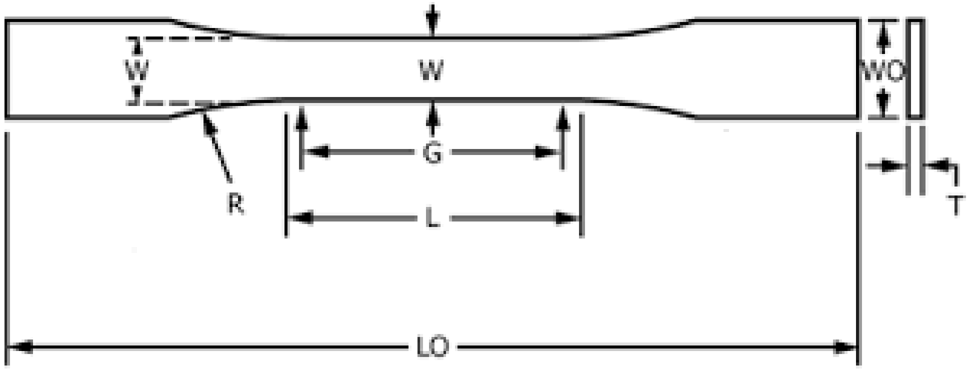


Figure 3.5 Measurement that should be considered. (Powell et al., 2017)

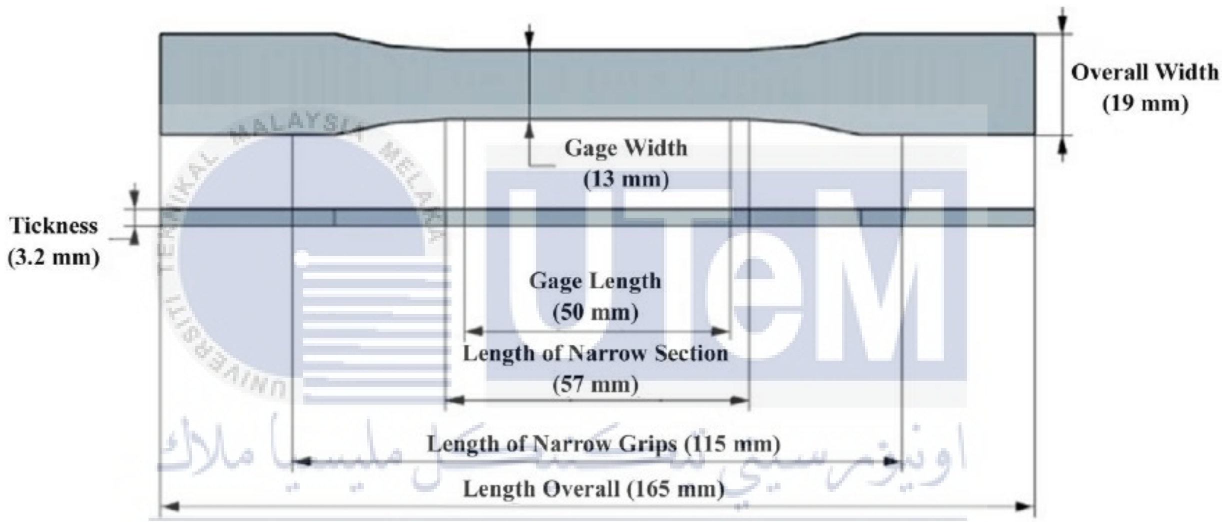


Figure 3.6 ASTM D638 Dog-Bone measurement standard. (Hibbert et al., 2019)

3.5 Abrasive Water Jet Machine Start up

The machine used for the cutting process is FLOW MACH 2-1313b which is located at FTKMP, UTEM it is shown in Figure3.4. This machine is used to cut various materials such as steels and ceramic tiles which are in plate form. The process starts with designing a pattern using 2-D or 3-D software and save it in DFX format. Ensure at least there is (tab) 4mm of uncut pattern in the design/program to prevent the work piece from falling into the bucket. Next, transfer the file to machine computer and preview the routes of the pattern.

After that, make sure the routes are acceptable before starting the machine. Several variable parameters in the abrasive water jet contour cutting of Aluminium using standardized Orthogonal Array L_{18} was employed in this study to execute the experiment using four factors with three levels, as shown in Table 3.3 and Table 3.4. Run the program and by using clamp meter, clamp the live wire to take voltage or current reading which will be covert to power. Analysis was performed to determine the energy consumption of the cutting process. Specifically, voltage and current reading are converted into power using the method outlined below.

