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POROSITY REDUCTION IN ALUMINIUM WELDING USING TIG-MIG HYBRID WELDING

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DECLARATION

I declare that this thesis entitled "Porosity Reduction Mechanism in Aluminium Welding using TIG-MIG Hybrid Welding" is the results of my own research except as cited in the references.

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The Effect of TIG MIG Hybrid Welding on Porosity Observation in Aluminium 5083

ABSTRACT

Welding is a manufacturing process in which two or more components are joined with heat, pressure, or a combination of the two, resulting in a joint after the components cool. The effect of the welding process on porosity formation in Aluminium 5083 was studied by comparing both conventional MIG and TIG-MIG hybrid welding process. This study focuses on applying the TIG-MIG hybrid welding compared with conventional MIG welding process in reducing the porosity formation of welded bead Aluminium 5083. In order to achieve a better result, 70A, 80A, 90A, and 100A current settings were compared for both welding processes. Weld profile and porosity formation was evaluated using an Optical Microscope. From the findings, lower current and welding speed were discovered to increase porosity in welded bead Aluminium 5083. During the MIG welding process, bubbles tend to travel upwards, and some pores are prevented from escaping adequately, specifically in the upper region where pores clustered. Thus, the TIG MIG hybrid welding procedure might delay the solidification time during welding, resulting in the lowest amount of Aluminium 5083 porosity formation. Overall, the purpose of this study was achieved, as the TIG MIG hybrid welding process was shown to reduce the formation of porosity in welded Aluminium 5083 beads.

Keyword: TIG MIG hybrid, Weld bead, Porosity

Kesan Kimpalan Hibrid TIG MIG Terhadap Pemerhatian Porositi Dalam Aluminium 5083

ABSTRAK

Kimpalan adalah proses pembuatan dimana dua atau lebih komponen dicantumkan dengan haba, tekanan, atau gabungan kedua-duanya, menghasilkan sambungan selepas komponen sejuk. Kesan proses kimpalan ke atas pembentukan keliangan dalam Aluminium 5083 telah dikaji dengan membandingkan kedua-dua proses kimpalan konvensional MIG dan hibrid TIG MIG. Kajian ini tertumpu kepada pengaplikasian kimpalan hibrid TIG MIG berbanding dengan proses kimpalan MIG konvensional dalam mengurangkan pembentukan keliangan aluminium 5083 manik yang dikimpal. Untuk mencapai hasil yang lebih baik, tetapan arus 70A, 80A, 90A dan 100A telah dibandingkan untuk kedua-dua proses kimpalan. Profil kimpalan dan pembentukan keliangan dinilai menggunakan Mikroskop Optik. Daripada penemuan, arus yang lebih rendah dan kelajuan kimpalan didapati meningkatkan keliangan dalam Aluminium 5083 manik yang dikimpal. Semasa proses kimpalan MIG, buih cenderung bergerak ke atas, dan beberapa liang dihalang daripada terkeluar dengan secukupnya, khususnya di kawasan atas tempat pori berkelompok. Oleh itu, prosedur kimpalan hibrid TIG MIG mungkin melambatkan masa pemejalan semasa mengimpal, menghasilkan jumlah pembentukan keliangan Aluminium 5083 yang paling rendah. Secara keseluruhannya, tujuan kajian ini tercapai, kerana proses kimpalan hibrid TIG MIG ditunjukkan dapat mengurangkan pembentukan keliangan dalam manik Aluminium 5083 yang dikimpal.

Kata kunci: Hibrid Tig Mig, Keliangan, Manik kimpalan

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LIST OF ABBREVIATIONS (optional)

GTAW	Gas Tungsten Arc Welding	1
SMAW	Shielded Metal Arc Welding	1
FCAW	Flux Cored Arc Welding	1
GMAW	Gas Metal Arc Welding	1
MIG	Metal Inert Gas	1
TIG	Tungsten Inert Gas	1
HAZ	Heat Affected Zone	11
Si	Silicon	21
Fe	Iron	21
Cu	Copper	21
Mn	Manganese	21
Mg	Magnesium	21
Zn	Zinc	21
Cr	Chromium Metal	21
Al	Aluminium	21
Ti	Titanium	21
DCEP	Direct Current Electrode Positive	22
DCEN	Direct Current Electrode Negative	22
SiC	Silicon Carbide	24
OM	Optical Microscopy	24
HF	Hydrofluoric Acid	24

