OPTIMIZATION OF ABRASIVE WATERJET CUTTING PROCESS ON FIBER GLASS REINFORCED POLYMER IN ORDER TO REDUCE DELAMINATION AND IMPROVE CUTTING SURFACE QUALITY

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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 " Optimization of Abrasive Waterjet Cutting Process On Fiber Glass Reinforced Polymer In Order To Reduce Delamination and Improve Cutting Surface Quality" 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 understanding the factors that contribute to delamination in fiberglass can help improve the overall structural integrity of composite materials. This study demonstrates potential choosing significant parameter with different factor to achieve reducing delam in material. This study offers the important of structual delamination of effect 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.

ABSTRACT

For the purpose of machining composite materials like glass fiber-reinforced polymers (GFRP), abrasive water jet machining (AWJM) is frequently used. Since AWJM has been in use for many years, extensive study has been done on the impacts of parameter settings, with a focus on reducing delam in composite and attaining the highest surface quality. A high-speed jet of abrasive and water erodes the material on the workpiece surface in the AWJM process, which has been shown to be a feasible and affordable method for removing material from composites. In abrasive waterjet cutting procedures for glass fibre reinforced polymer (GFRP) materials, delamination is a serious problem. The goal of this study is to eliminate delamination in GFRP materials by optimising the abrasive waterjet cutting parameters. The Taguchi method is used to maximise performance by identifying the crucial variables that affect the output and figuring out their ideal values. An abstract parameter is a modifiable element or variable that can be altered throughout the optimisation process in the context of the Taguchi method. To lessen or stop delamination, the Taguchi method can be used to optimise the factors that affect it. The study uses a thorough experimental methodology to look at how different cutting parameters affect the delamination event. The results show that abrasive water jet machining can produce parts with quality that is within the tolerances for these features.

ABSTRAK

Untuk tujuan pemesinan bahan komposit seperti polimer bertetulang gentian kaca (GFRP), pemesinan pancutan air kasar (AWJM) kerap digunakan. Memandangkan AWJM telah digunakan selama bertahun-tahun, kajian meluas telah dilakukan ke atas kesan tetapan parameter, dengan tumpuan untuk mengurangkan delam dalam komposit dan mencapai kualiti permukaan tertinggi. Pancutan pelelas dan air berkelajuan tinggi menghakis bahan pada permukaan bahan kerja dalam proses AWJM, yang telah ditunjukkan sebagai kaedah yang boleh dilaksanakan dan berpatutan untuk mengeluarkan bahan daripada komposit. Dalam prosedur pemotongan waterjet yang melelas untuk bahan polimer bertetulang gentian kaca (GFRP), delaminasi adalah masalah yang serius. Matlamat kajian ini adalah untuk menghapuskan delaminasi dalam bahan GFRP dengan mengoptimumkan parameter pemotongan waterjet yang melelas. Kaedah Taguchi digunakan untuk memaksimumkan prestasi dengan mengenal pasti pembolehubah penting yang mempengaruhi output dan memikirkan nilai idealnya. Parameter abstrak ialah elemen atau pembolehubah yang boleh diubah suai yang boleh diubah sepanjang proses pengoptimuman dalam konteks kaedah Taguchi. Untuk mengurangkan atau menghentikan delaminasi, kaedah Taguchi boleh digunakan untuk mengoptimumkan faktor yang mempengaruhinya. Kajian ini menggunakan metodologi eksperimen yang menyeluruh untuk melihat bagaimana parameter pemotongan yang berbeza mempengaruhi peristiwa delaminasi. Keputusan menunjukkan bahawa pemesinan pancutan air yang kasar boleh menghasilkan bahagian dengan kualiti yang berada dalam toleransi untuk ciri-ciri ini.

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CHAPTER 1

INTRODUCTION

1.1 Background

Glass Fiber Reinforcement (GFRP) is a type of composite material that consist of glass fibers embedded in a polymer matrix. Glass Fibre Reinforcement (GFRP) composite is an innovative building material with high strength, low density, and exceptional chemical resistance(Wang et al., 2022). Due to its performance and varied attributes such as mechanical characteristics and cheap pricing, GFRP have become one of the most appealing materials for researchers and producers in recent years, allowing us to utilise them in a variety of applications(Palanikumar, 2011). It is frequently employed in a variety of sectors, including such as construction, automobiles, aircraft and buildings. Glass fibre reinforced polymer (GFRP) composites are challenging to cut due to their inhomogeneity and anisotropy that refers to distribution of reinforcing fibres within the matrix that is not homogenous (Hegedus et al., 2020). Overall, GFRP is a great replacement for conventional materials in general because its higher performance, durability and strength. During GFRP manufacturing, composite features like the fiber reinforced polymer must be made glass fiber that have flexible glass filaments and textiles because fibers are treated with a unique chemical such as sizing agents and finish coatings.

Cutting glass fiber or composite material requires the use of specialized tools designed to handle the material safely include utility knives, rotary cutters and jigsaws with fine toothed blades. Beside that, waterjet cutting is a very effective way to cut glass fiber because it is more accurate to cut the glass fiber and the pressure of waterjet will high enough to cut through the glass fiber. It is important to consult with a waterjet cutting to determine the best process needs.

1.2 Problem Statement

The abrasive waterjet cutting technology is widely used in various industries due to cut a wide range of materials with high precision and minimal heat-affected zone. However, the machining process has some challenges that need to be addressed. A quality of the final product is often affected by factors such a taper, surface roughness and material damage. One of the critical challenges in the abrasive waterjet cutting process is the delamination of the material during cutting operation.The delamination can reduces the quality and accuracy of the final product.

Furthermore, the delamination can give impact failure on material fractures and structural integrity of material. The delamination with frayed and bubble surface area, also interfere between the seperated layers and become uneven. Therefore, there is need to develop an optimized abrasive waterjet cutting process that reduces delamination issue.

1.3 Research Objective

The main aim of this research is to reduce delamination issue in cutting process for GFRP. Specifically, the objectives are as follows:

a) To determine the parameters that have significant effect on delamination and surface quality of GFRP

b) To conduct a design of experiment using Taguchi Method in Minitab Software

c) To propose the optimized AWJM parameters for GFRP material cutting

1.4 Scope of Research

This research is focus on optimization cutting process of fiber glass composite using abrasive waterjet to achive the best parameter in order to reduce delamination issue. By using Taguchi Method, we can determine with different parameter in abrasive waterjet machine FLOW MACH 2 to reach the best surface quality of GFRP in a better result. The findings from this research are based on scope of laboratory for academic purpose and not for in industrial application. Hence, the results may not applicable for other types of abrasive mesh size 80 to 180 at waterjet machines.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Composites are becoming one of the most important materials utilised in a variety of industries due to its unique qualities such as lightweight, high specific strength, and high modulus(Islam et al., 2015). Due to their excellent physico-mechanical properties, notably a very high strength-to-weight ratio, composites have become increasingly utilised in a variety of high-tech and engineering systems with specific functions in recent years(Nsengiyumva et al., 2021). Composites are a class of materials that are engineered to have specific properties by combining two or more different materials together. Composites can be made from a variety materials , such as polymer, carbon fibers and glass fibers.Because of their better stiffness, strength-to-weight ratios, and other physical properties, composite materials have several potential applications in the aircraft industry(Sharma et al., 2022).There is a lot of element in composites and one of them is glass fibers that is commonly used in industry, it also have several advantages over a traditional building materials.

Materials reinforced with glass fibers are more resistant and tear, which increases their lifespan and durability. Despite the mechanical strength of these composite materials, their inability to degrade causes them to contaminate the environment(Alkbir et al., 2016). Additionally, it is highly resistance corrosion and making them ideal for lightweight applications. Glass fiber reinforcements are relatively inexpensive compared to other materials and can improve the emergence of materials that are used in architectural and design applications.

2.2 Glass fiber reinforced polymer

GFRP is a composite material consisting of a polymer matrix reinforced with glass fibres and used to support and bond the fibres. Glass fibre reinforced polymer (GFRP) is a durable and exceptionally lightweight composite laminate material used in a wide variety of engineering applications, including aerospace and automobile. This form of laminates is referred to as reinforced polymer material and consists of a layer of fibres and a matrix that is assembled and physically separable(Dhanawade et al., 2016). Glass fibre reinforced polymers (GFRP) in particular have proved effective in replacing traditional construction materials such as steel and aluminium for ship and submarine hull construction. GFRP has non-conductive properties as well as an economic advantage over other composite and traditional materials. The GFRP composites also demonstrated a low density and high corrosion resistance(Sutherland, 2018). The process of GFRP involves in several steps such as fiber preparation that prepared typically in the form of continuous filaments or rovings and resin mixing that is polymer matrix produced by mixing the resin with catalysts and occasionally impurities.

Glass Fibre Reinforced Polymer (GFRP) is susceptible to a variety of defectand common defects include such as delamination, matrix cracking and fiber pullout. Delamination refers to the separation or fracturing of GFRP layers. It can be caused by insufficient adhesion between layers during the curing process or by external forces. Beside that, matrix cracking also involves because formation of tiny cracks in the GFRP's polymer matrix that can be caused by tension concentration and excessive loading. Fiber pullout also categorized as a defect, its occurs when the glass fibres disengage partially or completely from the polymer matrix due to insufficient adhesion.

Delamination is the separation or fracturing of layers within a GFRP structure, especially along the cut edges. It can occur when a cutting instrument exerts excessive force or generates excessive heat. Delamination can impair the structural integrity and performance of composite materials. To minimise delamination, it is essential to use cutting techniques and instruments designed specifically for composite materials. Achieving a high-quality cutting surface is essential for GFRP components because it affects both the functionality and the aesthetics of the final product. Utilising precision cutting tools with keen blades or abrasive wheels suited for composite materials will improve the quality of the cut surface. To prevent delamination and guarantee a high-quality cutting surface, manufacturers frequently employ laser cutting, waterjet cutting, and ultrasonic cutting, which offer more precise and controlled mechanical stress.

Waterjet cutting is a versatile and precise technique of cutting that employs a high-pressure water jet to slice through a variety of materials, including metals, composites, ceramics, and even food products. Additionally, AWJ machining can process the most challenging cutting materials, with excellent cutting capabilities and no HAZ(Pahuja & Ramulu, 2019).The process of waterjet cutting involves pressurising water and forcing it through a small orifice to produce a concentrated water jet. Depending on the application, certain substances can be added to the water stream to improve its cutting capabilities. For harder substances such as metals, composites, stone and ceramics, water can be introduced to the stream. By efficiently eroding the material, the abrasive particulates enhance the waterjet's ability to cut.

2.3 Delamination issue

Delamination is a type of failure that occurs when layers of a material separate from each other. Delamination often known as hardly apparent damage, is a common failure mechanism in composites that occurs between neighbouring plies of the laminate throughout the manufacturing and servicing process(Hervin et al., 2021). It is commonly associated with composite materials,such as glass fiber where several layers of fibrous reinforcements are held together with a matrix material. It often starts as a small crack or seperation between the layers. Delamination occurs when a plane parallel to the surface separates and if this damage goes undetected, it could cause a calamitous structural collapse(Tan et al., 2019). Delamination is one of the most severe damages in composites, as it directly reduces the resulting composite part's strength(Geng et al., 2019). This is a failure process in polymer matrix composites, hence researching delamination is essential when investigating polymer matrix composites. Delamination occurs when the loads on the composite plies exceed the composite's interlaminar fracture toughness, causing layer separation, interlaminar fissures, and material discontinuities(Gaugel et al., 2016). The stress redistribution associated with delamination development can be a significant factor in the strength change of composite systems in long-term service, making delamination failure in composite materials an essential failure condition(Hu et al., 2022).