Relationship between Voltage, Current and Power, where

P = Power in Watts

V = Voltages in volts

I = Intensity (Electric Current) in Amperes

$$P = V \times I$$

$$V = P / I$$

$$I = P / V$$

Figure 3.7 FLOW MACH 2-1313b Abrasive Water Jet Machine

3.6 Selection on Orthogonal Array (OA)

For the present study, four machining parameters were selected as control factors as shown in Table 3.3. The L18 orthogonal array (OA) for the machining parameters is given in Table 3.4.

Table 3.3 Machining parameters and their respective levels

Column	Machining Parameter	Level 1	Level 2	Level 3
A	Water Pressure, Mpa	300	350	400
B	Feed Rate, m/min	50	100	150
C	Cutting Speed, %	60	80	100
D	Thickness of Material, mm	2.0	3.0	4.0

Table 3.4 L_{18} Orthogonal Array

Trial No	A	B	C	D	Power, P
1	1	1	1	1	
2	1	2	2	2	
3	1	3	3	3	
4	2	1	1	2	
5	2	2	2	3	
6	2	3	3	1	
7	3	1	2	1	
8	3	2	3	2	
9	3	3	1	3	
10	1	1	3	3	
11	1	2	1	1	
12	1	3	2	2	
13	2	1	2	3	
14	2	2	3	1	
15	2	3	1	2	
16	3	1	3	2	
17	3	2	1	3	
18	3	3	2	1	

3.7 Analysis on data by using Random Forest method

Random Forest is an efficient method for development data to aim at improving energy consumption on AWJ machine for this study. Random forests are a machine learning technique that combines several machine learning algorithms. Which are mixed with a succession of tree classifiers, with each tree casting a unit vote for the most popular class, and the final sort of result is obtained by combining these results. Random Forest has good classification accuracy.

There are four parameters that are being modified in this study which is water pressure, pierce time, cutting speed and the thickness of material. Three design levels L_{18} Orthogonal Array are used to match all input parameters. The examination of all potential combinations of influencing factors is necessary to discover the AWJ machine's optimal energy usage.

3.8 Result Planning

3.8.1 Collect Data

The data was collected for practice of analysis in order to determine the reduction of energy consumption on AWJ machine. The parameters were modified, and power consumption will be analyzed.

3.8.2 Data Analyze

After data was collected, Random Forest method is used to predict the result. The prediction model was a decision tree. The model forecasts from the subject observations to the model decision that determines the subject's goal value. Subject observations are also known as branches, while subject goal values are known as leaves. Bagging is a technique for minimizing the variance of an estimated prediction that is suited for decision trees. A recursive fit of a comparable regression tree was done for its regression application to provide bootstrap-sampled copies of training data with the mean value. A projected class was picked for categorization by the majority vote of each tree committee. Random forest is a kind of bagging that generates a huge number of individual trees and averages their findings. Bagging produces trees with similar distributions, making it difficult to enhance beyond variance reduction. Random Forest executes the tree-growing process by selecting random input variables, hence enhancing bagging by reducing correlation across trees without increasing variance excessively.

3.9 Summary

This chapter presents case studies to demonstrate that energy savings are inextricably connected to sustainability. Reduced energy usage leads to decreased costs for producers, whose ultimate objective is to earn a profit. This case study demonstrated that by adjusting machining settings, it is feasible to reduce energy usage while maintaining product quality. As a result, the product would continue to sell at lower energy prices, benefiting all three pillars of sustainability (environmental, economic, and social). The next chapter shall now present several case studies to demonstrate, verify and further validate the result estimation model methods presented in this chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis obtained from different process parameters of AWJ machining that effect the power consumption on abrasive water jet machine. The parameters are selected by condition of the AWJ machine at UTeM laboratory, FTKMP. Data samples are arranged using L_{18} orthogonal array and the prediction results are processed using Random Forest method. The power consumption that has been produced by AWJM is measured using a clamp meter. Before executing the process, levels of design were created using Orthogonal Array method. Level 18 were chosen for 4 parameters namely water pressure, feed rate, cutting speed and thickness of material. 18 dog bone samples were collected which had different combinations of parameters, Random Forest method is used to create an empirical modelling and calculate RMSE, R^2 score for the data. The visualization graphs from the data were discussed in this chapter. Through this project, promising results were obtained and discussed comprehensively in the subsequent section.

