STUDY OF WIRE ARC ADDITIVE MANUFACTURING AND POTENTIAL IN PART REPAIR

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HAZ	Heat Affected Zone
WAAM	Wire Arc Additive Manufacturing
MIG	Metal Inert Gas
CNC	Computerized Numerical Control
MAG	Metal Active Gas
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
AM	Additive Manufacturing
3D	Three-Dimensional
CO_2	Carbon Dioxide
SEM	Scanning Electron Microscope
EDS	Energy Dispersive X-Ray Spectroscopy
DBTT	Ductile-To-Brittle Transition Temperature
OM	Optical Microscope
WFS	Wire Feed Speed
LENS	Laser Enabled Net Shaping
SLS	Selective Laser Sintering
DED	Direct Energy Deposition
SLM	Selective Laser Melting
BJP	Binder Jet Printing
FEM	Finite Element Method
HF-WAAM	Hot Forging Wire Arc Additive Manufacturing

ABSTRAK

Pembuatan tambahan biasanya digunakan dalam banyak bidang seperti automotif, marine, pembinaan dan banyak lagi. Dalam penyelidikan ini, jenis pembuatan tambahan yang digunakan adalah salah satu pembuatan tambahan arka wayar, iaitu pengelasan MIG. Semasa proses pemendapan, banyak parameter akan mempengaruhi kualiti bahan yang didepositkan. Oleh itu untuk mengenal pasti parameter optimum, penyelidikan ini telah dilakukan dan tiga parameter yang telah dimanipulasi adalah voltan, kelajuan pengisi dan kadar suapan. Untuk setiap parameter, akan ada tiga tahap. Sebanyak 27 kombinasi eksperimen telah dihasilkan. Taguchi telah digunakan untuk mempermudah 27 kombinasi hingga 9 kombinasi setara untuk mempermudah kombinasi parameter. Berdasarkan parameter ini, beberapa ujian telah dilakukan untuk menilai bahan yang didepositkan ke aplikasi yang dimaksudkan, iaitu pembaikan produk. Penilaian dibuat berdasarkan ujian kekuatan, ujian kekerasan, dan pemerhatian struktur mikro. Analisis struktur mikro digunakan untuk menganalisis ukuran butiran dan keretakan dalaman atau jurang antara struktur butiran. Berdasarkan kaedah Taguchi, parameter optimum adalah pada kombinasi 2 voltan, 1 mm / saat pengisi kelajuan dan 100 mm / saat kadar suapan dan 6 voltan, 7mm / saat pengisi kelajuan dan 100 mm / min kadar suapan untuk dikimpal-penempaan dan dikimpal-mesin masing-masing

ABSTRACT

Additive manufacturing has commonly been used in many fields such as automotive, marine, construction and more. In this research, the type of additive manufacturing been used is by one of the wire arc additive manufacturing, which is MIG welding. During the deposition process, many parameters will influence the quality of the deposited material. Hence to identify the optimal parameters, this research has been conducted and three parameters that have been manipulated are the voltage, filler speed and feed rate. For each parameter, there will be three levels. A total of 27 experimental combinations have been produced. Taguchi has been used to simplify the 27 combinations to 9 equivalent combinations to simplify the parameters combination. Based on this parameter, several tests have been conducted to assess the deposited material to the intended application i.e., product repair. The assessment is made based on toughness test, hardness test, and microstructure observation. The microstructure analysis was used to analyse the grain size and the internal cracks or gap between the grain structures. Based on Taguchi method, the optimal parameters are at combination of 2 voltage, 1 mm/sec filler speed and 100 mm/sec feed rate and 6 voltage, 7mm/sec filler speed and 100 mm/min feed rate for weld-forged and weld-machined respectively.

CHAPTER 1 INTRODUCTION

1.1 Overview

Additive manufacturing (AM) or additive layer manufacturing which is also known as 3D printing. The application metal arc additive manufacturing is widely used in many applications such as aerospace, marine, automotive and more.

Most common type of material used in the additive manufacturing are polymer, ceramic and metal. Additive manufacturing (AM) technologies are a new way of manufacturing near-net shape metallic parts with complex geometries at low cost [1]. There are many types of metal arc additive manufacturing in the industries. These are the most commonly used powder-based metal additive manufacturing include selective laser sintering (SLS), selective laser melting (SLM), electron beam melting (EBM), direct energy deposition (DED) and laser enabled net shaping (LENS) [3].

Wire arc additive manufacturing is one of the metal additive manufacturing categorised under DED technique. It also known as 3D welding as the main process involve is by welding, but to deposit a material in 3D profile. However, the profile is produced at near net shape, which requires additional process like machining to obtain the final part with good dimensional accuracy. Even though very flexible, machining takes longer time to finish, and another alternative is by forging. Theoretically, forging offer quick solution and may improve part strength.

Therefore, the aims of the study were to identify the wire arc additive manufacturing and potential in part repair. The study involves many types of testing on the welded part. Type of test required to be done are impact, hardness test and microstructure study on the surface of the welding. This test should be done for three different mild steel material such as normal deposition, welding-milling and welding-forging.