2.4 Cutting surface quality

Surface quality in GFRP refers to the state and features of a component structure's outside surface. It plays a significant role in GFRP goods visual appeal,durability and performance. Several factors influence the quality of a cutting surface, including the cutting tool, cutting parameters, workpiece substance, and machine setup and selecting the proper cutting instrument and precise cut. The surface quality is affected by a number of parameter such as cutting speed, feed rate and depth of cut. The specific parameters that are used to measure surface quality will vary depending on the application.

A combination of factors must be carefully considered and optimised to guarantee high-quality cutting surface finishes. Futhermore, various cutting techniques such as turning, milling, grinding, and laser cutting have their own effects on surface quality, and adjustments in order to achieve the desired results. By concentrating on these factors, manufacturers can achieve superior cutting surface quality, resulting in enhanced product performance, customer satisfaction, and overall manufacturing efficacy.

2.5 Abrasive Waterjet

Abrasive waterjet (AWJ) machining is a non-traditional way to cut materials that has been getting a lot of attention because it doesn't cause thermal distortion, can do a lot of different things, and has a small cutting force(Alberdi et al., 2013). This technique combines waterjet cutting capabilities with the additional force given by abrasive particles, making it appropriate for cutting materials that are difficult or impossible to cut with water alone. Recently, the AWJ machining process has been used to produce a wide variety of materials using milling, drilling, and turning, among others(Kartal, 2017). The aerospace and automotive sectors are particularly competitive markets for abrasive waterjet cutting (AWJC). The reduced starting cost and lack of a heat-affected zone on the workpiece provide this technology a competitive edge over competing technologies(Liu, 2010).

When cutting with an abrasive waterjet, there are various key characteristics to consider in order to produce the best results. These parameters can be changed depending on the material being cut, its thickness and the desired cutting speed. However, depending on the operating circumstances, the erosion processes connected to AWJ material removal lead to varied surface smoothness and roughness(Axinte et al., 2014).

Figure 2.1 Waterjet flow MACH 2

2.5.1 Advantages of abrasive waterjet

The advantages of abrasive waterjet machining (AWJM) over other cutting methods are numerous. Here are some of the primary benefits of employing an abrasive waterjet:

- **No Heat-Affected Zone (HAZ):** Since AWJM is a cold-cutting method, it does not generate significant heat during the cutting procedure. This precludes the possibility of heat-induced distortion, warping, or damage to heat-sensitive materials.

- **No Direct Mechanical Forces**: The AWJM cutting process is non-contact, meaning no direct mechanical force is applied to the workpiece. This minimises the possibility of mechanical stresses, deformation, or burrs on the cut edges.

- **Environmentally favourable**: AWJM is an environmentally favourable method of cutting. During cutting, it does not produce harmful fumes, gases, or particles, reducing the need for additional ventilation or extraction systems.

- **Versatility**: AWJM can cut a wide variety of materials, including metals, alloys, ceramics, glass, stone, and even heat-sensitive materials. It can work with different sizes of materials, from thin sheets to thick blocks.

- **Fast Setup and Changeover**: Thanks to CNC code, AWJM makes it easy to set up and switch between cutting jobs quickly. The ability to programme complicated cuts that don't need special tools.

2.5.2 Disadvantages of abrasive waterjet

In addition to its many benefits, abrasive waterjet machining (AWJM) has a few drawbacks to consider. Here are some of the most significant drawbacks of abrasive waterjet:

- **Slower Cutting Speed**: Compared to other cutting techniques, such as laser and plasma cutting, abrasive waterjet cutting can be slower. The process entails material erosion, which requires more time than instantaneous melting or vaporisation techniques employed by other methods.

- **Initial apparatus Cost**: The apparatus required for abrasive waterjet machining can have a higher initial cost than other cutting techniques. The high-pressure water pump, , abrasive delivery system, and cutting head can be costly to acquire and keep up.

- **Operating Costs**: Due to the utilisation of abrasives, which must be continuously supplied for effective cutting, AWJM can incur higher operating costs. During the cutting process, the abrasive particles wear out and must be replaced frequently, increasing the continual cost.

- **Noise and Water Disposal**: Due to the high-pressure water pump and cutting action, AWJM can generate noise, which may necessitate noise reduction measures in certain settings. In addition, the disposal of used water and abrasive slurry can be a concern for the environment and waste management systems.

2.6 Waterjet machining parts

During waterjet machining, different parts work together to make the cutting process easier. Here are some of the most important parts of a waterjet cutting system:

- **Reseivoir** : The reservoir is utilised to store water for use as a projectile. The reservoir provides water for the jet machining procedure.

- **Pump** : This pump will absorb water from the reservoir and transfer the water with great force. The turbines are used to generate water pressure between 1500 and 4000 bar. To accomplish this pressure, a 50-100 horsepower electric motor is utilised.

- **Intensifier** : Intensifiers are utilised to enhance the pressure of water jets and produce high-pressure liquid jets. This intensifier is linked to the accumulation mechanism. It absorbs water at low pressure and exhales it at high pressure through an accumulator.

- **Accumulator** : The accumulator is utilised to temporarily store water based on demand. Linked to the accumulator control valve. It maintains a steady high-pressure water flow and eliminates pressure fluctuations.

- **Control Valves** : This control valve regulates the water pressure and volume and directs the water to the flow regulator. Here, the pressure energies are transformed into kinetic energy.

- **Nozzle** : This nozzle will transform the high-pressure jet's pressure into kinetic energy. At the extremity of the nozzle, as the field decreases, the kinetic energy increases. The water discharge from the nozzle is then directed at the object being worked on.

- **Drain** : This drain are utilised to capture water after the workpiece has been cut. From here, water is sent for additional purification or recirculated.

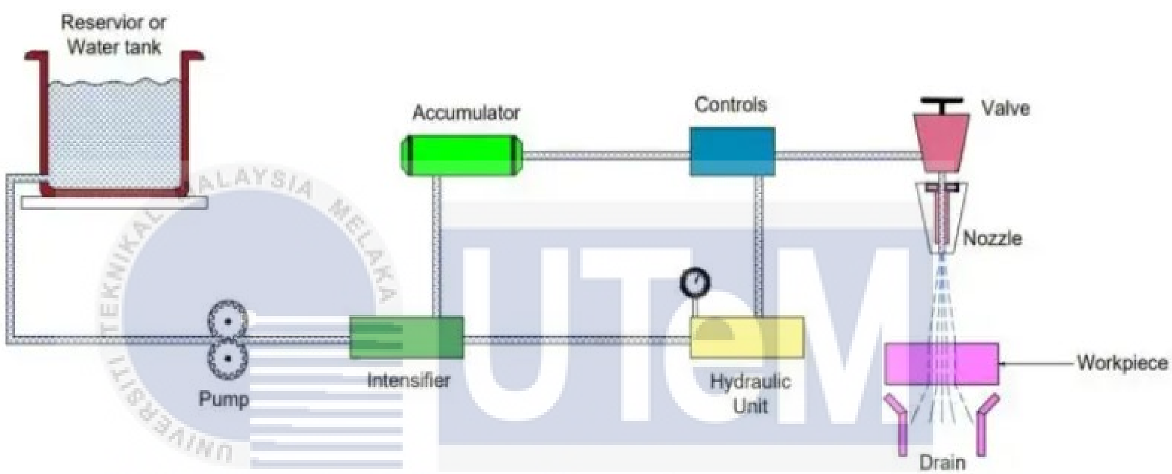


Figure 2.2 Waterjet machining application

2.6.1 Cutting head

The abrasive waterjet cutting head is an integral part of the abrasive waterjet machining (AWJM) method. It is responsible for conveying a high-velocity stream of water and abrasive particles to cut through a variety of materials.

Mixing chamber : The mixing chamber is responsible for mixing the pressurised water and abrasive particles. It assures the uniform distribution of abrasive particles in the water stream, allowing for efficient cutting.

Orifice: The orifice is an important part of the cutting head because it controls how big and round the waterjet stream is. It is usually made of a hard, long-lasting material like sapphire or diamond to resist the high-pressure flow and rough particles.

Focusing Tube: In some cutting head designs, the abrasive waterjet stream is further shaped and concentrated by means of a focusing tube. By decreasing the jet's divergence, the focusing tube helps maintain the jet's stability and enhances cutting precision.

Pressure valve : Helps to control how fast the mixture of water and grit moves through the system. Operators can control the flow rate and get the best cutting conditions for different materials and thicknesses by changing the valve.

- **Abrasive feed mechanism** : The cutting head contains a mechanism for introducing abrasive particles into the mixing chamber. Depending on the configuration of the cutting head, either a venturi system or a separate abrasive feed line can be used to accomplish this.

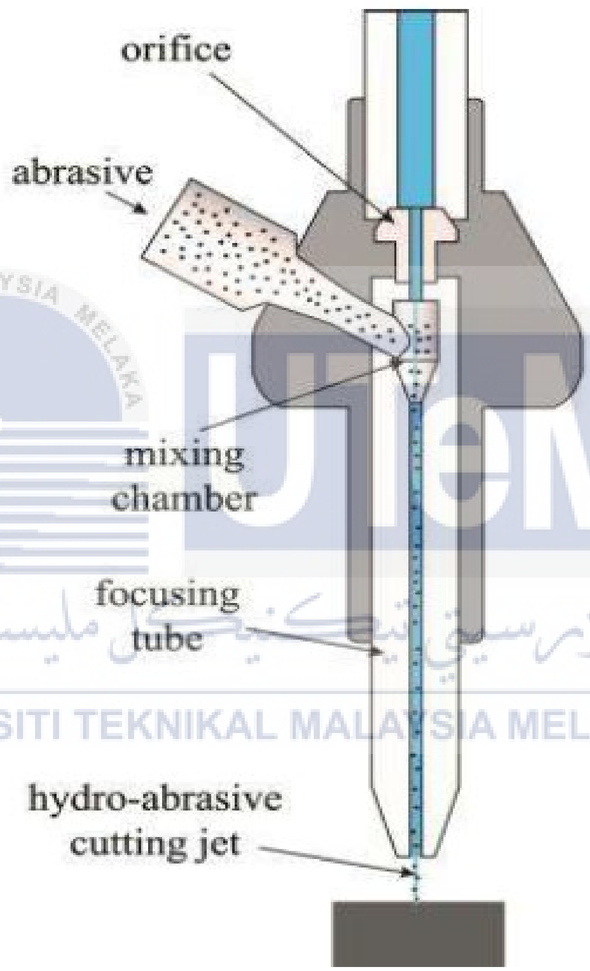


Figure 2.3 Waterjet Cutter

2.7 Abrasive waterjet machining process

The abrasive waterjet machining (AWJM) process uses a high-pressure stream of water with abrasive bits in it to cut or machine materials. Here is a process includes general overview of the AWJM process :

- **Generation of High-Pressure Water**: The process begins with the production of high-pressure water. Typically, a pump is used to pressurized water to pressures between 30,000 and 90,000 pounds per square inch (psi).