4.2 Aluminium Dog-bone specimens

Dog bone shape with ASTM standard is a perfect candidate because it is not too big which means required small space on the AWJM cutting area. Aluminium was also chosen to be used in this research because it is an anti-corrosion material so it will not be affected by water.

Figure 4.1 Aluminium dog bone sample

Table 4.1 Constant Parameters

Parameter setting	
Work Material	Aluminium Plate
Abrisive Grit Size	80 Mesh
Stand-off Distance	3.0 mm
Jet Impingement Angle	90º
Pierce time	5 seconds
Nozzle Size	7.14 o.d
Nozzle Material	Carbide Tungsten

4.3 Design of Experiment (DOE)

Design of Experiments is a statistical technique used in technology systems operation, quality engineering, to identify significant or sensitive factors (independent variables) and levels their factor values that influence system performance and variability (dependent variables). This technique is especially useful when there is the need to understand the interactions and effects of several system variables and an absence of concrete information.

4.4 Selection of Factors and Factors Levels

DOE table design was only possible by selecting the right factors and the levels. Four factors were selected for the samples in this study with three levels that are shown in table. Table 4.2 shows the parameters selected based on machine capabilities in UTeM laboratory. After evaluating factors and levels for the study, it was important to select an accurate orthogonal array of factors and their levels.

Table 4.2 Factor Levels

	Factors			
Level of Design	Water Pressure, Mpa (A)	Feed Rate, m/min (B)	Cutting Speed, % (C)	Thickness of Material, mm (D)
1	300	50	60	2.0
2	350	100	80	3.0
3	400	150	100	4.0

For this study, 18 samples of dog bone will be produced using AWJ machine and energy consumption will be taken during the cutting process for each trial. The trial for process parameters is as shown in table 4.4.

Table 4.3 The combination of parameters for effective factors

	Factors			
Trial	Water Pressure, (Mpa)	Feed Rate (m/mm)	Cutting Speed, (%)	Thickness of Material (mm)
1	300	50	60	2
2	300	100	80	3
3	300	150	100	4
4	350	50	60	3
5	350	100	80	4
6	350	150	100	2
7	400	50	80	2
8	400	100	100	3
9	400	150	60	4
10	300	50	100	4
11	300	100	60	2
12	300	150	80	3
13	350	50	80	4

14	350	100	100	2
15	350	150	60	3
16	400	50	100	3
17	400	100	60	4
18	400	150	80	2

4.5 Findings and Data Analysis

4.5.1 Energy Consumption Result

There were 18 samples that be cutted by AWJ machine with respectives trial matrix. The measurement of energy consumption for each sample are taken by using clamp meter during the cutting process. The reading taken from the clamp meter is curent and converted to power using the formula:

$$Power = 415 \times \sqrt{3} \times Amax$$

Table 4.4 Energy consumption for each sample

Trial No	Water Pressure (Mpa)	Feed Rate (m/mm)	Cuting Speed (%)	Thickness of Material (mm)	Current (A)	Power (Watt)
1	300	50	60	2	47.7	34286.81
2	300	100	80	3	48.5	34861.85

3	300	150	100	4	50.2	36083.81
4	350	50	60	3	48.2	34646.21
5	350	100	80	4	49.3	35436.89
6	350	150	100	2	47.1	33855.53
7	400	50	80	2	47.4	34071.17
8	400	100	100	3	48.6	34933.73
9	400	150	60	4	49.7	35724.41
10	300	50	100	4	49.2	35365.01
11	300	100	60	2	47.8	34358.69
12	300	150	80	3	48.5	34861.85
13	350	50	80	4	49.6	35652.53
14	350	100	100	2	47.2	33927.41
15	350	150	60	3	48.4	34789.97
16	400	50	100	3	48.7	35005.61
17	400	100	60	4	49.4	35508.77
18	400	150	80	2	47.5	34143.05

4.5.2 Modeling Development

The important controlling process parameters in AWJ cutting include water pressure (MPa), feed rate (m/mm), cutting speed (%) and thickness of material (mm). First, develop a mathematical model to relate the process control parameters to the process response characteristics. The empirical model for the prediction of parameters that influence the energy consumption on AWJM in terms of the controlling parameters will be established by means of Random Forest regression analysis. The experimental results were obtained using the design of experiment (DOE) technique. (Kolahan & Khajavi, 2009)