LIST OF SYMBOLS (optional)

CHAPTER 1

1 INTRODUCTION

1.1 Background of Study

Welding is a process that involves joining of two or more metals by heating both metals or applying pressure or both of them to create a solid bond (Olabode et al., 2013). Welding technology had a growth, with new materials have been developed, welding processes, and equipment. Some of the welding methods that commonly used in industry nowadays, including gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW), flux-cored arc welding (FCAW), and laser welding. Each of these methods has its advantages and disadvantages, and the choice of welding technique depends on factors such as the materials to be joined, the required weld quality, and the production environment. Welding requires specialized skills, knowledge, and training to perform safely and effectively. Welders must have a thorough understanding of welding principles, techniques, and safety procedures to ensure that the welds they produce are strong, durable, and free of defects. Proper preparation of the materials, selection of the appropriate welding process, and maintenance of the equipment are also critical to achieving high-quality welds.

GMAW which also knows as MIG (metal inert gas) welding, is a widely utilized welding process which offers versatility, efficiency, and the ability to produce high-quality welds. It involves the use of a continuously fed wire electrode and a shielding gas to join metal parts together. MIG welding, inert gases like argon and helium are utilized as shielding gas, and the electrodes are rolled so that they may be reused indefinitely (Ribeiro et al., 2020). The welder controls the rate at which the wire electrode is fed into the welding gun during the MIG welding process. An electric arc is established between the wire electrode and the metal workpiece, generating the heat necessary to melt the metal and create the weld. Simultaneously, a shielding gas is employed to shield the weld from atmospheric contamination that could lead to defects in the weld metal. Common shielding gas is argon. It is suitable to weld a wide range of metals, including aluminum, and copper alloys. It also requires minimal post-weld cleaning, as the shielding gas provides and effective protection against oxidation and contamination.

GTAW is also knows as TIG (tungsten inert gas) welding, since it can provide highquality welding at cheap cost and simple application, it is the welding method of choice for combining aluminum alloys (Subbaiah et al., 2012). During TIG welding process, a tungsten electrode is held in the welding torch, and the welder manually controls the welding process. Hold the TIG torch with a comfortable grip and position it at the desired angle relative to the workpiece. Maintain a consistent torch-to-work distance. A shielding gas, commonly argon, is utilized to prevent air contaminants from affecting the weld, ensuring a clean and defect-free weld. Thin materials like aluminum, stainless steel, and copper alloys are ideal candidates for TIG welding. It is also preferred for welding materials that are highly reactive or prone to oxidation, as the shielding gas provides excellent protection against atmospheric contamination.

Hybrid welding TIG-MIG is a process that combines the features of TIG welding and MIG welding to produce high-quality welds with increased efficiency. In TIG-MIG doublesided welding, a MIG welding arc provides the primary heat while a TIG welding arc provides the supplementary heat (Weijie Gou and Lihong Wang 2022). The combination of TIG and MIG welding in hybrid welding offers several advantages. Firstly, the precise and stable heat source provided by TIG welding minimizes the risk of overheating or burning the metal being welded. Secondly, the high deposition rate and continuous feed of filler material from the MIG welding torch enable faster welding speeds and higher productivity. Hybrid welding offers greater flexibility and control during the welding process. It can be used to weld a wide range of materials and thicknesses, from thin sheets to thick plates. The process also minimizes distortion in the metal being welded, reducing the need for post-welding correction. However, hybrid welding does have some limitations. The equipment and setup costs for hybrid welding are generally higher compared to other welding processes. Additionally, hybrid welding requires skilled operators who are experienced in both TIG and MIG welding techniques. The process may not be suitable for welding in tight spaces or hard-to-reach areas due to the size and manoeuvrability of the welding torches.