- **Nozzle and Focusing Tube**: The water and abrasive mixture is then pushed through a small hole in the cutting nozzle. This speeds up the abrasive-filled water and makes it move at a high speed. Often, a focusing tube is used to focus and guide the rough waterjet stream even more.

- **Cutting factors**: Water pressure, abrasive flow rate, standoff distance (the distance between the nozzle and the workpiece), and cutting speed are some of the factors that can be changed to make the cutting process work best. These factors depend on the thickness of the material being cut and the quality of the cut that is wanted.

- **Finishing and extra operations**: Depending on the application, the edges of the material that have been cut may need additional steps like deburring or finishing to get the final surface quality that is wanted.

2.8 Input parameter in abrasive waterjet

Abrasive waterjet cutting is a flexible production method that uses a high-pressure water stream mixed with abrasive particles to cut through a wide range of materials. Depending on the purpose and material being cut, the process parameters for abrasive waterjet cutting can be different. The most common input setting for abrasive waterjet cutting are tranverse speed, cutting pressure, nozzle stand off and abrasive size. To accomplish the desired results, these input parameters can be adjusted and optimized based on the precise requirements of the cutting application to determine the optimal cutting parameters for a specific material.

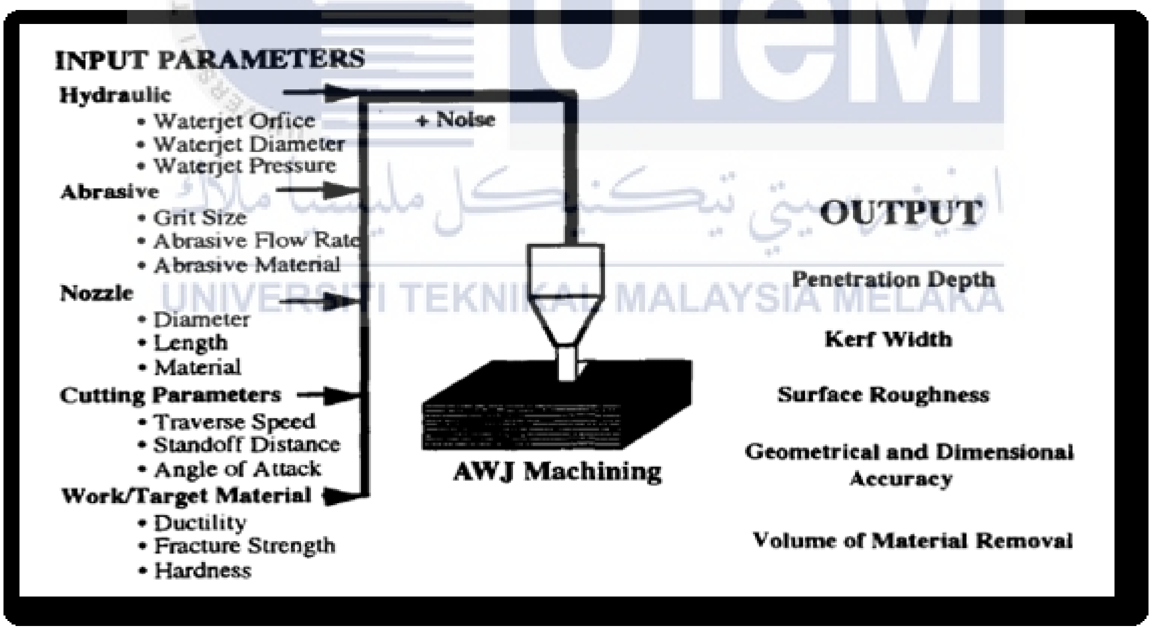


Figure 2.4 Abrasive waterjet machining process parameter

2.8.1 Tranverse speed

The tranverse speed of an abrasive waterjet is the rate at which is the rate at which abrasive particles, often combined with water, escape the nozzle of a waterjet cutting system in a direction perpendicular to the waterjet's main flow. The tranverse speed is a key factor in cutting process in abrasive waterjet system and it can controls abrasive particles impact the material being cut, which affects both cutting speed and precision.

2.8.2 Cutting pressure

The pressure at which the water and abrasive mixture is pushed through the nozzle during the cutting operation is referred to as the cutting pressure is an abrasive waterjet. It is one of the crucial factors that influences how effectively an abrasive waterjet system can cut material. Usually, the cutting pressure is expressed in psi (pound per square inch) or bar units. Higher cutting pressure often lead to higher cutting speeds which improves the effectiveness of the abrasive particles penetration into the material. In abrasive waterjet system, the cutting pressure is adjusted by modulating the pressure of the water pump that provide the high pressure flow. It should be noted that the cutting pressure should be optimized for each individual cutting application

2.8.3 Nozzle diameter

The internal diameter of the nozzle through which the high-pressure water and abrasive combination is discharged during the cutting process is referred to as the nozzle diameter in an abrasive waterjet. It is a important parameter that impacts the abrasive waterjet system’s cutting performance and quality.Typically, it is measured in millimetres (mm) or inches (in). The nozzle diamter is determined by variables such as the material being cut, its thickness and the size of the abrasive particles utilised. Its important to remember that the nozzle diameter also influences how much abrasive material is consumed and how quickly the nozzle wears out also finind the ideal balance between cutting speed, precision and choosing the nozzle diameter.

2.8.4 Nozzle stand off

In an abrasive waterjet, the nozzle standoff is the distance between the nozzle tip and the surface of the material being cut. It is a critical parameter that can have a major incfluence on the abrasive waterjet system’s cutting performance, quality and efficiency. The standard untis for nozzle standoff distance are milimetres (mm) and inches (in) and its quite important in attaining the optimum cutting performance. The cutting speed and effieciency may be impacted by the nozzle standoff distance which can speed up cutting.

2.8.5 Abrasive size

The particle size of the abrasive material that is combined with water and thrust through the nozzle during the cutting process is referred to as the abrasive size in an abrasive waterjet. Typically, abrasive particles used in waterjet systems range in size from 30-240 mesh (about 500-40 microns). The size of the abrasive can affect how the cut surface is finished also finer abrasive sizes give good surface finishes, while coarses abrasive sizes will produce a rougher surface finish. The required surface finish determined by the application requirements and might impact the abrasive selection.

2.8.6 Cutting path

In abrasive waterjet machining, the cutting path is the trajectory of the waterjet nozzle as it slices through the material. It is defined by a set of parameters that determine the cut's course and quality. The feed rate determines the velocity of the nozzle along the cutting path and it is commonly measured in inches per minute (IPM) or milimeters per minute (mm/min).Optimize the feed rate in order to accomplish the desired cutting speed without sacrificing cut quality. The waterjet cutting machine can be programmed to control and change these settings with the help of special software. In order to obtain precise, high quality cuts in abrasive waterjet machining, it is essential to optimize the cutting path parameter.

2.9 Design of experimental using Taguchi Method

Taguchi method is a systematic approach to product design and development that seeks to improve quality and reduce variability. It is structured and systematic method for focus on identifying the optimal settings of the input variables to reduce variability. Researchers have employed the Taguchi approach for machinability tests, and the results have been excellent(Jebarose Juliyana et al., 2022).The Taguchi Method involves design of experiments, determination of the optimal level of the control factors and confirmation of the results. Originally developed to enhance manufactured goods, it is now one of the most effective optimization techniques for determining the optimal value for a given objective function by analyzing the impact of critical control factors(Pandey et al., 2017).

Based on the concepts of experiments, the Taguchi method is a well-known, cost-effective way to improve product quality and reliability(Nath & Krishnan, 2019).In contrast to many optimization methods that are founded on advanced statistical methods, the Taguchi method focuses on the efficient application of an engineering strategy to optimize a problem(Teimortashlu et al., 2018).It can determine and choose the quality attribute or performance parameter for GFRP that you wish to optimise or improve.Beside that, Taguchi Method can determine the ideal factor values that results in the desired quality features based on the analysis findings. In order to get the desired surface quality or performance in GFRP,adjust the process parameters appropriately.

2.10 Significant factors of AWJM parameter on delamination and cutting surface quality

Surface roughness is a measure of the texture on the surface of a material. It can be influenced by various factors such as the manufacturing process or material properties. Surface roughness is an important factor in the performance of GFRP as it affects the bonding strength and adhesion between the composite material. In manufacturing and engineering, surface roughness is crucial factor that affects a surface's aesthetic and practical qualities. It is frequently measured and defined to make sure that a surface satisfies certain criteria for funtionality,aesthetics or performance.

The best parameters to get surface roughness of GFRP depend on material properties that can depend on various parameters. High dimensional precision and cutting quality are achieved by using the suggested higher levels of abrasive flow rate, cutting feed, low levels of pressure, and standoff distance(Ibraheem et al., 2015).The most important elements affecting delamination, according to research on a GFRP to study the impact of operational parameters, are traverse speed, mixing tube size, and abrasive flow rate(Schwartzentruber et al., 2018).The primary goal of the current work is to determine how the AWJ parameter affect surface roughness to make a material more quality.

2.11 Summary or Research Gap

Abrasive waterjet cutting is a versatile and widely used machining method that uses a high-pressure waterjet mixed with abrasive particles to cut through different materials. It also has a number of benefits, such as the ability to cut complex shapes and make high-quality cuts. This summary focuses on the process parameters of tranverse speed, cutting path, standoff distance, and cutting speed in order to optimize cutting efficiency and surface quality. The cutting characteristics of various materials, such as metals, composites, ceramics, and polymers, have been studied to determine the optimal process parameters for particular applications.

Surface quality is a crucial aspect of abrasive waterjet cutting, and studies have investigated the factors that affect surface irregularity, such as abrasive size, cutting speed, and cutting parameters. This highlights the ongoing efforts to optimize abrasive waterjet cutting for enhanced cutting performance and surface quality. The investigation of process parameters, material considerations, and surface quality that effectively employ this versatile cutting method.

CHAPTER 3

METHODOLOGY

3.1 Introduction

GFRP is a composite material made up of a polymer matrix reinforced with glass fibers. Glass Fiber Reinforcement (GFRP) is a type of composite material that consist of glass fibers embedded in a polymer matrix. Fiber glass reinforcement a composite material called polymer is constructed of polymer matrix that has been secure with glass fibers. It is known for its high strength to weight ratio, sturdiness and chemical corrosion resistance.It is frequently employed in a variety of sectors, including such as construction, automobiles, aircraft and buildings. GFRP can be easily moldable into various forms and sizes. It is perfect material for electrical and electronic applications due to its exceptional thermal and electrical insulation qualities.

GFRP is highly corrosion resistant, making is a good choice for applications and unlike steel, does not rust or corrode to resulting in a longer service life and lower maintenance costs. Overall, GFRP is a flexible and long lasting material that combines the strength of glass fibers with the flexibility.Its qualities make an appealing alternative for a wide range of application where strength and corrosion resistance are important factors.