1.2 Problem Statement

At present, broken parts is typically being dumped in a landfill., this practice is not sustainable as new part requires additional time, machines and materials to be consumed before it can be used. Metal additive manufacturing via welding or called as wire arc additive manufacturing is a fast and flexible method, which allows to build a complex 3D profile at intended location However, properties like hardness and impact toughness that are required for a certain part to function are affected by the heat produced during welding. Since present approach by machining to obtain the final dimension may not change the properties. Therefore, an alternative such as forging to replace machining needs further exploration to study the effect to improve the properties.

1.3 Objectives

This research objectives are:

- To assess the performance of MIG based wire arc additive manufacturing (WAAM) via impact toughness test, hardness test and microstructure observation.
- To evaluate the feasibility for WAAM to part repair based on the research outcomes.

1.4 Scope of Project

The study fully involves experimental work, comprises of specimen preparation using MIG welding. The specimens are then prepare either using machining (milling machine) or also cold forging using 100 tonne mechanical press machine. Lab test were be carried out on the specimen for impact test using Rockwell Hardness Test using Izod Test, hardness test and microstructure observation using SEM Machine.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview

Many researchers around the world have analyse additive manufacturing-based welding and being continuously investigated to enhance the process as a sustainable and durable production method. The problem related to additive manufacturing process is the formation of uneven heating on the surface due to different speed of welding. Many researchers conducted various methodologies for the additive manufacturing with using different types welding process.

2.2 Types of Metal Additive Manufacturing

Generally, there are many types of additive manufacturing (AM), the material based can be metallic and also non-metallic for the additive manufacturing process. In this research the material that will be used is a metallic substance, there are many types of metal additive manufacturing process available in these current industries. The types of metal additive manufacturing process that will be focus here are Selective Laser Sintering (SLM), Laser engineered net shaping (LENS) and Binder Jet Printing (BJP). MIG, TIG and Arc Welding is also a type of metal additive manufacturing process.

SLM is a solid metal AM process. When compared to polymer manufacturing techniques, a more complex controlling setup is usually required. A bed of material powder is fed into the manufacturing chamber in this procedure. A roller, also known as a coater, is used to feed metal powder materials into the production area. Similar to earlier AM procedures, a computer design file will provide the geometry of each layer, and an integrated laser head will receive the G-codes and move along the specified paths. The components that came into touch with the laser will melt after each laser pass, but the remaining powder particles will remain unaffected. These particles can be reused until the heat effects of the laser beam no longer influence them. These procedures are generally performed in a vacuum or using inert gases at atmospheric pressure. After layer-by-layer production, a final component with a density of over 99 percent with outstanding mechanical and chemical characteristics may be produced. In SLM melt pools, the most common response is to fuse the particles together and mechanically and chemically bind them.

LENS (laser engineered net shaping) is a type of additive manufacturing (AM) technique used mostly for metallic materials. This method is similar to SLM with a few tweaks. While a computer-controlled head moves above the surface, powder materials are fed into nozzles that are coaxial with the laser head. The feedstock is pushed to the laser's tip by air or inert gases, and the materials are melted by a focused laser point with adjustable energy densities once it reaches the deposition surface. Similar to SLM, LENS fabricates components with a density of over 99 percent, and they work consistently in mechanical and chemical environments. This technique may create complex geometries, and it, like other AM techniques, necessitates the use of supports and overhangs in some designs to prevent component deformation during the process. The flowing feedstock, on the other hand, can assist in cooling the deposited components as well as improving the density and stability of the structure. Despite the fact that this is a powder-based technique, rods, wires, and larger particles have been used. Conel, NiTi, stainless steel, and several other soft metals, such as aluminium and copper, are among the materials that LENS can manufacture. As is well known, AL and Cu have high reflectivity, which causes problems during laser processing, but our technique reduces or eliminates this negative impact. The feed rate of materials, reflectivity of materials, melting point of feedstock, laser power, and laser scanning speed are all factors that influence process and component quality. There is a lot of freedom in manufacturing new materials by changing these characteristics. LENS' primary disadvantage over SLM is its poorer geometric precision, which necessitates post-processing such as high-speed machining. It has also been stated that a finishing heat treatment is required in some complicated sections [4].

Binder jet printing (BJP) is a common type of additive manufacturing (AM) method that is mostly utilised for metals. There have, however, been several accounts of polymeric and ceramic materials being used. This technique, like SLM and LENS, uses a computer-controlled head to inject sticky materials ink. A roller or coater, similar to the one used in SLM, will transport a consistent thickness of materials into the manufacturing chamber on the other hand. In the following phase, adhesives will be applied to the distributed material in the geometry of the specified slice of the 3D CAD file. The difference between this technique and the previous two is that it employs an adhesive injector head to bind the materials instead of a laser head to melt the powder. The component is done but not finished until all of the layers are placed and bonded using adhesives. The final stage in the fabrication of BJP components is to cure them in a furnace at a particular temperature. The temperature at which the adhesive and base components cure vary. However, a new BJP equipment in the lab scale has been suggested, which applies heat and cures the adhesives after each layer has been deposited. Furthermore, in order to achieve the particular characteristics of ceramic materials, high temperature firing is required in some cases. The particle size of the powder feedstock has a direct impact on the density of the components produced in this process. The higher the density, the smaller the particle size. It has been claimed that during BJP, densities of above 99 percent are attained [4].