Aluminum is a lightweight, strong, and corrosion-resistant material that is commonly used in various industries. Because of its low density, high strength, and superior corrosion resistance, aluminum is a popular material in the transportation sector (Golumbfskie et al., 2016) (Chenxiao Zhu et al., 2017). However, welding aluminum can be challenging due to its unique properties, such as high thermal conductivity, low melting point, and high reactivity. These properties make it difficult to focus heat on a specific area during welding, prone to warping and distortion, and form a thin oxide layer on the surface when exposed to air. To overcome these challenges, specialized welding techniques and equipment are used for aluminum welding. The most commonly used techniques are TIG welding and MIG welding. TIG welding is particularly well-suited for aluminum welding because it allows for precise control over the heat input, which is critical to prevent warping and distortion of the weldment. TIG welding also allows for the use of a variety of filler materials, which can be matched to the specific alloy of aluminum. MIG welding is another popular method for aluminum welding because it is fast and efficient, although it requires a high level of skill and experience to achieve high-quality welds. Proper preparation of the aluminum surface is also critical for achieving high-quality welds. The oxide layer that forms on the surface of aluminum must be removed prior to welding to ensure a strong weld. This can be done through mechanical methods, such as wire brushing or grinding, or chemical methods, such as using an acidic cleaner.

Porosity is a common issue that can occur during the welding of aluminum. It refers to the presence of voids within the weld. Several factors contribute to the formation of porosity in aluminum welding. Porosity defects in welding may alter the mechanical characteristics of the final product by decreasing its toughness, fatigue life, and ductility (Tjaronge et al., 2015). Firstly, aluminum readily forms oxide films on its surface, which can hinder proper fusion during welding and trap gas, leading to porosity. Therefore, thorough cleaning and the use of appropriate cleaning agents are crucial to remove these oxide films before welding. Additionally, moisture and contaminants such as oils, greases, or dirt can release gases during welding, resulting in porosity. Ensuring a dry welding environment and thorough cleaning of the aluminum surfaces help mitigate this issue. The choice and flow rate of shielding gas are also important. Shielding gas like argon used to protect the weld pool from atmospheric contamination. Insufficient or improper shielding gas coverage can lead to gas absorption and result in formation of porosity. Employing proper welding techniques, such as maintaining a stable arc, and optimizing parameters like current, voltage, and travel speed, can minimize the risk of porosity.

1.2 Problem Statement

Porosity is the presence of cavities in the weld metal caused by gas trapped in the weld pool during solidification. In this study, the TIG-MIG hybrid welding method was used to identify effect of TIG-MIG hybrid welding on porosity formation during aluminium welding. Since one of these weaknesses of aluminium is the formation of porosity, which will affect the weld joint's mechanical properties. Hence, MIG welding will be used as the heading process, while TIG welding will be used as the trailing process, in lowering the cooling rate of the weldment, which may help to reduce the porosity. It is usually assuming that the presence of hydrogen is the major cause of porosity formation, even though hydrogen can come from a variety of sources (Mazur, 2009). Due to rapid solidification and cooling rate, MIG welding also tends to encourage the formation of porosity. Therefore, it is believed that introduction of TIG arc during MIG welding can affect the solidification behaviour of the weld pool, thus result in the reduction of the porosity formation in alauminium welding.

1.3 Objectives

The objectives of this study are as follows:

1. To study the effect of TIG-MIG hybrid welding on porosity formation in aluminium welding.
2. To analyse the pattern of porosity formation in as-welded aluminium.

1.4 Scope of Study

Investigating the parameters that influence porosity development during the welding process would fall within the purview of research on the mechanism for reducing porosity in aluminum welding utilizing TIG-MIG hybrid welding. Porosity, or the existence of tiny cavities or gas pockets inside the weld material, may compromise the strength and durability of the weld. The purpose of the research would be to pinpoint the causes of porosity and investigate whether or not TIG-MIG hybrid welding might be used to mitigate the issue. Experiments would be performed in which a number of TIG-MIG hybrid welding attempts would be performed under a range of welding settings. Welding parameters such as current, arc voltage, travel speed, shield gas flow rate, and wire feed rate will be studied. These factors would be adjusted to study their influence on weld porosity development and elimination. To further investigate the link between porosity reductions and weld quality, the microstructure and mechanical characteristics of the welds would also be assessed. To learn how the TIGMIG hybrid welding technique affects porosity generation and elimination, the metallurgical changes that take place during welding will be studied. The purpose of this research is to determine the optimal welding settings and process conditions for producing aluminum welds using TIG-MIG hybrid welding with as little porosity creation as possible. The study's findings would be contrasted with the current body of research on the ways in which aluminum welding may reduce porosity, and the study's practical ramifications would be examined. The overarching goal of the research is to figure out what factors influence the amount of porosity in a weld and how to minimize it using a TIG-MIG hybrid welding method for aluminum.