3.2 Research Design

Select the investigations may be repeated to be conducted to validate the results. By selecting and optimising the cutting parameters, it is possible to improve the surface quality and dimensional accuracy of a machined part. The subsequent sections will present results, analyses and discussions based on the methodology employed as shown in figure 3.1 :

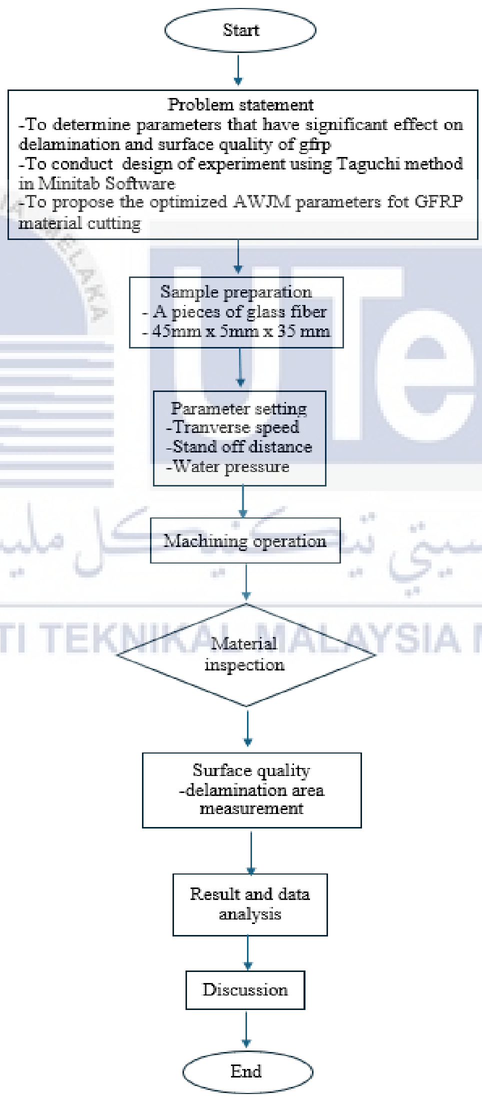


Figure 3.1 Flow Chart

3.3 Material

The material known as GFRP is categorised as a pure element. Because GFRP has a high tensile strength, it can bear pulling or stretching forces without breaking. It also has strong flexural strength, which allows it to withstand bending or deflection. GFRP is stiff and resistant to deformation under applied loads because to its high elastic modulus. Furthermore, GFRP is lightweight, with a low density that allows it to be several times lighter than steel.

Table 3.1 Properties of GFRP composites

Property	Material Type	
	CFRP	**GFRP**
Density (gm/cm^3)	1.50–2.10	1.25–2.50
Tensile Strength (MPa)	600–3920	483–4580
Young's Modulus (GPa)	37–784	35–86
Elongation (%)	0.5–1.8	1.2–5.0

3.3.1 Pure fiber glass sample

Pure fiber glass is a primarily offering consistent structual properties throughout the vessel and they may also have some limitations, and consider the quality of material used when evaluating the performance in longevity life. Fiber glass materials have high melting point, typically ranging from 1300°C to 1400°C, this high melting point ensures that glass fibers maintain their structural integrity.

Fiber glass are known for their high strength to weight ratio and providing durability while keeping the overall weight of the vessel relatively low. It's inherently resistant to corrosion, making it ideal for marine environments where exposure to water and salt is common. This resistance ensures a longer lifespan for boats, reducing maintenance needs In terms of both initial construction and long-term maintenance, fiberglass is often more cost-effective compared to materials like wood or aluminum. Fiberglass is highly resistant to corrosion from moisture, chemicals, and environmental factors, making it suitable for use in harsh conditions and generally resistant to many chemicals for making it suitable for applications where exposure to corrosive substances is a concern

Figure 3.2 Sample of fiber glass

In this research, a piece fiber glass with length of 45mm with 5mm height and 35 width are being used tested in term of drilling a hole with different specification to find the significant value of parameter for optimization in order to reduce delamination to get the most appropriate variable to choose.

3.3.2 Abrasive

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.

In this research, we used Garnet Sand as our abrasive material with a mesh size of 80 in the waterjet machine for drilling hole sample, fiber glass. 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 effectivehardness 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.

Figure 3.3 Abrasive Garnet sand

3.4 Machine specification

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. Cutting speeds and the capacity to cut through tougher materials may both be boosted as pressure is increased. The waterjet system is dependent on the nozzle, which is a critical component. It is in charge of calculating the width of the water stream as well as the cutting precision. The nozzles diameter using by this waterjet machine is 1.0 mm. The detail specification of machine used to conduct this research are shown in table below.

Table 3.2 AWJM background machine

Machine	Waterjet cutting machine
Brand	Flow
Model	FLOW MACH 2 1313B
Table size	Width: 1,310.6 mm Length: 1,310.6 mm
Water cutting pressure	50 000 psi (max)
Nozzle	1.0 mm (diameter)
Software	• Flow Path – design software • Flow Cut – machine cutting software

Figure 3.4 AWJM Machine

3.4.1 Work process

1. clamp a sample fiber glass on the table of the waterjet machine and make sure the sample is tight
2. set the nozzle position above the sample fiber glass to be cut which is X,Y and Z value
3. the distance cutting is set to 90 mm only to ensure that the finished sample does not fall into the machine
4. insert the value of the parameter
5. press X and Y home then click set current position as user home.
6. Click the low-pressure button then pump on
7. Wait for 10 seconds then click high pressure button
8. wait until the meter's needle attach number 5 then click the cutting start button.
9. Wait until the process of cutting finish
10. After the cutting process finish, make sure that nozzle is at home position by click x and y home then choose "go to the latest used defined-home".
11. Wait until the nozzle at home position
12. To run next sample, offset the previous sample by adding 30 mm to x and y value.
13. Set the traverse speed, water pressure(thickness) and standoff distance according to the table of experiment.

3.5 Experimental Set up (Taguchi Method)

Because parameter optimisation in abrasive waterjet is critical to achieving desired results, multiple approaches are employed to establish a link between experiment parameters and results. The statistical design of experiment (DOE) approach has proven a significant tool in this context for understanding the link between parameters and results. Even though it has been used in a variety of study fields, its application to abrasive waterjet of fiber glass remains an important area of study. In this research, the version of MINITAB used as shown in figure below.

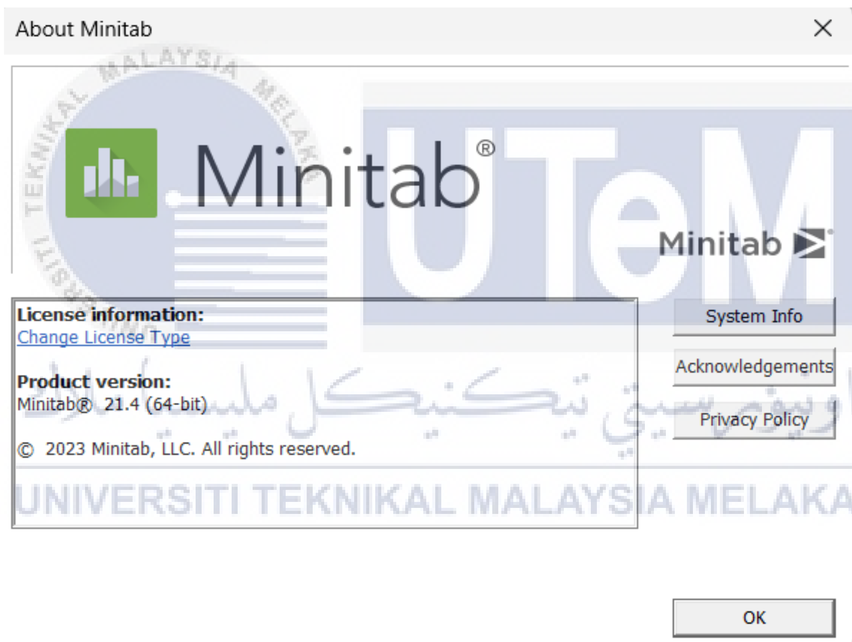


Figure 3.5 Minitab software background

3.5.1 Orthogonal arrays (2 level)

Lots of engineers today organise industrial trials utilising Taguchi's catalogue of orthogonal arrays. However, Taguchi offers either no or insufficient details on the procedures employed to generate these arrays. Furthermore, Taguchi shows orthogonal arrays in ways that differ from how these arrays are often shown in statistical literature. As a result, it is difficult to see the connections between Taguchi's arrays and the comparable ones published elsewhere. Recent ads and testimonials on the success of Taguchi's orthogonal array experiments add to the confusion by creating the idea that these arrays are anything other than fractional factorials and classical experiment designs. In this research, only 2 level use which is low level and high level.

3.5.2 Creating of orthogonal arrays

To choose sample locations for creating response surfaces to be employed in the optimisation process, orthogonal arrays were used. Orthogonal arrays can be utilised directly to determine design variables in the discrete design space. Design variables must have discrete values. In this part, we will look at how to utilise orthogonal arrays to generate a discrete design from a set of discrete data.

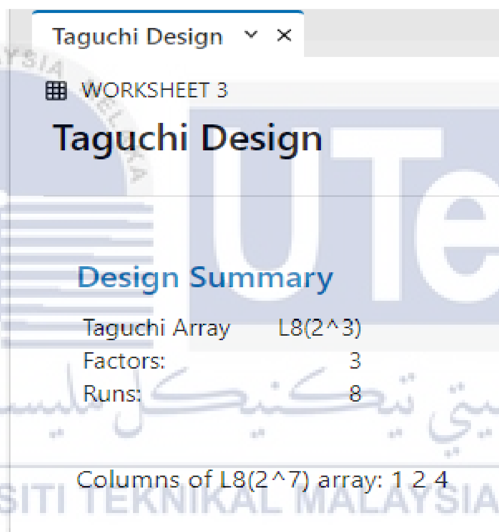
The uncontrolled optimization in order to reduce delmaination is considered. Consider a problem with three design variables to show the method. Let the variables' values be shown in Table x; that is, we have three design variables, each with two levels.

Table 3.3 Type of level and variable parameters

Level \ Variables	Tranverse speed	Standoff distance	Thickness
Low	40	1	5
high	80	5	10

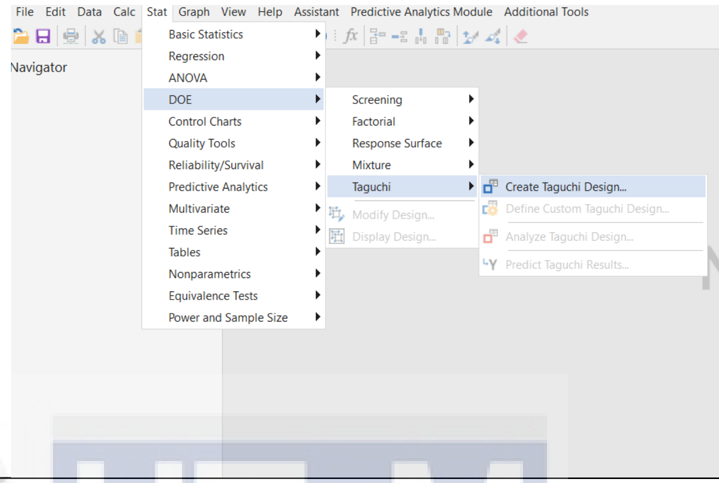
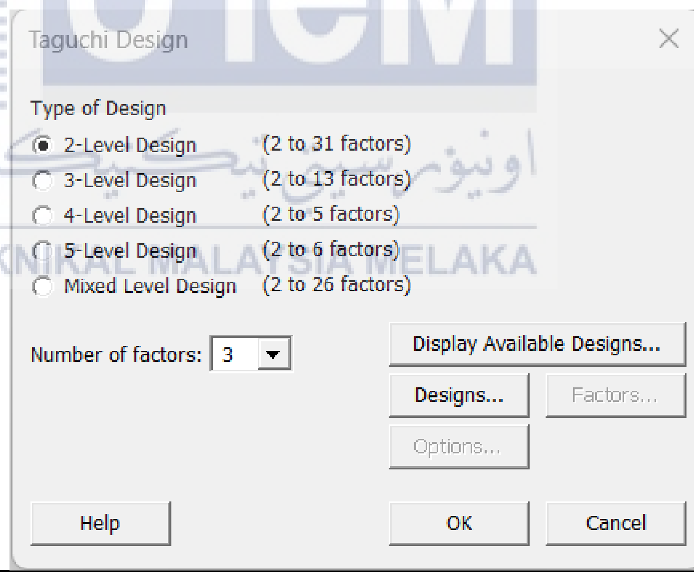
The $L_8(2^3)$ orthogonal array can be used for the situation of three design variables. In this technique, just 8 design variable combinations are used to determine the number of experiments