2.2.1 Advantage of Metal Additive Manufacturing

Polymers, ceramics, and metals are among the materials that may be used in AM technology. Researchers and industry are becoming more interested in metallic materials among these materials. In addition to the benefits listed above, metal additive manufacturing may have certain environmental benefits, such as reduced waste, improved quality, lower pollutant emissions, and the ability to make parts on demand. [5].

According to Dehghanghadikolaei [4] journal article. high flexibility and process speed are two advantages of this technology. The method, on the other hand, is versatile in terms of material selection and can produce high-accuracy final components once the component is produced. SLM is a technique that can work with a variety of materials, including engineering plastics, polymers, ceramics, and metal oxides, and it uses a high-powered laser to melt powders. SLM is also the quickest of all AM techniques, and it can manufacture many components in a single round. The most notable advantage of LENS method is that it may deposit materials in areas that require filling. For example, if a hole, fracture, or other physical issue occurs in expensive forming dies and moulds, it may be quickly filled with a chosen material utilising LENS [4]. However, when it comes to the surface quality of BJP-fabricated components, they generally require polishing and machining to reduce surface roughness and flatness variations. The use of hot isostatic pressing on BJP-fabricated components has been proposed as a way to enhance surface quality and density [4].

Welding process in metal have also many advantages such as a good weld will be stronger than the parent or base metal. Hence, the product that been made or repaired by welding process will be better, in terms of mechanical strength. This process is applicable to all metals and alloys and difficult shapes can be produce or repaired by this welding process.

Metal additive manufacturing allows the construction sector to build complicated structural forms with less weight and a shorter lead time. Metal additive manufacturing is being utilised to produce bespoke components on demand. Furthermore, metal AM is advantageous in situations when building components are lost or damaged, and on-site manufacture utilising AM can be advantageous because waiting for replacements can cause construction delays and expenses [5].

2.3 Wire Arc Additive Manufacturing (WAAM)

There are many possible ways to develop additive manufacturing through welding process. The welding technique commonly being used now are semi-automatic and automatic welding process such as gas wire arc welding, submerged arc welding, flux-cored arc welding, electro slag welding and gas tungsten arc welding. However. in this project is only based on gas wire arc welding which is known as MIG. Today, the science continues to advance robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties [1]. Padin [1], They study the limitation comes when the usage of MAG welding. This welding will use active gas instead of inert gas, there might be some chemical reaction on the hot deposited metal. Hence, the testing might not be very accurate.

The type of welding used is 3D MIG welding where the material will get deposited layer-by-layer. Additive manufacturing (AM) techniques adopt layer-by-layer accumulation with the aid of CAD/CAM model to develop three dimensional (3D) products [2]. The reason for doing layer-by-layer welding is because to get a thicker metal deposition surface so it will be easier to conduct the testing on the deposited metal. During the superposition of several layers using the go and back strategy, the heat accumulation in the previous deposits led to a progressive change in the geometry of the deposits [3]. The advantage of this research by Ortega [3] is about the analysis of the direction of deposition. It is very important to analysis the direction because different direction can cause different output with some defect. The best way to make the deposition of welded metal is by go and back method where the thickness is evenly distributed.

Despite the fact that the mechanical qualities of WAAM parts are frequently comparable to those of traditional machined components, a full understanding of the relation between process parameters and mechanical properties of WAAM generated parts is still necessary [2]. The macromorphology, microstructure, and mechanical characteristics of components are all affected by heat input during the WAAM process. While the wire feeding rate stays constant, the heat input varies when different arc modes are used. Based on Chaoqun [2], research that has been discussed here, the analysis is done by using the same feed rate. However, in this research the aspect that been changed is the parameters on the deposited material. One of the variable parameters that will be changed here is the feed rate. Another aspect that influences the mechanical characteristics of WAAM components is the metal transfer mode, which results in a variable rate of liquid droplet transfer despite the same wire feeding rate [2].

Welding process is also one of the most commonly used types of metal additive manufacturing process. There are many ways to conduct welding process, such as MIG (Metal, Inert Gas) or GMAW (Gas, Metal Arc Welding), TIG (Tungsten Inert Gas) and Arc welding.

A thin wire serves as the electrode in MIG welding, and it is fed from a spool attached to a gun through a flexible tube to the nozzle on the welding gun or torch. When the welding gun's trigger is pressed, the wire is fed constantly. Since tungsten has a high melting point, it is used as an electrode in TIG welding. When a tig weld electrode heats up but does not melt, we call it a non-consumable electrode. Non-consumable electrodes do not indicate that they will not endure indefinitely, but they do mean that they will not melt and become part of the weld. Hand-operated metal arc welding, flux shielded arc welding, and stick welding are all terms used to describe arc welding. The arc is struck between the metal rod or electrode (flux coated) and the workpiece, melting the surface of both the rod and the workpiece to form a weld pool in this sort of welding process.