1.5 Significances of Study

There are a number of reasons why it's important to investigate how TIG-MIG hybrid welding reduces porosity in aluminum. The first benefit is that it helps solve a key problem with aluminum welding by decreasing porosity development. Weakened welds and decreased mechanical characteristics due to porosity might lead to early product failure. The creation of porosity may be greatly reduced by the use of TIG-MIG hybrid welding by establishing optimum welding settings and process conditions. Second, this research has the potential to save businesses money by lowering rates of finished-goods rejection and rework. Products that fail quality assurance tests because of porosity may cost firms a lot of money. Costs associated with rework and rejection may be avoided if porosity creation is limited from the outset. Third, TIG-MIG hybrid welding may boost output by decreasing the amount of time spent cleaning and reworking welds once they are completed. The productivity of the welding process may increase as a result. And last, lowering the rate at which pores grow when welding may help the planet. Porosity formed during welding procedures may lead to high levels of pollution emissions, including greenhouse gases. TIG-MIG hybrid welding may lessen the damage done to the environment by welds by lowering the rate at which pores develop. Overall, the welding industry stands to greatly benefit from research into the mechanism by which TIG-MIG hybrid welding may minimize porosity in aluminum welding. This includes opportunities to boost quality while cutting costs, increasing output, and decreasing pollution.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Aluminium Welding

Aluminum welding is prone to a flaw known as porosity, which compromises the joint's quality and mechanical qualities. According to Ma, X et al (2016), this study looked at what causes porosity during MIG welding of aluminum alloys. The purpose of the research is to determine what factors influence the formation of porosity in aluminum welds. During the study, different settings for things like wire feed speed, welding current, and shielding gas flow rate. Non-destructive testing and metallographic analysis are used to determine the extent of porosity in the resultant weldment metal. According to other research, it was found that elevating either the wire feed speed or the welding current resulted in increased porosity. This is because there are more chances for gas entrapment as a result of the greater energy input and the creation of bigger weld pools. That the flow velocity of the shielding gas had an effect on porosity creation, with lower porosity resulting from insufficient gas covering and gas shielding. The presence of hydrogen and nitrogen that may get trap into the pool of molten aluminum during the welding process, thus produce pores inside the weld if the weld solid too soon or if there is inadequate gas shielding. The process for creating porosity may be affected by the solubility of gases in aluminum and the solidification properties of the alloy. (Lin Li et al. 2022) it's important to control the input energy accurately during the welding process on aluminum because too high energy can easily result in welding defects such as porosity due to low melting point, high thermal conductivity, low hardness and high reactivity with oxygen.

2.2 Type of Welding Used

In this experiment, the types of welding used to study the existence or lack of porosity on aluminum are MIG welding and TIG-MIG hybrid welding.

2.2.1 MIG Welding

The welding procedure known as MIG (metal inert gas) or gas metal arc welding (GMAW) is often used to connect aluminum. MIG welding is a frequently used welding method due to its various advantages, which include high productivity, simplicity of application, and low cost (Kamawasmy et al., 2020). MIG welding is a welding method that creates metal fusion by producing a high-temperature welding are between the fill wire and the workpiece. MIG welding starts when the welding wire is oriented toward the workpiece (Wang et al., 2020). The welding creates heat, which melts the welding wire and the workpiece metal together, resulting in a permanent connection between the two pieces of metal. Shielding gas is used in MIG welding with aluminum to prevent ambient contamination of the weld zone. That gas provides an inert environment, eliminating the potential for oxygen and nitrogen reactions that may lower weld quality and cause flaws. In this position, the shielding gas, may completely enclose the weld and protect it from the elements, allowing a long-lasting connection to be made.