In Random Forest, the parameters were tuned to find the model with the highest testing accuracy. Specifically, we tune the number of iterations (that is, the number of subtrees) and use RMSE error (tested against data subsets that are not included in subtree construction) and coefficient of determination also called as R^2 score is used to evaluate the performance of a linear regression model. It is the amount of the variation in the output dependent attribute which is predictable from the input independent variable(s) to determine the best possible model. (Matthias Schonlau, 2020)

```
df= pd.read_csv ('C:/Users/pc/Documents/Codee/Aqil.csv')
df.head(21)
print(df.head(21))

#split data into response and variable
x= df.drop(['Power'],axis=1)
y=df["Power"]

#Random Forest Model
model =RandomForestRegressor(n_estimators=15,random_state=0).fit(x,y)

y_pred =model.predict(x)
```

Figure 4.2 Coding for modelling development

4.5.3 Root Mean Squared Error

The Root Mean Squared Error (RMSE) is one of the two main performance indicators for a regression model. It measures the average difference between values predicted by a model and the actual values. It provides an estimation of how well the model can predict the target value (accuracy).

The lower the value of the Root Mean Squared Error, the better the model is. A perfect model (a hypothetic model that would always predict the exact expected value) would have a Root Mean Squared Error value of 0. The Root Mean Squared Error has the advantage of representing the amount of error in the same unit as the predicted column making it easy to interpret. The RMSE technique can model the response in terms of significant parameters, their interactions and square terms. Thus, this method can predict the effect of paramerters on the response and is a better tool for prediction compared to Taguchi's technique.

```
#Root Mean Square Error
rmse = float(format(np.sqrt(mean_squared_error(y,y_pred)),'.3f'))
print("\nRMSE:\n",rmse)
```

Figure 4.3 Coding for RMSE in Python

```
RMSE:
 44.166
```

Figure 4.4 RMSE result empirical modeling

The result of the RSME data for this model is quite high because the data is not strong enough meaning that the data is not much due to AWJM machine problems but it can still be adopted with the R^2 score result.

4.5.4 Coefficient of Determination (R^2 score)

Coefficient of determination also called as R^2 score is used to evaluate the performance of a linear regression model. It is the amount of the variation in the output dependent attribute which is predictable from the input independent variable(s). It is used to check how well-observed results are reproduced by the model, depending on the ratio of total deviation of results described by the model.

```
r2=float(format(np.sqrt(r2_score(y,y_pred)),'.3f'))
print("\nR2:\n",r2,)
```

Figure 4.5 Coding for R^2 score in Python

```
R2:
 0.998
```

Figure 4.6 R^2 score result

The best possible score is 1.0 and it can be negative (because the model can be arbitrarily worse). In the general case when the true y is non-constant, a constant model that always predicts the average y disregarding the input features would get a R^2 score of 0.0. As shown at Figure 4.6 above, due to the high values (90%) of the regression models obtained these models can be used as prediction models for the response variables being studied.