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2.4 Forging

According to Duarte [4], research paper, the type of forging machined been used is hot forging wire and arc additive manufacturing (HF-WAAM) in this the deposited material gets forged imediately after the deposition process is done [6]. During the WAAM process the temperature of the specimen will be very high. The reason of using this type of forging it to make viscoplastic deformation to occur. Hence, recrystallization of the previous solidified structure occurs that refine the microstructure of the deposited material. The cold forging process in producing parts for the automotive and aerospace domain has been greatly influenced over the past two decades by advancement in the technology with modern finite element method (FEM) simulation tools [7]. The welded specimen is deformed plastically into the required shape and restricted by the dies with the application of force in the cold forging process. Using the cold forging process has a number of advantages, including improved dimension accuracy and surface quality.

2.5 Hardness

The hardness test determines the plastic deformation of the deposited metal which created by welding process. Correlation between hardness value and tensile strength can be done because both of these factors are indicators of metals resistance against the plastic deformation. This approximation can be used to define tensile strength based on hardness values [8]. Based on the Martina [9], research the hardness tests aim at verifying if there is decrease on the samples in particular when higher WFS and thus deposition rates are achieved. If this happens, as 17-4 pH is a precipitation-hardening stainless steel post heat treatment and different hardening processes may be required to increase the hardness of the material, but during this process the material has a tendency to lose its toughness. The strength and hardness of the material diminishes as the grain size rises with the increase in WFS, and this tendency may be deduced from the hardness test results, which show that as the WFS increases, the hardness begins to progressively decline [9].

2.6 Impact

Impact test will be used for determining the toughness of the metallic materials. There are two type of impact tester machine, Charpy and Izod are the most commonly used impact tester. Impact testing is largely employed for characterizing a material's ductile-to-brittle transition temperature DBTT. Usually V-notch will be applied to the testing specimen. According to Rossoll, 2002 research the function of the V-notch is provide a pre-crack to the specimen. This is to encusre that the force applied during the impact is focused at a specific location. This impact determines the amount of energy absorbed by a material during fracture and determines the toughness of the material [10]. According to Sultana [11] research, the average impact value for a mild steel is 45.33 J with a dimension of notch with 5mm [11].

2.7 Microstructure in Wire Arc Additive Manufacturing

Based on the research done by Zharif, [12], in microstructure study of the grain on the welded surface is depends on several factor. The study was tested based on the voltage, current and also the speed of welding. With increasing the input energy, grain size in the heat affected zone of carbon steel and stainless steel 304 showed a decrease in size of crystallite and the size of the grain boundaries increase. Increment [12]. The increment of the size of the grain boundaries will cause changes on the strength of the welding. From this research it shows that, when the size of grain boundaries increases the strength of the welding increases. The phenomenon of grain growth does not occur as the grain size decrease and lead to recrystallization [12]. Acording to Kalpakjian [13], when a molten metal mass begins to solidify, crystals begin to form at random and unconnected orientations at various sites inside the liquid mass. After that, each of these crystals forms a crystalline structure, or grain. Each grain is made up of either a single crystal (for pure metals) or a polycrystalline aggregate for polycrystalline aggregates (for alloys) [13].

2.7.1 Characteristic of the Grain in Wire Arc Additive Manufacturing

Based on Padin [1], a weld's microstructure is divided into three areas. a fusion zone in which the material will be melted, a heat affected zone in which the material has not melted but its microstructure has been changed, and a base metal.

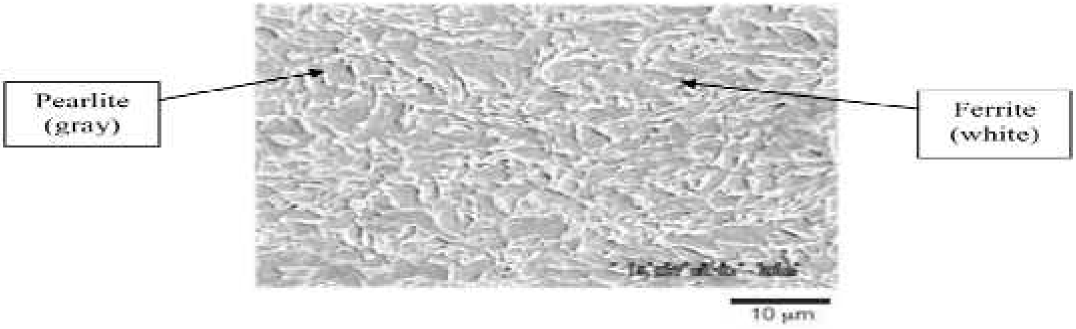

Figure 2. 1 Microstructure low carbon steel [14]

Low carbon steel is a fine-grained steel with a ferrite phase structure. Because of the soft matric ferrite with excellent ductility, the mechanical characteristics of low carbon steel are excellent. This is a factor that causes low carbon steel to have superior mechanical qualities, as seen by its high yield and tensile strength, as well as its high absorption force.[14]

The mechanical characteristics of metals are greatly influenced by grain size. Large grain size, for example, is related with poor strength, hardness, and ductility at room temperature. Zinc granules on the surface of galvanized sheet steels, for example, can be so big that they are visible with the naked eye. Large grains also result in a rough surface look after the material has been plastically deformed, especially when sheet metals are stretched. [13].