However, porosity can occur when the weld metal is not adequately protected from the outside air during the welding process. Weldment strength and mechanical qualities may be affected by adjusting GMAW welding parameters such welding current, welding speed, arc stress, and gas flow rate (Ishak et al., 2015). Aluminum, being a highly conductive material that allows heat to escape rapidly, requires careful management of its heat intake. Overheating or significant distortion may be avoided by carefully managing the heat input during welding. Weld penetration and bead appearance may be optimized by adjusting welding parameters including voltage, current, and wire feed speed. MIG welding may produce high-quality aluminum welds if the correct processes are followed, welding parameters are optimized, and the right methods are used. Figure 2.1 illustrates the MIG welding process.

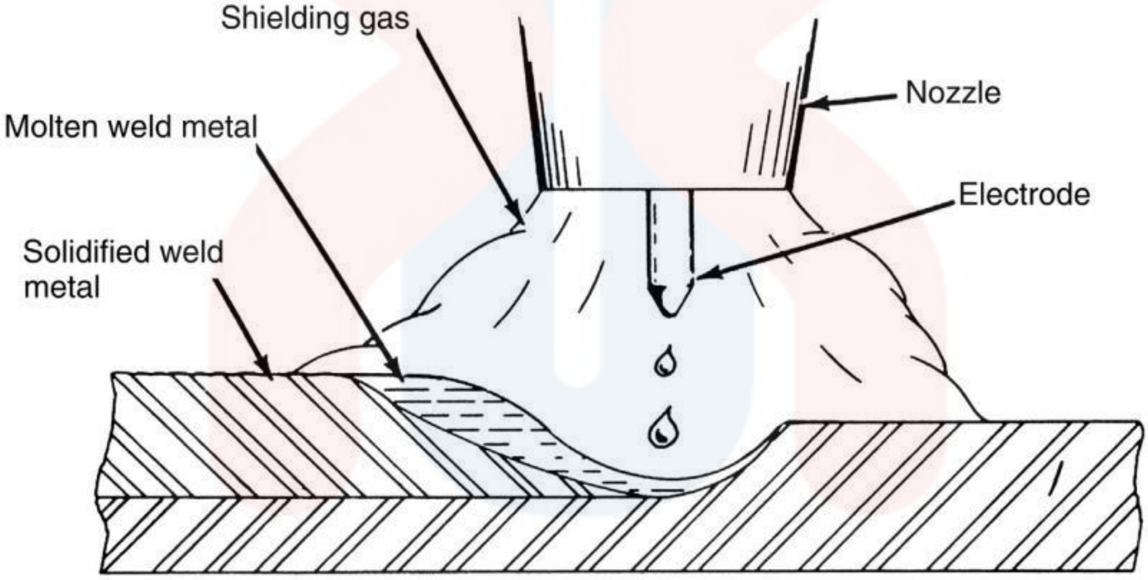


Figure 2.1: MIG welding process (Antonini, J. M. 2014)

2.2.2 TIG-MIG Hybrid Welding

TIG-MIG hybrid welding combines the advantages of tungsten inert gas (TIG) welding and metal inert gas (MIG) welding into a single procedure. Because it strikes a good balance between speed, heat input control, and productivity, it sees extensive application for aluminum welding. According to Zong et al. (2019), Heat-sensitive metals benefit most from TIG and MIG hybrid welding when the main objective is to reduce the amount of heat applied to the material. Besides, TIG-MIG hybrid welding creates joints with greater tensile strength, a smaller Heat Affected Zone (HAZ), and greater micro-hardness than standard MIG welding. (Meng et al., 2014). In addition, when using a TIG-MIG hybrid welding, the MIG length continuously grows as the TIG current is increased. This resulted in a narrower weld and a lower temperature field as compared to convensional MIG welding (Zong et al., 2019). According to Rose Alifah Ellyana Roslan et al (2020), the introduction of TIG current would influence arc stability, arc behaviour, and metal droplet transfer. In order to obtain a stable MIG are when the TIG are is trailing, the researchers conclude that the TIG current must exceed 100 A. Although extensive research has been conducted on the TIG-MIG hybrid welding process, few studies have analysed the arc and molten metal droplet behaviors using aluminum alloys and a trailing TIG arc. This could be due to the low weldability of aluminum alloys mentioned in the preceding section. Most studies on TIG-MIG hybrid welding processes have only focused on the leading TIG arc and used mild carbon steel as the base material due to its high weldability (Odebiyi et al., 2019) in order to determine the optimal welding parameter as well as the arc behaviour and metal droplet transfer mode. Figure 2.2 shows the TIG-MIG hybrid welding process.