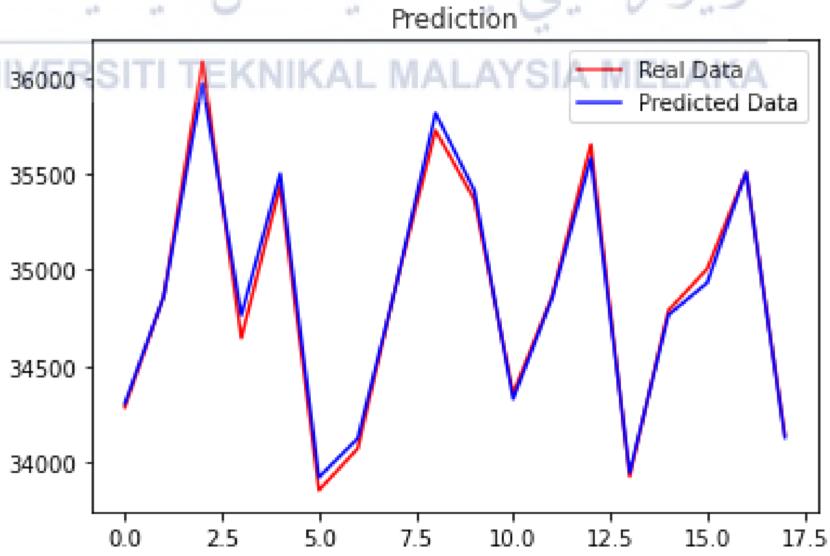


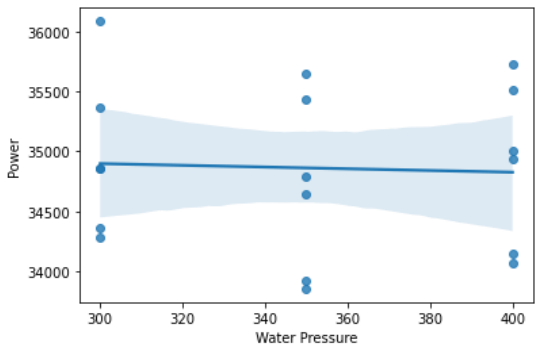
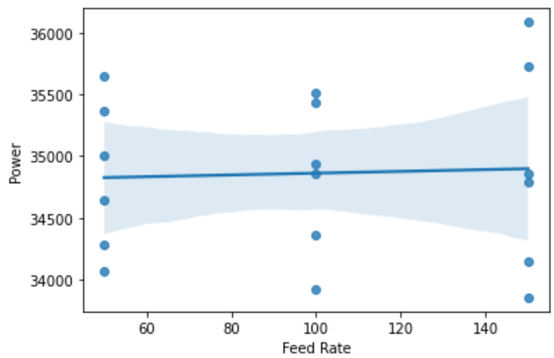
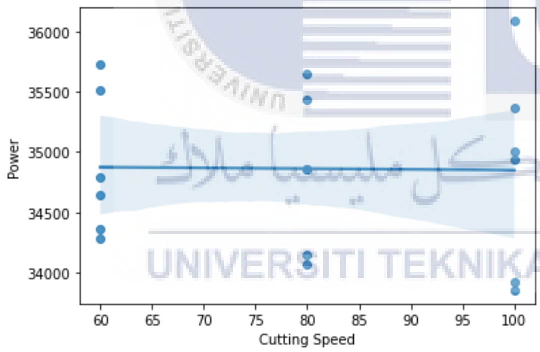
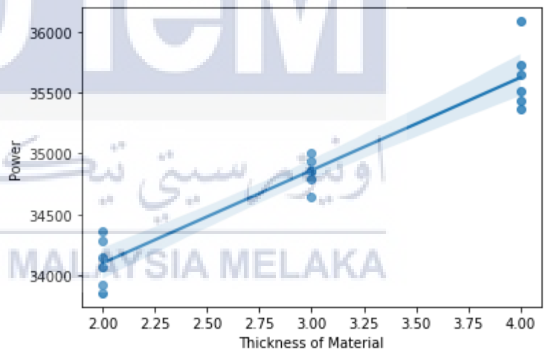
Figure 4.7 Accuracy Plot model

Figure 4.7 above shows the accuracy plot model for both real data and predicted data. The red line represent the data from experiment and the blue line represent the data from Random Forest regressor model. From the accuracy plot model, the real data and the predicted data almost have the same value which mean the Random Forest model succesfully predicted the result.

4.5.5 Main Effect Plot

The validity of the developed empirical model enabled the use of the model for the analysis of the effects of the process parameters on the specific cutting energy. Initially, the main effects of the process parameters on the specific cutting energy were analyzed by changing the combination parameter at a time, while keeping the other seven parameters constant.

Table 4.5 Effects of process parameters on AWJM energy consumption

(a)  Water Pressure	(b)  Feed Rate
(c)  Cutting Speed	(d)  Thickness of Material

From the Table 4.6 above, could be observed that the most significant and influence parameter affecting specific cutting energy on AWJM is the thickness of material and followed by feed rate. From table 4.6(d) it is seen that there exists a linear relationship between specific cutting energy and material thickness. It can be seen that the increase of material thickness will increase the specific cutting energy as a consequence of higher volumetric materials removal rates. From Table 4.6(b), feed rate parameter also influence the energy consumption on AWJM cutting process although it is quite low, but still in a positive values which consider has affects on specific cutting energy. But on the other hand, (Janković et al., 2018) concluded that most significant parameter affecting specific cutting energy is the feed rate, the not thickness of material. The prove is shown on the Figure 4.7 below where graph (c) is feed rate and (a) is thickness of material.