2.7.2 Characteristic of the Grain in Plastic Deformation Part

The grain boundaries and mass continuity are preserved during plastic deformation. Because dislocations are entangled with grain boundaries and with one other, the deformed metal has more strength. The degree of deformation (strain) to which the metal is subjected determines the growth in strength, the higher the distortion, the stronger the metal becomes. The strength of metals with smaller grains is stronger because they have a greater grain-boundary surface area per unit volume of metal, resulting in greater dislocation entanglement [13].

2.8 Limitation of Current Technology of Metal AM

Based on the all the research that has been discussed here, all the researchers have been using the same feed rate and hot forging in their research. However, in this research the aspect that been focus are the parameters and the forging process on the deposited material. The parameters that the researchers above the feed rate that been usen are the same but in this research, one of the variable parameters that been used is the feed rate. The mechanical characteristics of stainless-steel structures produced by WAAM are now being studied primarily for hardness and tensile strength. Although the mechanical characteristics of WAAM parts can be equivalent to those of traditional machined components in many situations, a thorough understanding of the relationship between process parameter and mechanical properties of WAAM produced parts is still required. According to Guessasma [15], analysis porosity should not be considered systematically as a negative issue in AM since it can be a positive driving factor for permeability. Another type of defects is the presence of support material trapped between internal surfaces. The material is needed to withstand the fragile printed structure during the printing process. While this material is studied to provide limited adhesion to the deposited materials, its residual amount contributes to increasing the weight of the structure and modifies the load bearing distributions. These two drawbacks alter the expected performance of the optimal design . This residual might cause some defect in the part and result in distortion and induces internal stresses. Welded joints are more breakable and hence their fatigue strength is less than the parent metal with the same type of material. Porosity, cracks, and lack of fusion are the typical defects found in stainless steel parts produced by WAAM. Process parameters, such as deposition paths and heat input, cause defects during deposition[16]. The electric current works directly on the feedstock, GMAW has greater difficulties with excessive heating, spattering, and porosity than GTAW and PAW-based WAAM. [17]. Some porosities and lack of fusion appears on the cross section of GMAW duplex stainless-steel samples, especially between the beads [14]. Common defects and their formation reasons in WAAM metallic parts are listed in Figure 2.2 below.

WAAM Techniques	Material	Defects	Reasons	
WAAM	304 stainless steel	Porosity	Insufficient energy for complete melting the layers; gas generation.	
WAAM	Metals (Steel, Al, Ti, etc.)	Porosity	Raw material-induced	Contaminants of wire and substrate
			Process-induced	Insufficient fusion or spatter ejection
		Delamination	Incomplete melting or insufficient re-melting of the underlying solid between layers	
GTAW	Inconel 625	Solidification cracking	Existence of liquid film at terminal solidification	
GTAW	Intermetallic Al/Cu	Grain boundary crack	Intermetallic phase-equilibrium is freely broken	

Figure 2. 2 Defects in WAAM metallic parts

The flaws can also be caused by defects in the raw materials, such as contamination of the substrate and filler metal. Dirt, moisture, and oil on the substrate and filler metal's surfaces can readily be absorbed into the molten pool, resulting in porosity following solidification [18]. In order to obtain acceptable mechanical characteristics, flaws such as lack of fusion, fractures, and porosity must be kept to a minimum. During the stainless steel WAAM process, precise control of heat input and thermal history, appropriate shielding gas and tight gas seals, high quality feedstock, and clean substrate surfaces all assist to prevent faults [2].

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CHAPTER 3 RESEARCH METHODOLOGY

3.1 Workflow of the Research

There are two processes of work as shown in Figure 3.1. First is to prepare the specimen by MIG welding process then proceed with surface finishing and testing. Next is to prepare 5 parent mild steel by cutting process the proceed with surface finishing and testing.