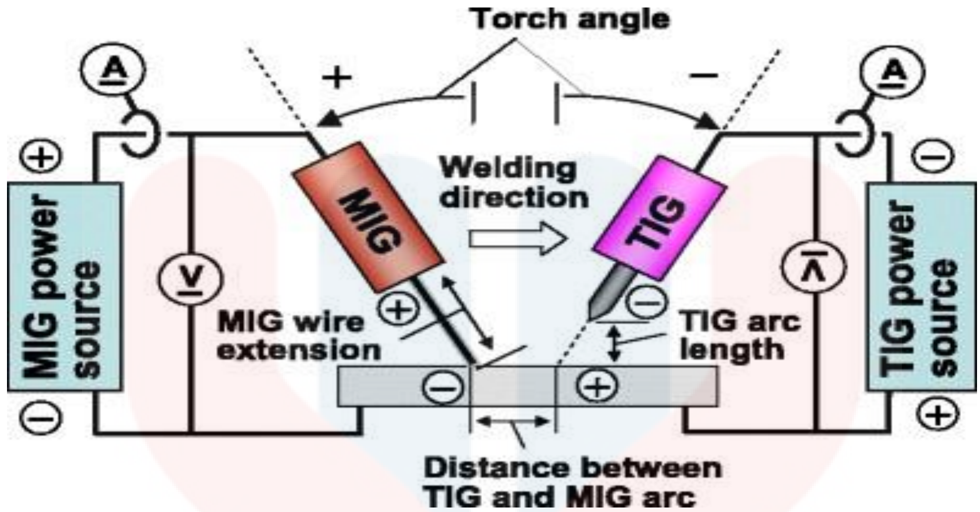


Figure 2.2: TIG-MIG hybrid welding process (Kanemaru et al., 2013)

2.3 Porosity Formation in Aluminium Welding

Porosity formation in aluminium welding can be caused by factors such as oxide contamination, moisture absorption, inadequate shielding gas, filler metal contamination, and improper welding technique. To reduce porosity, it is important to clean the surfaces thoroughly, keep the aluminium dry, use appropriate shielding gas, employ clean filler metal, and apply proper welding techniques with suitable parameters. Referring to relevant welding guidelines and standards is also important.

2.3.1 MIG Welding

Arc welding procedures like metal inert gas (MIG) welding, which combine affordability and dependability, are widely used in a variety of industries. (Rose Alifah Ellyana Roslan et al., 2020). However, metals undergo a challenging process that might result in poor weld formation quality during or after welding. Several defects, including porosity and cracking, may have an impact on mechanical properties. Filler wire, air, and hydrogen present during the welding process, as well as environmental elements like temperature and air humidity, all have an impact on the porosity of aluminum. (Huang et al., 2020). Hydrogen atoms are created during the MIG welding process when H2O combines with the molten metal. High temperatures in the molten pool make it simple to dissolve hydrogen atoms. The hydrogen atoms may decrease as the welding process goes on and the temperature drops. Porosity production may be impacted by the hydrogen atoms' solubility in the molten pool (X. Han et al., 2020a). Atoms of hydrogen are spread out across the molten pool during the heating stage of MIG welding. The process of dissolving the element produces bubbles of hydrogen gas. The fluid dynamics of the metal have an impact on hydrogen atom mobility. Since trapped hydrogen bubbles in the molten pool cannot escape during cooling because hydrogen becomes less soluble, porosity results. According to Kah et al. (2015), the porosity has an uneven form and a huge size. To get the best welding performance, the welding parameters, including current and voltage, travel angle, and trip distance, must be taken into account. The amount of heat supplied to the material being welded is one of several factors that influence the development of pores within the weld bead. About 40% of the total heat input into the weld zone comes from the metal droplets themselves due to their high heat content. (Rose Alifah Ellyana Roslan et al. 2020). Although heat input cannot be detected directly, by examining the arc voltage, current, and velocity, we may determine how much heat was generated. It is believed that reducing the cooling rate and increasing heat input may lessen the amount of porosity that forms within the weld bead of welded metals. The molten pool's solidification was slowed down as a consequence.