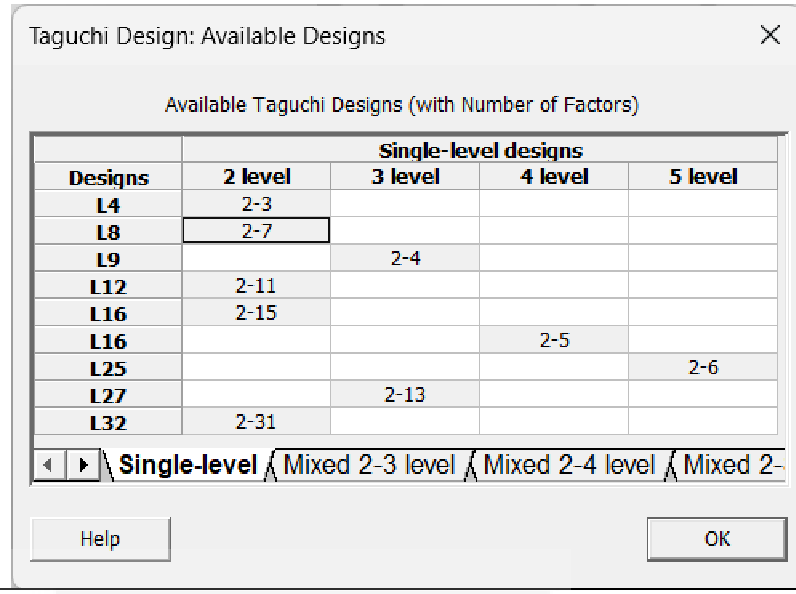
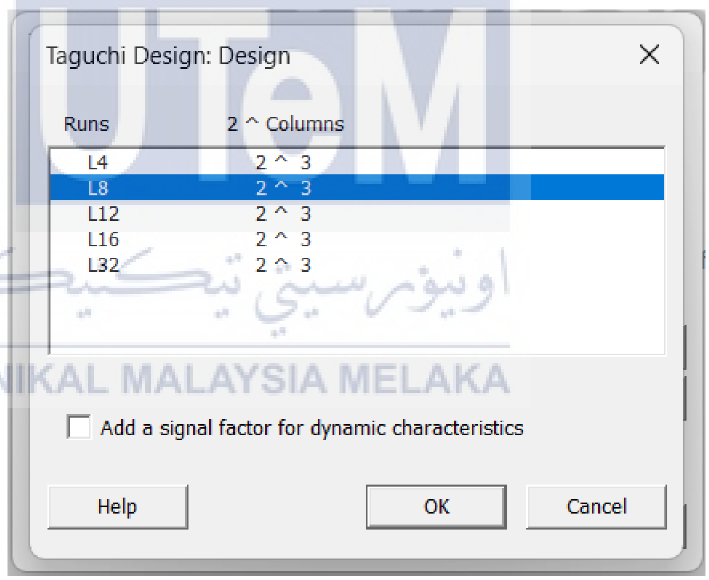
Table 3.4 Value of parameters inserted in minitab



↓	C1	C2	C3
	Tranverse speed	Nozzle stand off	thickness
1	40	1	5
2	40	1	10
3	40	5	5
4	40	5	10
5	80	1	5

3.5.3 Work process of creating orthogonal array

	INSTRUCTION	PICTURE
1	Open MINITAB, select stat, choose DOE, choose Taguchi then click create Taguchi design	
2	This display will pop-out after step 1 is done. For type of design select 2-level design and make sure number of factors is 3 according to the number variable.	

<table>
<tr><td>3</td><td>Click display available design and chose l8 (2-7) then click ok.</td><td>
</td></tr>
<tr><td>4</td><td>Click design then select L8 (2^3) then ok</td><td>
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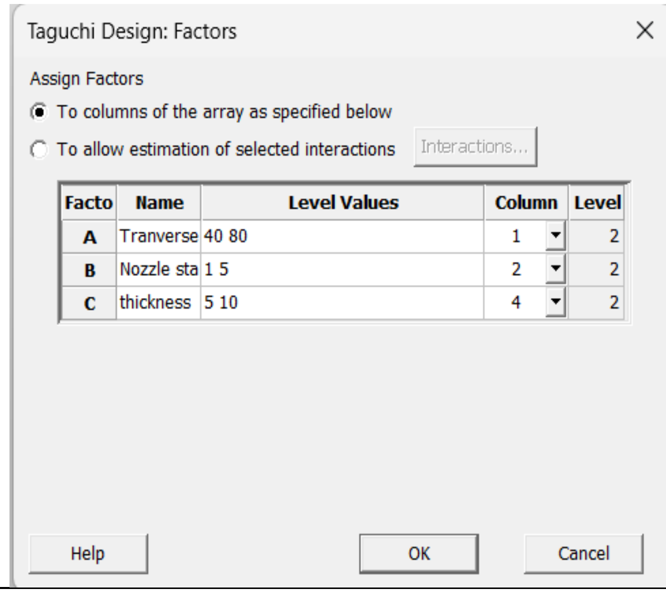
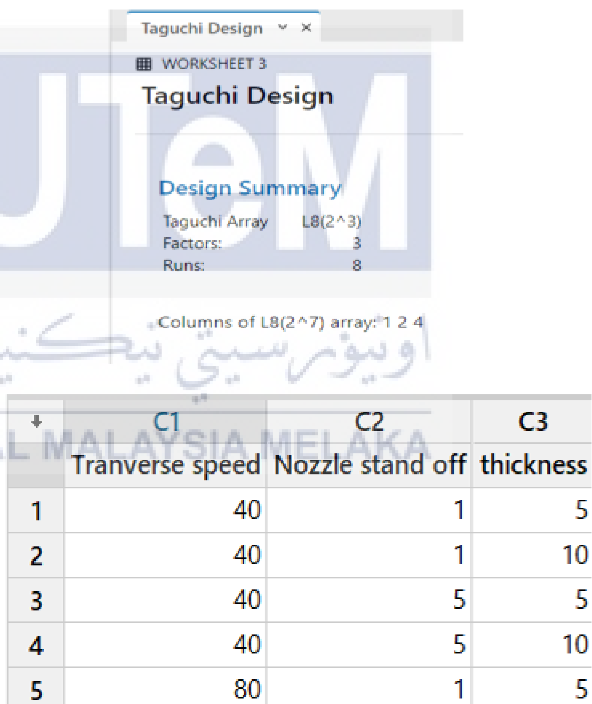
<table>
<tr><td>5</td><td>Click factor and insert all variable and value of the level, then click ok.</td><td>
</td></tr>
<tr><td>6</td><td>The orthogonal array will display</td><td>
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3.6 Characterization

3.6.1 Delamination measurement

Figure 3. 6 Nikon SMZ 745T

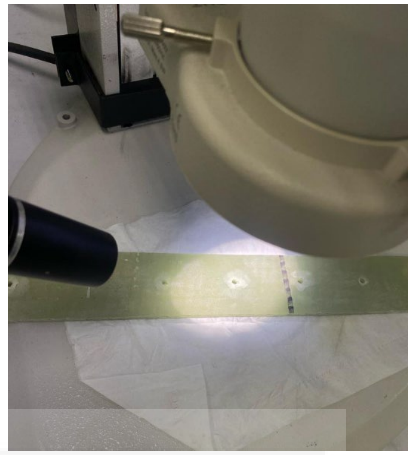

Figure 3. 7 Analyzing delamination

To measure the area of delamination, we use Nikon SMZ 745T as shown in figure 3.6. The Nikon SMZ 745T Stereomicroscope provides an invaluable instrument for analyzing and comprehending delamination in composite materials through delamination testing. The microscope's adaptable features, sophisticated optics, and movable magnification, though not intended for this use, provide a platform for preliminary examination and characterisation of possible delamination in a variety of materials. Nikon SMZ 745T Stereomicroscope emerges as a valuable asset in delamination testing within composite materials. Its optical excellence, coupled with imaging capabilities, facilitates surface-level inspection. Its contributes significantly to a comprehensive understanding of delamination and ensuring the safety.

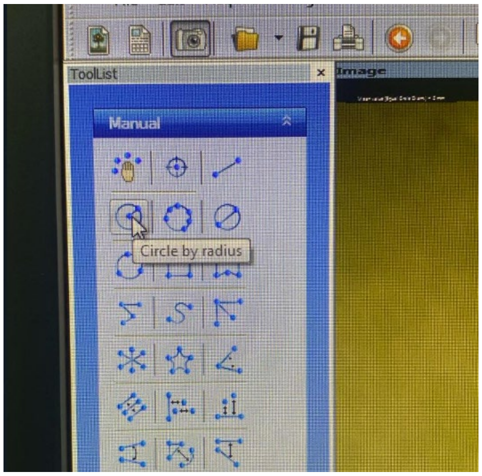

Figure 3.8 Manual measurement toolist

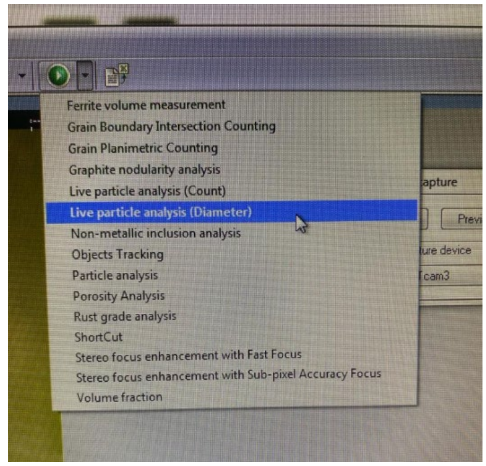

Figure 3.9 Click live particle analysis

Here a procedure to visually examine and document delamination using this microscope :

- **Sample Preparation**: Arrange material such that it can be observed under a microscope, making sure it is properly positioned and illuminated.

- **Observation**: Use the Nikon SMZ 745T to observe the sample and identify the particles or areas you want to measure. Adjust the magnification and lighting for optimal visualization

- **Live Analysis**: Set up your imaging software to receive live feed or images from the Nikon SMZ 745T. Depending on the software, you may be able to analyze particles, measure their diameters, count them, and perform other relevant analyses

- **Imaging**: Capture high-resolution images of the suspected delamination regions using the microscope's imaging capabilities.

- **Analysis and Reporting** : Analyze the captured images to identify the extent and nature of the delamination and compile the documented images into a report.