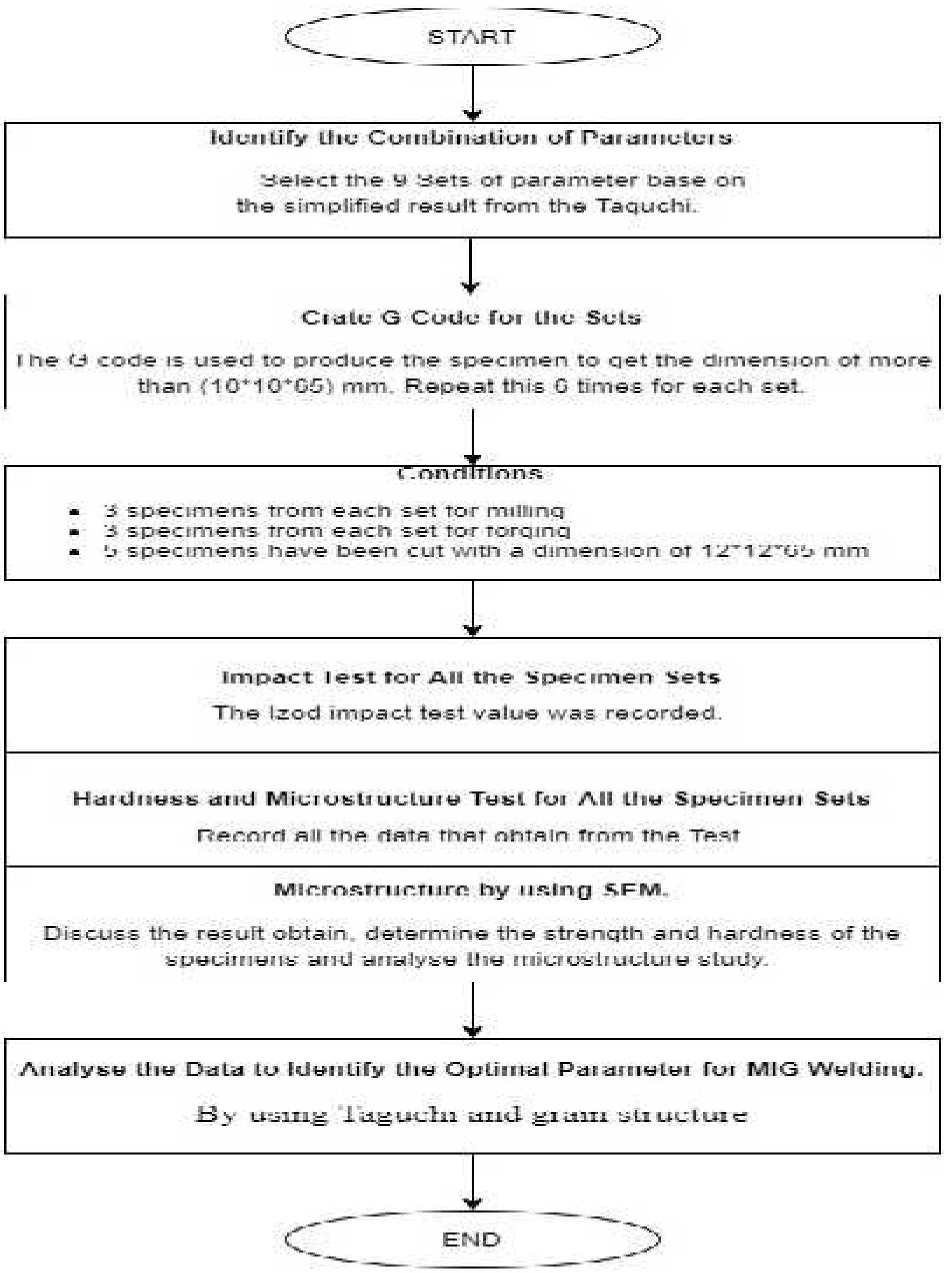

Figure 3. 1 Workflow for the analysis.

3.2 Simplify the Parameters for MIG Welding.

Based on the table above there are three different levels with three different parameters which is known as voltage, filler speed and feed rate been used for this research as list in Table 3.1. A total of 27 combinations of the levels and parameters can be obtain. The function of Taguchi is to reduce the variance in a process through robust design experiments. To simplify the experiment the 27 types of combination can be reduce to equivalent 9 sets by using Taguchi as summarized in Table 3.2.

Table 3. 1 Classification of the parameters.

		L1	L2	L3
A	**Voltage (V)**	2	4	6
B	**Filler Speed (mm/sec)**	1	3.5	7
C	**Feed Rate (mm/min)**	50	100	150

Table 3. 2 Initial sets combination for the analysis.

Set	A, B, C
1	2,1,50
2	2,3.5,100
3	2,7,150
4	4,1,100
5	4,3.5,150
6	4,7,50
7	6,1,150
8	6,3.5,100
9	6,7,50

This are the 9 parameters that initially has been set during the MIG welding process. The voltage (A) and the filler speed (B) were set in the MIG welding machine, where the feed rate (C) has been set by the G code coding, to control the MIG notch.

3.3 Specimen Preparation Using Wire Arc Welding Machine.

Before the material deposition process start several setups should be followed according to:

1. Pressure in the CO_2 tank should be at least more than 2 bar.
2. Check the cable connection.
3. Check the filler tension.

4. Keep a distance about 1cm gap between the torch and the base.
5. Test the direction of the CNC code, to make sure the direction of the MIG torch is in the right direction and the feed rate was fixed at 50.
6. For set 1 the parameter that has been fixed in the MIG is by 2 voltage and the filler rate was fixed at 1.
7. After all the set up was done the welding process started, it is repeated for 6 times for each set. For all the nine sets followed the same method to produce the specimen.