2.3.2 TIG-MIG Hybrid Welding

MIG-TIG hybrid welding, combines the advantages of both MIG (Metal Inert Gas) and TIG (Tungsten Inert Gas) welding processes. According to Kanemaru S, Sasaki T, Sato T et al (2013) on TIG-MIG hybrid welding process, because of the hybridization effect with the TIG arc, the MIG arc may remain stable even in pure inert shielding gas, allowing the TIG-MIG hybrid welding process to accomplish the benefits of both processes. Porosity formation in TIG-MIG hybrid welding of aluminum can be attributed to factors such as surface contamination, improper shielding gas selection, unsuitable welding parameters, and electrode contamination. Contaminants, inadequate gas coverage, excessive heat input, and impurities transferred from the electrode can contribute to the presence of small voids or gas pockets within the weld metal. To mitigate porosity, it is essential to ensure thorough surface cleaning, use high-purity shielding gases with proper flow rates, optimize welding parameters, and regularly inspect and clean the tungsten electrode. By addressing these factors and implementing appropriate practices, the formation of porosity can be minimized, resulting in stronger and more reliable aluminum welds. Even though a great lot of studies on TIG-MIG hybrid welding have been conducted, the influence of the TIG-MIG hybrid welding process on the development of porosity in the welded Aluminium has not been widely discovered yet.

2.4 Factor in Porosity Formation

Porosity is a major problem in welding because it may weaken the weld connection. Differences in hydrogen solubility between liquid and solid aluminum alloys influence the formation of porosity during welding (Huang et al., 2018). Porosity formation is a complex process that is influenced by fluid mechanics and metallurgical solidification, as stated by Ryan et al. (2018). Welding may cause faults like porosity, which can increase stress concentrations. Hydrogen in the molten pool causes metalurgical porosity, which is often present during welding (Han et al., 2020). Hydrogen isn't the only thing that may change porosity environmental factors do as well (Pequet et al., 2002). Conditions that affect porosity include air temperature, air humidity, and dissolved oxygen (Ahsan et al., 2016). Arc current and high heat input conditions also affect the existence of porosity during welding (Ascari et al., 2012; Ahsan et al., 2016).

2.4.1 Environmental influence on porosity (Air temperature)

Air temperature is one of the environmental elements that affects the occurrence of porosity in a welded joint. Porosity in the weld metal area often occurs due to the high solubility of hydrogen in aluminum at the aluminum melting temperature. The increase in air temperature caused by the liquefaction of aluminum makes hydrogen soluble. Welding creates porosity because hydrogen gas is trapped on the metal being connected when it melts (Mathers, 2002). To be more specific, welding temperature affects the compaction and cooling phases (Vishnyakov et al., 2018). Weld quality suffers as air temperatures fluctuate. Temperature control in the welding area is essential for producing a satisfactory weld. Welding at high temperatures makes the material brittle, which weakens the weld (Congcong Zhu et al., 2019).

2.4.2 Environmental influence on porosity (Humidity Environmental)

The amount of moisture in the air is a factor in how porous a material is. Moisture has a crucial role in the progression of hydrogen-induced porosity in welded joints. Porosity in the weld reduces its strength. Diffused hydrogen ion concentrations are shown to increase with both an increase in air and water vapor pressure. Therefore, high porosity is affected by the relative humidity. Increases in relative humidity lead to larger pores and coarser grains in the weld microstructure, both in the fusion zone and the HAZ (Korenberg et al., 2004). Gou et al. (2015) Aluminum alloys are welded with humidity fluctuations of 50%, 70%, and 90%. Welded connections at 90% humidity provide high porosity. However, when the relative humidity is just 50% at the weld joint, the porosity values are relatively low; and when the relative humidity is 70%, the porosity values at the weld junction reach their maximum diameter and area. Therefore, the increased porosity is due to rising humidity (Gou et al., 2015).