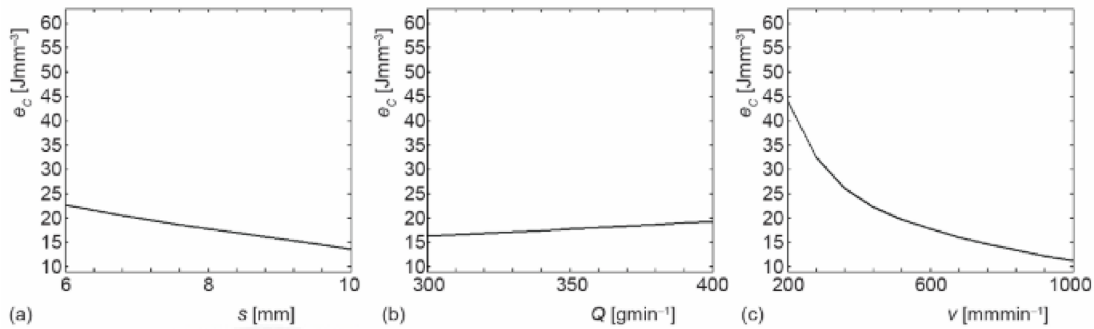


Figure 4.8 Effects of the process parameters on specific cutting energy (Janković et al., 2018)

From Table 4.6 (a) and (c), both water pressure and cutting speed parameter has negative effect specific cutting energy on AWJM which means a little influence. The value of the water pressure and cutting speed was not significant in reducing the specific energy of the machining process. In order to analyze interaction effects of the process parameters on the AWJM energy consumption, heat map and bar plot graph were generated to obtained the exact value that be shown on Figure 4.8 and Figure 4.9 below.