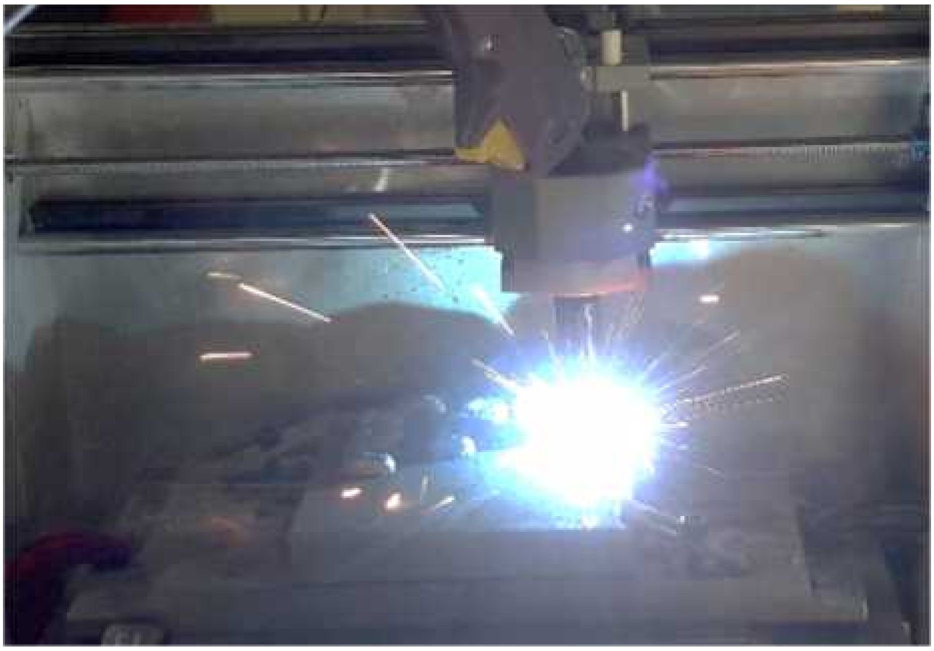

Figure 3. 2 MIG welding machine been controlled by CNC

Figure 3.2 show the torch of the MIG welding machine which depositing the molten mild steel metal on the aluminium plate.

Figure 3. 3 Image of the deposited mild steel metal by MIG

Figure 3.3 shown 6 deposited mild steel for set 9. The same process is done for all the other eight sets and each set required 6 specimens to be produce. CNC G code has been used to control the direction of the MIG torch. The G code is shown in Appendix A. The images of the set 1 to set 8 are shown in the Appendix B.

3.4 Forging

After all the specimens are completed by MIG welding process, three specimens from each set need to be forged. The type of forging machine used is 100 ton forging machine. The specimen has been forged several times to get exact 10mm thickness. The forged specimens then need to be machined to get a 10 mm width. Figure 3.4 shows the forged specimen after the milling process is done.

Figure 3. 4 Forged specimen.

3.5 Milling

The other three specimens from each set that has not been forged is used for fully machined where the thickness and the width has to be machined until 10 mm. the material has been removed layer by layer each removal layer has a thickness of less than 1mm. This is to ensure that the surface of the specimen to be in a good condition. Figure 3.5 shows the machined specimen.

Figure 3. 5 Machined Specimen

3.6 Impact Test

After completing the forging and milling process for all the 9 sets with six specimens in each set. Three from the forged, and the other three from machined with the dimension of (10*10*65) mm. All the completed specimens should be done impact test. Before conducting the impact test approximately about 2mm notch with 45 degrees should be produce. In this research Izod impact test has been used. Figure 3.6 shows the notch on the specimen.

Figure 3. 6 Image of the parent mild steel after notching.

After the notch is done on the specimen, the scale in the Izod impact test should be set at 150 Joules. After doing all the set up the specimen is ready for the impact and the reading for the specimen are recorded. Some of the specimens were cracked, those specimens should be redo, the parameter of the specimens also should be changed to get a proper testing result.

3.7 Reselecting the Parameters for MIG Welding Due to Failure

This reselecting is done after the impact test. This is because, there will be some defect in the specimen, the defects are only known during the impact test. The Figure 3.7 shows some of the defected specimen after the impact test.

Figure 3. 7 Rejected specimen after the impact test due to internal crack

Based on the impact test most of the specimens from set 3, 4,7 and 8 should be redo. This is because the specimen got cracked after the impact test. This shows the parameters of the specimen are not suitable for layer welding. This sets should be repeat with different combination of other parameters. The selected parameters are shown in the Table 3.3 below, this parameter will be replaced for the pervious sets, after the parameter selection the steps 3.3 to 3.6 have been repeated. The finalised sets of parameters are shown in Table 3.4.

Table 3. 3 Reset parameter set.

Set	A, B, C
3	2,7,50
4	2,3.5,50
7	4,3.5,100
8	6,7,150

Table 3. 4 Finalized sets combination for the analysis

Set	A, B, C
1	2,1,50
2	2,3.5,100
3	2,7,50
4	2,3.5,50
5	4,3.5,150
6	4,7,50
7	4,3.5,100
8	6,7,150
9	6,7,50

3.8 Preparation of the Reference Sample

To compare the characteristic of the material from the deposited material from the MIG welding a reference sample has been used. The preparation of the reference sample is explained in detail below:

1. A long 12*12 mm bar cut in to 5, with a length of 65 mm, a metal cutter machine has been used to cut the mild steel bar.
2. Once the cutting process is done the specimen should be done milling. This is to ensure the dimension of the specimen is same with the previous sample where the dimension is 10*10*65 mm. The steps in 3.6 should be followed to get the impact toughness of the parent mild steel metal.
3. All the impact test reading from the MIG welded specimen is compared with the parent mild steel.