3.7 Waterjet parameter

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

- **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

- **Cutting pressure** : The waterjet's cutting force and its capacity to pierce the workpiece depend on the pressure at which it is delivered. The force that is applied to the water as it travels through the cutting nozzle is referred to as the waterjet's pressure. Furthermore, higher pressures can lessen delamination and enhance the quality of the surface

- **Tranverse Speed** : The cutting speed is the velocity at which the waterjet moves across the surface of the workpiece. It has an impact on both cutting quality and delamination. Due to the impact forces generated on the workpiece surface, higher cutting speeds often result in more delamination. It is critical to optimize the cutting speed based on the material qualities and desired cutting quality in order to minimize delamination and provide satisfactory surface finishes.

- **Standoff Distance** : The distance between the nozzle tip and the workpiece surface is referred to as the standoff distance. It is critical in determining cutting quality and minimizing delamination. Maintaining an adequate standoff distance is critical to ensuring that abrasive particles penetrate the material properly without producing excessive deformation or delamination.

The optimal values of these parameters will vary depending on the material and it is important to experiment with different parameters to find the best combination for a particular application. In addition to above parameters, the standoff distance,tranverse speed and cutting pressure are some input factors that also hav significant impact on the quality of the machining produced by the AWJM process.

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter provides a detailed explanation and description result employed to attain the stated objective. Furthermore, this paper aims to determine the best parameter and the steps taken to accomplish this investigation. The primary of the study which optimization of abrasive waterjet process on fiber glass reinforced polymer in order to reduce delamination and improve cutting will be discussed after doing several chapter. The abrasive waterjet cutting process was optimised, which helped to improve cutting efficiency and quality. It show prominent economical machining process for composites in manufacturing sector and machining with various parameters such as water pressure, tranverse speed and stand off distance are shown prominent parameters for achieving reducing delamination. Furthermore, understanding and measuring delamination and surface quality are critical for maintaining the cut material's integrity and functionality. Taguchi orthogonal array is the best technique for estimated the combinational levels for AWJM to reduce delamination issue in fiber glass. Design of Experiment (DOE) of selected parameters was designed by mini tab software and number of experiments were prepared with MINITAB software because of evaluating better process parameters, total 8 experiments were performed with different parameters which is 10 holes for each fiber glass parts to find the best combination for a particular application in order to optimizing for reducing delamination. Overall, there have 80 holes that have been drilled on fiber glass and need to measure the area of delamination through microscope.

4.2 Sample delamination of fiber glass

Delamination in fiberglass refers to the separation of layers within a fiberglass structure, resulting in a weakening or failure of the material. This issue can occur due to various factors, such as manufacturing defects, improper construction, exposure to extreme conditions, or impact damage. Here shows a sample of fiber glass that have been drill using different parameters using AWJM

Figure 4.1 One sample fiber glass

Figure 4.2 Separated part of fiber glass

4.3 Parameter used

The parameter used for research to run the experiment is water pressure, standoff distance and traverse speed. Initially, traversal speed was expressed as a percentage, with 80% for high level and 40% for low level. To convert the percentage value to the real value of traverse speed, the value of traverse speed is collected when the sample is cut. When utilising a high-level percentage, the number for traverse speed is 76 mm/min, thus to find the value for 40%, divide 76 by 2. As a result, the traversal speed at the lowest level is 38 mm/min. For the water pressure value, we use a material thickness of 5 mm for low level and 10 mm for high level. during a cut of 10 mm, water pressure shows a value of 300 MPa. to get the value for low level, the value of 300 MPa must be divided by 10 mm and then multiplied by 5 mm equal to 150 MPa and the value of standoff distance for low and high level is 1 mm and 5 mm respectively.

Table 4.1 Parameter Value

Level \ Variables	Tranverse speed (mm/min)	Standoff distance(mm)	Water pressure (MPa)
Low	38	1	150
High	76	5	300

4.3.1 Orthogonal Array Based On The Parameter

Based on the value of parameter, the table of orthogonal array were generated to reduce the number of experiments. Table 2 below show the orthogonal array produced by Taguchi method.

Table 4.2 Number time of the experiment with different parameter

Design of experimental Orthogonal array	Tranverse speed (mm/min)	Standoff distance (mm)	Water pressure (MPa)
1	76	5	300
2	38	1	150
3	38	1	150
4	76	5	300
5	38	1	300
6	76	5	150
7	38	5	150
8	76	1	300

4.4 Experimental result

The drilling for the sample has been chosen to reflect the inherent variety in surface texture that may occur within material. This method is especially useful for choosing the best piece of sample with good surface quality and ensuring that the estimated area of delamination is a more trustworthy and accurate assessment of true surface quality. Averaging several trial measurements improves the statistical robustness of the data, providing a more thorough.

Table 4.3 All sample of experiment based on delamination and average value

No	1	2	3	4	5	6	7	8	9	10	Average
Sample 1	10.01	11.41	6.16	8.14	7.47	6.1	6.12	7.37	5.25	6.42	7.45
Sample 2	7.54	10.45	7.8	10.59	9.64	8.62	8.35	5.14	8.17	7.08	8.35
Sample 3	7.03	8.6	6.1	8.98	7.24	6.89	6.5	6.62	9.80	4.57	7.24
Sample 4	5.99	5.56	5.25	4.82	6.92	8.81	8.5	5.33	6.38	7.3	6.49
Sample 5	7.11	5.99	4.75	4.05	11.14	9.36	4.64	10.7	6.15	12.92	7.69
Sample 6	8.25	5.14	6.00	7.07	4.72	6.05	4.76	5.87	8.06	6.57	6.25
Sample 7	7.13	6.00	9.33	5.87	4.19	9.21	11.57	9.13	9.11	7.12	7.87
Sample 8	5.15	10.85	9.29	7.24	12.25	10.48	9.52	8.85	10.88	9.14	9.35

4.5 Taguchi analysis on area delamination

By analysing the experimental data of all the selected materials, it was discovered that the optimal selection of the four basic parameters, namely, water pressure, abrasive mass flow rate, nozzle traverse speed, and nozzle standoff distance, is critical in controlling process outputs such as surface roughness. Figure 2 show the effect of water pressure, tranverse speed and the standoff distance on delamination.

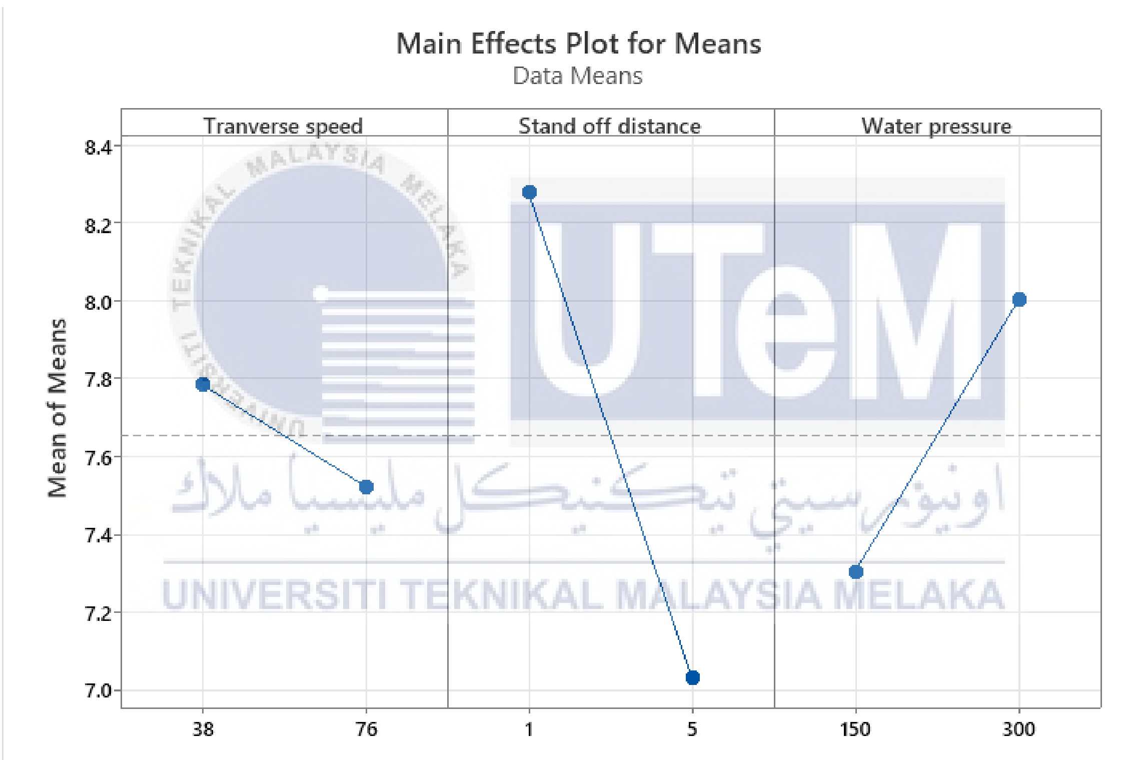


Figure 4.3 Main effects Plot for Means result

4.5.1 Effect of tranverse speed on delamination

Figure 1 depicts the relationship between traverse speed and delamination. Delamination has a negative relationship with traverse speed, as traverse speed increases, surface roughness decreases. Specification high tranverse speeds, on the other hand, can give affect the cutting action, resulting in increase surface quality and d reduce the delamination.

4.5.2 Effect of standoff distance on delamination

Figure 1 demonstrates that this parameter has a significant impact on the surface roughness. Ra changes from 8.3 µm to 7.1 µm The delamination decreases dramatically as the standoff distance increases, with the increase being greater at larger standoff distances. Therefore, a greater standoff distance necessitates that surface irregularities be removed with this reduced velocity and pressure.

4.5.3 Effect of water pressure on delamination

Figure 1 depicts the effect of water pressure as a process parameter. This evolution appears to be linear, as Ra increase with decreasing water pressure. This increase in Ra can be attributed to the decrease forces caused by the decrase pressure. Therefore, greater pressure necessitates greater energy to eliminate surface irregularities, resulting in a superior surface quality. Delamination has a negative relationship with water pressure, as water pressure rises, the thickness increase.

4.5.4 Variable ranking on area delamination

Based on the response table for mean analyses from Taguchi method for delamination, the most parameter that influence the cutting process is traverse speed, next is standoff distance and the last one is water pressure.

Table 4.4 Ranking for means area delamination

Response Table for Means

Level	Tranverse speed	Stand off distance	Water pressure
1	7.785	8.278	7.305
2	7.523	7.030	8.003
Delta	0.262	1.248	0.698
Rank	3	1	2

Stand off distance has the largest Delta value (1.248), suggesting the biggest variance in average area of delamination its levels (38 mm/min and 76 mm/min). The second greatest Delta value (0.698) is for water pressure, indicating that it has a moderate influence on average delamination area. Tranverse speed has the least Delta value (0.262), suggesting the smallest variation in average delamination between its two levels (150 MPa and 300 MPa). This implies that within the studied range, altering the tranverse speed has the least significant effect on delamination issue.