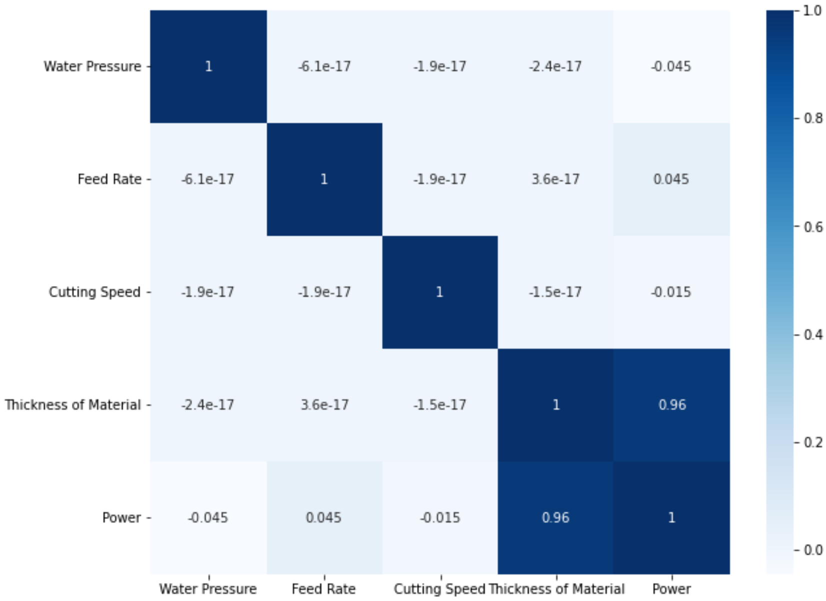


Figure 4.9 Heat Map of Parameters that influence energy consumption on AWJM

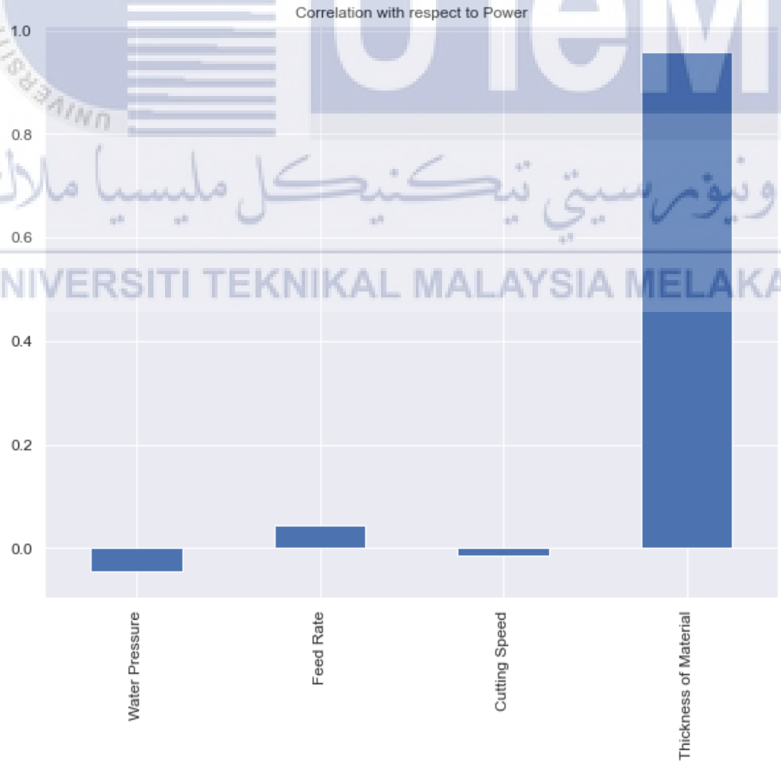


Figure 4.10 Bar Plot correlation with respect to Power.

The heat map and bar plot graph above shows that implies which parameters has the greatest impact on energy consumption and which parameters is associated with the characteristic values of high and low influence to AWJM energy consumption. Thickness of material is the most influenced to the energy consumption which is 0.96 and follow by feed rate which 0.045. But the other two paramater, water pressure and cutting speed has a negative value which is -0.045 and -0.015 both.

From the main effect plot as shown in Table 4.6, the best combination of parameters can be identified by selecting the lowest y value which power consumption from each factor. In this case, the most significant factor that has an effect on strength are thickness of material (D) followed by feed rate (B), water pressure (A) and cutting speed (C). Table 4.6 shows the summary of best combinations of parameters.

Table 4.6 Best combination of parameters

Factor	Values
Thickness of Material (D)	2mm
Feed Rate (B)	150 m/mm
Water Pressure (A)	350 Mpa
Cutting Speed (C)	100 %

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter were concluded all findings and to present a few recommendations for future use. The objectives for this study make an analysis on abrasive water jet cutting process parameter by using Random Forest method were achieved and concluded in this chapter.

5.2 Conclusion

Product quality and efficiency are important for the abrasive waterjet cutting process. Because of its numerous advantages over traditional processing methods and the ability to expand into new fields of application, AWJ cutting technology is rapidly evolving. Furthermore, because the main materials used in the machining process (water and sand) are inert and environmentally harmless, as well as the absence of airborne dust particles, smoke, and gases, this technology can be described as ecological or clean. Many of the environmental effects of machining are caused by the energy consumed. As a result, the specific cutting energy is frequently used as a quantitative measure of the machining process's environmental affinity.

The cutting ability, kerf geometries of the machined surfaces, and amount of energy used in terms of process parameters in AWJ cutting of aluminium alloy were explored experimentally in this work. The following concussions may be drawn from the study of main outcomes in the covered experimental environment.

- The thickness of material is the most significant process parameter that influenced the energy consumption on Abrasive Water Jet cutting process.
- The energy consumption on AWJM is less sensitive to the changes in water pressure and material cutting speed and this may be due to narrower changer intervals of these parameters.
- The Random Forest empirical model trained with algorithm proved to be successful for modelling the relationships between process parameters and specific cutting energy in the AWJ cutting.

The application of the AWJ cutting technology in a manner that is both efficient and effective necessitates, in a broader sense, the consideration of several performance indicators such as quality criteria, including surface roughness and dimensional, productivity, cutting time, cutting cost, and energy consumption for the actualization of the specified cutting process. An alteration in the values of the process parameters will have a unique impact on the process indicators. Because of this, it is necessary to achieve a state of equilibrium between the process indicators using process modelling and optimization. In this regard, the mathematical model that was developed for estimating the specific cutting energy can be used as an objective function in the formulation of various optimization problems with the aim of ensuring that an efficient amount of energy is used in addition to the satisfaction of other significant performance indicators.

5.3 Recommendation

In this section, a few recommendations and suggestions are made to help to improve futures research. In the future, researchers may present robust results and use different DOE to obtain better results.

First, the variable parameters of AWJM should be more. The more parameters that are investigated can show what parameters will influence the energy consumption on AWJM cutting process. The prediction of empirical model also will be more valid and accurate to produce a good result.