3.9 Hardness Test

After completing the impact test for all the 9 sets from MIG welded specimens and the parent mild steel metal, hardness test should be done for all the specimens and also for the parent mild steel metal. All the specimens need to be cut into smaller piece approximately 10*10*20 mm.

This is because, the top and bottom surface is in irregular shape it is impossible to take the hardness reading on an irregular surface. The all the specimens were cut by using the specimen cutting tool Figure 3.8 shows the specimen cutting tool which uses water as a colling agent during the specimen cutting process.

Figure 3. 8 Specimen cutting machine

Ones the specimens were cut into a proper flat surface (transverse surface) the specimen is ready for the hardness test. After the specimen preparation the scale in the Rockwell Hardness tester machine should be set. The scale that has been used in this research is HRC where the force applied on the specimen is 150kg with diamond cone to make indentation on the specimen Figure 3.9 shows the Rockwell machine and the scale set up on the machine.

Figure 3. 9 Rockwell machine use in HRC

Hardness test has been done on two surfaces for each specimen, which is known as transverse and longitudinal. Where the top surface taken as the longitudinal view and the cross-sectional area taken as transverse. An average of five hardness results were taken for each surface. All the recorded data are shown in Appendix C.

3.10 Analysing the Microstructure

The microstructure test is done to see the grain on the surface of the specimen. The grain view is captured on both surface which are the transverse and longitudinal.

There are several steps to be carry out for the microstructure analysis.

1. The specimen that used for the hardness test will be used again for the microstructure analysis.
2. The specimen first should be ground by using manual hand grinder with four different type of sandpaper grades which are 240, 320, 400 and 600 as shown in the Figure 3.10.
3. The grinding process should be done with running water on it. This is to ensure that the grinding process to be more effective.
4. After grinding, polishing should be done, the polishing is done with two different levels. 1st level by using diamond paste with oil and for the 2nd level by using aluminum oxide powder with water flow. This polishing process is done by using the rotatory grinder.
5. After the polishing process is done the specimen should be proceed with etching process. Then the specimen is observed under the Olympus microscope Figure 3.11. The magnification level been used to observe the grain is ×500.
6. These steps are repeated for all the specimens including the parent mild steel metal and for each specimen it is done for two side which is known as transvers and longitudinal. All images gather from the microstructure are shown in the Appendix D.

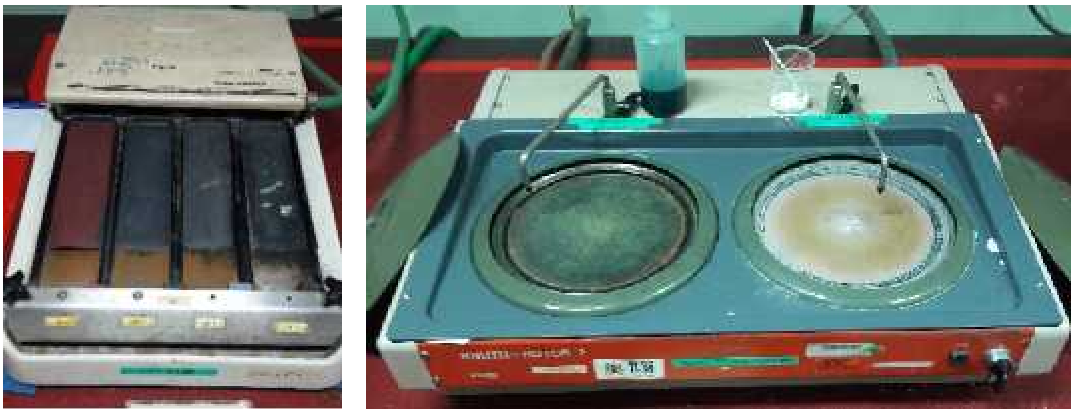

Figure 3. 10 Hand grinding and rotatory grinder

Figure 3. 11 Olympus microscope used to observe microstructure.

3.10.1 SEM Analysis

The microstructure of best specimen from the weld-forged, weld-machined and the parent mild steel have been observed under scanning electron microscope by using S-3400N model. The image of the microstructure that have been captured using SEM will be discussed in Chapter 4. All the image from the SEM is shown in appendix E. The Figure 3.12 below shows the SEM machine that has been used for the microstructure observation.

Figure 3. 12 SEM machine use in microstructure observation

There are some steps to be followed to do the microstructure analysis. The method that used to polish the specimen before the test in SEM are the same as the method that were stated in the previous Sub-chapter 3.10. Before using SEM, the specimens should be applied coating to reduce charging on surface oxide. Once the polishing and coating work is done the specimen is ready to be observe under the SEM. The image magnification used is x500, x1000 and x1500, the image obtain is shown in Appendix E. The specimen used for SEM analysis are from the highest impact test value from the weld-forged, weld-machined and parent mild steel. For each specimen the microstructure analysis using SEM is done on the transverse and longitudinal surface.

3.11 Optimal Parameters.

After obtaining all the results, the hardness and impact test result was analysed using Taguchi in the Minitab 16. Signal to Noise Ratio has been determined by using the software. The criteria that have been used for the Taguchi analysis is the larger the better. The reason for using this criterion is because, when the value of the impact test is high, it shows the specimen has more strength with that specific parameter.