4.6 Result Table for Signal to Noise Ratios

Table 4.5 Table for signal to Noised Ratios

Response Table for Signal to Noise Ratios

Smaller is better

Level	Tranverse speed	Stand off distance	Water pressure
1	-17.83	-18.33	-17.23
2	-17.41	-16.91	-18.01
Delta	0.43	1.42	0.77
Rank	3	1	2

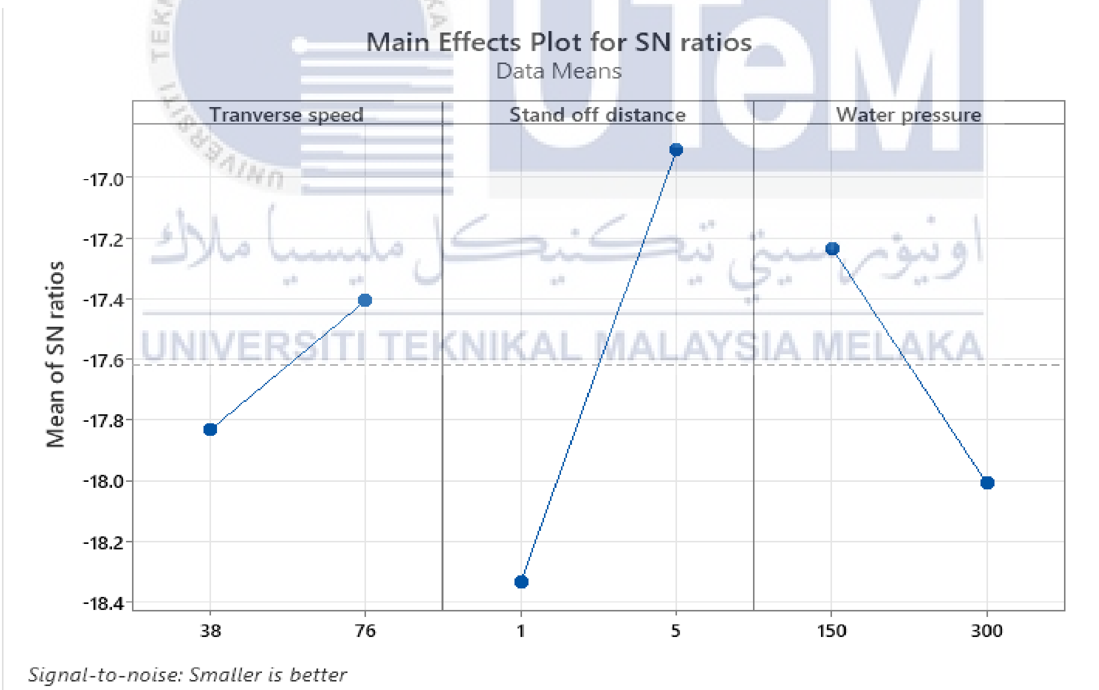


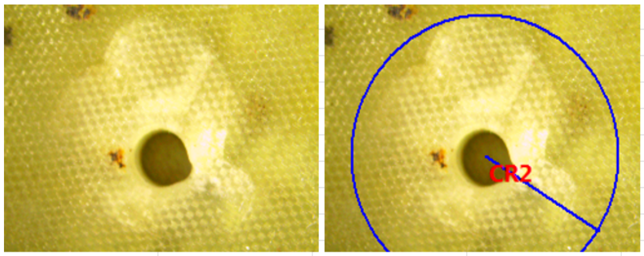
Figure 4.4 Plot Chart for Signal Noise Ratios

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

In this experiment, the minimum surface delamination is the indication of better performance. Therefore, the smaller-is-better for the delamination was selected for obtaining ideal result. The following S/N ratios for the lower-is-better case. From this result we can see that the optimal machining performance for Ra was obtained as 150 Mpa water pressure (Level 1), 1 mm standoff distance (Level 1), and 76 mm/min transverse speed setting that give the minimum area delamination.

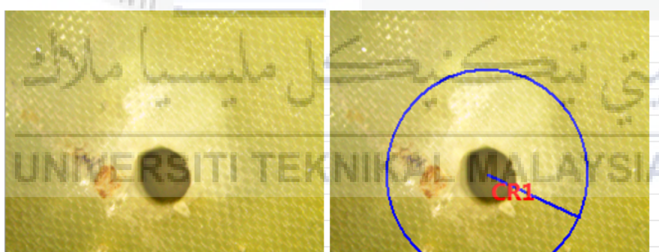
4.7 RESULT AREA OF DELAMINATION IN FIBER GLASS SAMPLE

SAMPLE 1



Manual measurements (Data + Statistics)

Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR2	314.7566	62.8915	10.0095	20.019
Mean		314.7567	62.8916	10.0095	20.0190
Min		314.7567	62.8916	10.0095	20.0190
Max		314.7567	62.8916	10.0095	20.0190
Sum		314.7567	62.8916	10.0095	20.0190
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

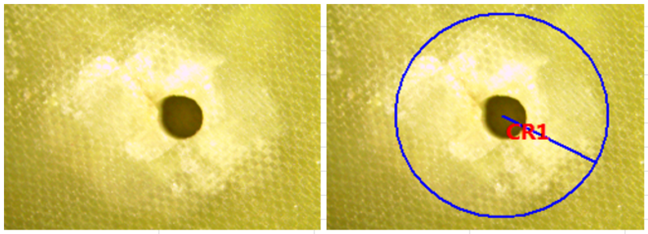


Manual measurements (Data + Statistics)

Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR1	175.6515	46.9819	7.4774	14.9548
Mean		175.6516	46.9819	7.4774	14.9548
Min		175.6516	46.9819	7.4774	14.9548
Max		175.6516	46.9819	7.4774	14.9548
Sum		175.6516	46.9819	7.4774	14.9548
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

Figure 4.5 Sample 1

SAMPLE 2

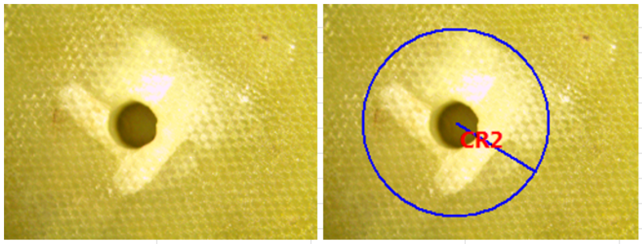


Manual measurements (Data + Statistics)					
Number	**Name**	**Area, mm*mm**	**Length, mm**	**Radius, mm**	**Diameter, mm**
1	CR1	195.3897	49.5513	7.8863	15.7726
Mean		**195.3897**	**49.5514**	**7.8863**	**15.7727**
Min		**195.3897**	**49.5514**	**7.8863**	**15.7727**
Max		**195.3897**	**49.5514**	**7.8863**	**15.7727**
Sum		**195.3897**	**49.5514**	**7.8863**	**15.7727**
Std.Dev.		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Variance		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Skew		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Excess		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Var.Coeff.		**0.0000**	**0.0000**	**0.0000**	**0.0000**

Manual measurements (Data + Statistics)					
Number	**Name**	**Area, mm*mm**	**Length, mm**	**Radius, mm**	**Diameter, mm**
1	CR1	219.1351	52.476	8.3518	16.7036
Mean		**219.1351**	**52.4760**	**8.3518**	**16.7036**
Min		**219.1351**	**52.4760**	**8.3518**	**16.7036**
Max		**219.1351**	**52.4760**	**8.3518**	**16.7036**
Sum		**219.1351**	**52.4760**	**8.3518**	**16.7036**
Std.Dev.		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Variance		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Skew		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Excess		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Var.Coeff.		**0.0000**	**0.0000**	**0.0000**	**0.0000**

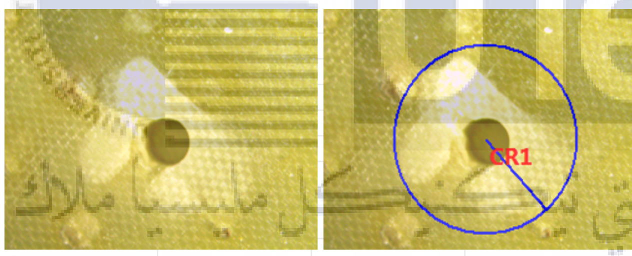
Figure 4.6 Sample 2

SAMPLE 3



Manual measurements (Data + Statistics)

Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR2	155.5025	44.2052	7.0354	14.0709
Mean		155.5026	44.2052	7.0355	14.0710
Min		155.5026	44.2052	7.0355	14.0710
Max		155.5026	44.2052	7.0355	14.0710
Sum		155.5026	44.2052	7.0355	14.0710
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

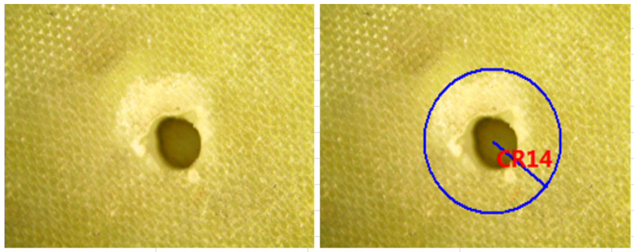


Manual measurements (Data + Statistics)

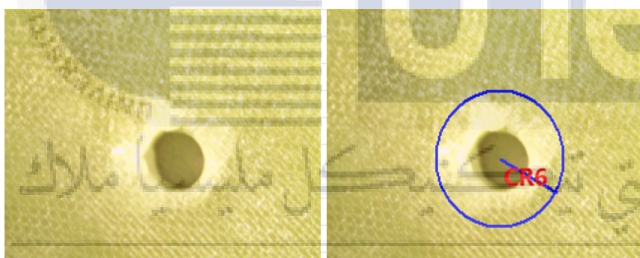
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR1	149.3395	43.3203	6.8946	13.7893
Mean		149.3396	43.3204	6.8947	13.7893
Min		149.3396	43.3204	6.8947	13.7893
Max		149.3396	43.3204	6.8947	13.7893
Sum		149.3396	43.3204	6.8947	13.7893
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

Figure 4.7 Sample 3

SAMPLE 4



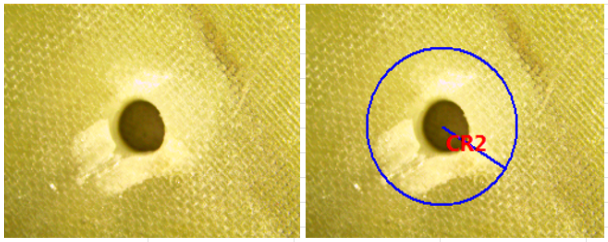
Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR14	86.6864	33.005	5.2529	10.5058
Mean		86.6864	33.0051	5.2529	10.5058
Min		86.6864	33.0051	5.2529	10.5058
Max		86.6864	33.0051	5.2529	10.5058
Sum		86.6864	33.0051	5.2529	10.5058
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000



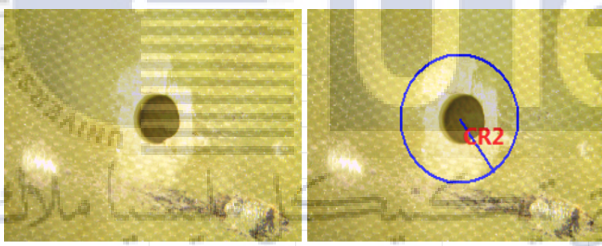
Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR6	73.1729	30.3235	4.8261	9.6522
Mean		73.1730	30.3236	4.8261	9.6523
Min		73.1730	30.3236	4.8261	9.6523
Max		73.1730	30.3236	4.8261	9.6523
Sum		73.1730	30.3236	4.8261	9.6523
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