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APPENDICES

APPENDIX A GANTT CHART PSM 1

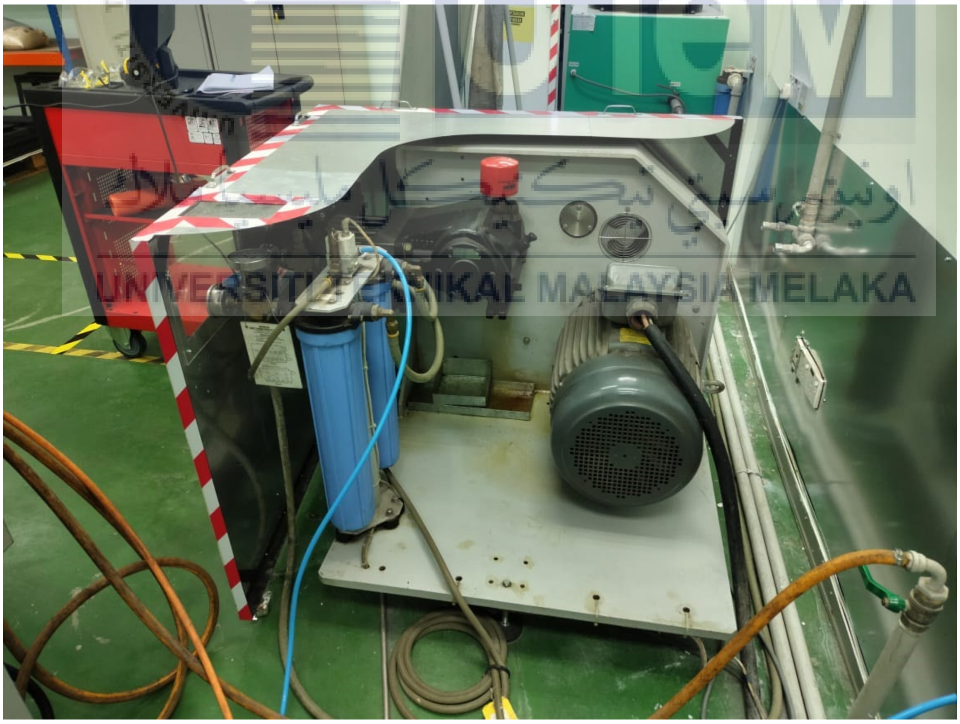
	TASK	STATUS	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23
1	**Multipurpose Bookshelf**	PLAN												
		ACTUAL												
2	**Topic Selection**	PLAN												
		ACTUAL												
3	**Discussion With Supervisor**	PLAN												
		ACTUAL												
4	**Data Collection**	PLAN												
		ACTUAL												
5	**PSM Planning**	PLAN												
		ACTUAL												
6	**Definition**	PLAN												
		ACTUAL												
7	**Basic Analysis**	PLAN												
		ACTUAL												
8	**Finding & Reading References**	PLAN												
		ACTUAL												
9	**Define the Problem Statement**	PLAN												
		ACTUAL												
10	**Literature Review Writing**	PLAN												
		ACTUAL												
11	**Logbook Submission**	PLAN												
		ACTUAL												

APPENDICES

APPENDIX BGANTT CHART PSM 2

	TASK	STATUS	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23
12	**Report Writing**	PLAN												
		ACTUAL												
13	**PSM 1 Draft Submission**	PLAN												
		ACTUAL												
14	**PSM 1 Presentation Preparing**	PLAN												
		ACTUAL												
15	**PSM 1 Presentation**	PLAN												
		ACTUAL												
16	**PSM 1 Correction Writing**	PLAN												
		ACTUAL												
17	**Purchase Material Selection**	PLAN												
		ACTUAL												
18	**Setup System Criteria**	PLAN												
		ACTUAL												
19	**System Developing**	PLAN												
		ACTUAL												
20	**System Verification**	PLAN												
		ACTUAL												
21	**PSM 2 Draft Submission**	PLAN												
		ACTUAL												
22	**PSM 2 Presentation Preparing**	PLAN												
		ACTUAL												
23	**PSM 2 Presentation**	PLAN												
		ACTUAL												

APPENDIX D PROJECT DEVELOPMENT




AC CLAMP METER
REL
MAX/MIN
HOLD
True RMS
CAT III 300V
CAT II 600V
COM
LIVE