Figure 4.8 Sample 4

SAMPLE 5



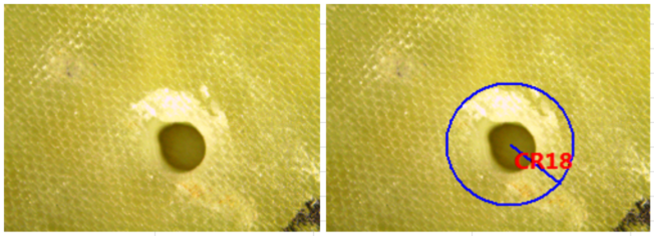
Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR2	112.7243	37.6368	5.99	11.9801
Mean		112.7243	37.6369	5.9901	11.9802
Min		112.7243	37.6369	5.9901	11.9802
Max		112.7243	37.6369	5.9901	11.9802
Sum		112.7243	37.6369	5.9901	11.9802
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000



Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR2	71.0589	29.8823	4.7559	9.5118
Mean		71.0590	29.8823	4.7559	9.5118
Min		71.0590	29.8823	4.7559	9.5118
Max		71.0590	29.8823	4.7559	9.5118
Sum		71.0590	29.8823	4.7559	9.5118
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

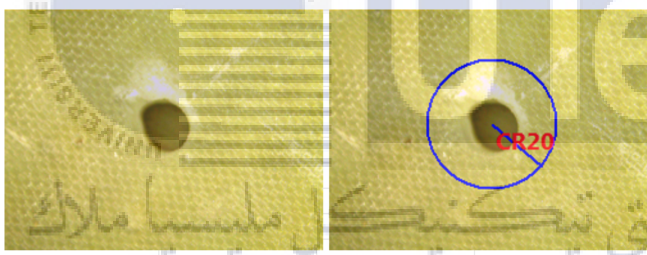
Figure 4.9 Sample 5

SAMPLE 6



Manual measurements (Data + Statistics)

Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR18	70.1133	29.6828	4.7242	9.4483
Mean		70.1134	29.6828	4.7242	9.4483
Min		70.1134	29.6828	4.7242	9.4483
Max		70.1134	29.6828	4.7242	9.4483
Sum		70.1134	29.6828	4.7242	9.4483
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

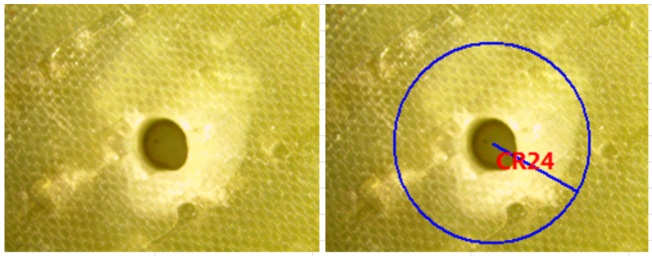


Manual measurements (Data + Statistics)

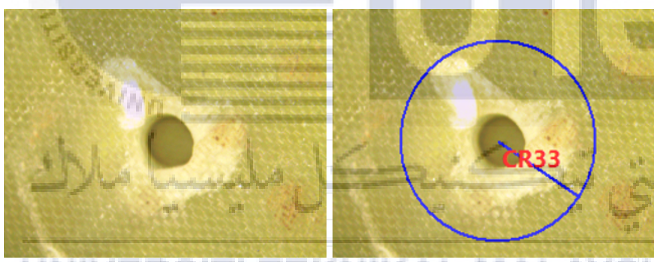
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR20	71.4298	29.9601	4.7683	9.5366
Mean		71.4298	29.9602	4.7683	9.5366
Min		71.4298	29.9602	4.7683	9.5366
Max		71.4298	29.9602	4.7683	9.5366
Sum		71.4298	29.9602	4.7683	9.5366
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

Figure 4.10 Sample 6

SAMPLE 7



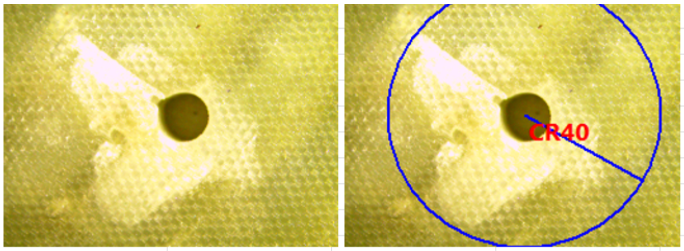
Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR24	159.9277	44.8298	7.1348	14.2697
Mean		159.9278	44.8298	7.1349	14.2698
Min		159.9278	44.8298	7.1349	14.2698
Max		159.9278	44.8298	7.1349	14.2698
Sum		159.9278	44.8298	7.1349	14.2698
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000



Manual measurements (Data + Statistics)					
Number	Name	Area, mm*mm	Length, mm	Radius, mm	Diameter, mm
1	CR33	159.7046	44.7985	7.1299	14.2598
Mean		159.7046	44.7985	7.1299	14.2598
Min		159.7046	44.7985	7.1299	14.2598
Max		159.7046	44.7985	7.1299	14.2598
Sum		159.7046	44.7985	7.1299	14.2598
Std.Dev.		0.0000	0.0000	0.0000	0.0000
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		0.0000	0.0000	0.0000	0.0000

Figure 4.11 Sample 7

SAMPLE 8



Manual measurements (Data + Statistics)					
Number	**Name**	**Area, mm*mm**	**Length, mm**	**Radius, mm**	**Diameter, mm**
1	CR40	285.2408	59.8702	9.5286	19.0572
Mean		**285.2408**	**59.8702**	**9.5286**	**19.0573**
Min		**285.2408**	**59.8702**	**9.5286**	**19.0573**
Max		**285.2408**	**59.8702**	**9.5286**	**19.0573**
Sum		**285.2408**	**59.8702**	**9.5286**	**19.0573**
Std.Dev.		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Variance		0.0000	0.0000	0.0000	0.0000
Skew		0.0000	0.0000	0.0000	0.0000
Excess		0.0000	0.0000	0.0000	0.0000
Var.Coeff.		**0.0000**	**0.0000**	**0.0000**	**0.0000**

Manual measurements (Data + Statistics)					
Number	**Name**	**Area, mm*mm**	**Length, mm**	**Radius, mm**	**Diameter, mm**
1	CR41	372.3134	68.4005	10.8862	21.7725
Mean		**372.3135**	**68.4005**	**10.8863**	**21.7726**
Min		**372.3135**	**68.4005**	**10.8863**	**21.7726**
Max		**372.3135**	**68.4005**	**10.8863**	**21.7726**
Sum		**372.3135**	**68.4005**	**10.8863**	**21.7726**
Std.Dev.		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Variance		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Skew		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Excess		**0.0000**	**0.0000**	**0.0000**	**0.0000**
Var.Coeff.		**0.0000**	**0.0000**	**0.0000**	**0.0000**

Figure 4.12 Sample 8

4.8 Result Discussion

. Interesting results came from our investigation into the factors that significantly affect surface quality and delamination during abrasive waterjet drilling on fiber glass. Extensive study and analysis revealed that transverse speed, standoff distance, and water pressure all had a significant impact on determining the ideal surface quality for optimal delamination. Gaining an understanding of these fundamental elements provides critical insights into the intricacies of the machining process and lays the groundwork for subsequent optimization attempts.

We systematically optimized the revealed essential parameters to decrease delamination using the Taguchi method's orthogonal matrix. The Taguchi method's strong trial design allows us to quickly investigate a large range of parameter combinations. This methodology's optimized settings not only improved surface quality but also reduced delamination in fiber glass, illustrating the Taguchi method's utility in achieving optimal cutting conditions. The Taguchi approach's organized nature allowed for a thorough exploration of the parameter space, resulting in improved machining results.

Using scope analysis, we determined the best possible surface quality and delamination on the cutting surface of fiber glass. This step was essential in demonstrating that the Taguchi approach's optimized parameters resulted in enhanced machining results. This comprehensive evaluation results in a more nuanced understanding of the capabilities and limitations of the abrasive waterjet cutting technique on fiber glass.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

As we approach the finish line of our investigation into the complicated topic of single-pass abrasive waterjet drilling on fiber glass, this final segment provides a chance to synthesised a variety of insights and discoveries that have emerged throughout the course of study. The emphasis on material cutting and optimization to reduce delamination has resulted in a thorough examination of the relationship between process parameters and the final properties of machined fiber glass surfaces. This voyage has been defined by an in-depth examination of the intricacies involved in achieving cutting accuracy and efficiency.

Fiber glass material is experimented for desired machining quality. The effects of key parameters such as traverse speed, standoff distance and water pressure which are controlling the surface quality and reducing delamination are studied. In this conclusion, we review the main goals that directed our study and provide an update on our understanding of surface evolution and parameter optimization. Using the sophisticated design of experiments tool of the Taguchi approach, we successfully enhanced the discovered significant parameters. The orthogonal matrix made it possible to conduct a methodical research to find the ideal parameter, leading to the identification of the ideal configurations for enhanced surface quality and decreased delamination. Our results show that the Taguchi technique can be effectively used to achieve robust optimization, which can lead to improved accuracy and efficiency in abrasive waterjet operations.

5.2 CONCLUSION

In this conclusion, This case study has already been achieved in various objectives to give accurate results in many ways. We have identify and analyze the parameters influencing delamination, surface quality in GFRP and highlight the parameters that emerged as significant based on the experimental analysis. Beside that, this case study explained effects on the final surface characteristics and quality of GFRP materials and also acknowledge any limitations of the study, such as constraints in the experimental setup or potential unexplored variables. Futhermore, its explain how important these tuned parameters are to preserving high-quality results and improving GFRP cutting efficiency.

State again that the main goal of the study is to thoroughly investigate the effects of parameters on delamination and surface quality in GFRP by using the Taguchi Method. Its Describe the selection of these components' levels and the construction of the Taguchi Orthogonal Arrays, which allow for the efficient exploration of parameter interactions and also Emphasize the practical applications of these findings in GFRP manufacturing process optimization to lower delamination and enhance surface quality.

5.3 RECOMMENDATION

The comprehensive examination of surface quality and adjusting parameters to reduce delamination during abrasive waterjet cutting on fiber glass yields several recommendations to guide future research and practical applications. A complete approach is required to optimize fiberglass and minimize delamination. Begin by focusing on material aspects, such as selecting resin systems that are highly compatible with fibers and performing surface treatments to improve bonding. Applying the Taguchi Method provides a methodical way to improve parameters and successfully lower delamination in composite materials. It is possible to easily ascertain the interactions between these parameters and their corresponding optimal levels by employing Taguchi's orthogonal arrays in an organized experimental design. Applying the Taguchi analysis-derived optimum parameter values can greatly lower the chance of delamination.

Finally, the recommendations for the investigation and optimization of abrasive waterjet cutting operations on fiber glass emphasize the detailed nature of this sophisticated machining approach. In essence, these ideas would speed up the research and development of abrasive waterjet drilling on fiber glass, directing future efforts toward accuracy, flexibility, sustainability, and the continual advancement of machining processes. The synergistic application of these theories has the potential to alter not just our understanding of abrasive waterjet cutting, but also the trajectory of machining technologies in the broader field of materials processing.

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APPENDIX

Gantt chart