2.5 The effect of porosity on the mechanical properties of weldment aluminium from other method welding

The loss of ductility in the weld joint and the manner of fracture during fatigue failure are both affected by porosity. (Ferreira et al. 1999). Mechanical features of welding are negatively impacted by porosity, and fatigue stress may be reduced as a result (S. Wu et al., 2019). Porosity may affect the tensile strength in the fusion zone and the efficiency of the welded connection (Leo et al., 2015). In recent years, there has been exciting new development in our understanding of how porosity impacts welding. The microstructure of the weld metal, the choice of materials, the mechanical properties of the weld joint, and many other factors may all be considered in relation to porosity in welding. The effects of porosity on welded joints are the focus of the investigations listed in Table 2.5

Table 2.5: Lists various studies on porosity that concentrate on talking about how it affects welded joints.

No	Reference	Material	Method	Finding from literature	Finding
1	Gou et al. (2015)	A7N01A-T5 aluminium alloy	Welded joint for high-speed trains	Microstructural porosity and fatigue strength of A7N01S-T5 aluminum alloy weld joints as a function of moisture content	Increased humidity causes a rise in porosity and a decrease in fatigue strength at the weld joint.
2	Han et al. (2016)	6082-T6 aluminium alloy	Laser-MIG hybrid welding	The impact of welding parameter on porosity distribution, and the relationship between	When the weld's arc current reaches 140 A, porosity develops surrounding the fusion zone. The porosity is impacted by the gas flow rate. The tensile strength

				mechanical characteristics	decreased from 260 MPa to 202 MPa and the
				and porosity distribution 6082-T6 welding joint for aluminum alloy	fatigue strength decreased from 113 MPa to 56 MPa as the porosity rate increased, indicating that the weld connection had become brittle.
3	Samiuddin et al. (2020)	Aluminium alloy AI-5083	Tungsten inert gas welding (TIG)	Impact of compaction fractures and porosity on TIG AA 5083 welding	As the heat input value lowers, the hardness value also decreases. Due to variations in the heat input levels that cause porosity and grain size change, the hardness in the bottom welding region is significantly reduced.
4	Wu et al. (2015)	Aluminium alloy 7075-T6	Laser-MIG hybrid welding	Interaction between pores and fatigue deterioration at	Fatigue cracking in welding is caused by gas porosity. The weld joint experiences a fatigue

				the 7075-T6 interface	cycle as a result of the elevated pore count.
5	Zhen et al (2018)	Aluminium alloy 5A06	Laser-MIG hybrid welding	Microstructure and porosity distribution in welded seams made of the 5A06 aluminum alloy	Due to dissolved gas and Mg evaporation, metallurgical pores were discovered in the welded joints. The pore size is between 29 and 52 micrometers. The softerening of the weld joint is influenced by pore development.
6	Chen et al. (2020)	Aluminium alloy 5182 and 6061	Laser welding	Laser welding's effects on the mechanical properties, microstructure, and porosity of 5182 and 6061 aluminum alloys	Mg evaporation makes the welding process unstable and reduces the amount of real heat input. The 6061/5182 junction significantly affects tensile strength and has a higher fracture sensitivity. Due to the presence of the element

					Mg, pores and porosity are evident. With an increase in the Mg element level, microhardness falls.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Materials

Aluminum, A5083 with dimensions of 150 mm x 25 mm x 2 mm is used for this project. Additionally, pure argon will be used in both TIG and MIG welding as a shielding gas, along with two distinct sets of power sources. The chemical composition of aluminum A5083 as a base metal and aluminum 5356 as a filler wire are both listed in tables 3.1 and 3.2.

Table 3.1: Chemical composition of Aluminium 5083

Element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ai
Concentration (%)	0.1	0.3	0.1	>0.5	3.5-4.0	0.12	0.9	Balance

Table 3.2: Chemical composition of Aluminium 5356

Element	Al	Mg	Fe	Si	Cu	Zn	Ti	Cr	Mn	Other total	Other each
Content (%)	92.9 95.3	4.50 5.50	0.40	0.25	0.10	0.10	0.060-0.20	0.050-0.20	0.050-0.20	0.15	0.050

3.2 Method

To is the welding process, the bead on plate method used in order to weld the aluminium. The aluminum base metal cleaned physically and chemically to remove any impurity sources, such as dust, rust, moisture, or oil, on to be carefully evaluated.

3.2.1 MIG Welding Process

The production of porosity in TIG-MIG hybrid welding process is compared to that of the MIG welding process to guarantee the validity of the tests. The parameter set for MIG welding the same with the parameter setting in TIG-MIG hybrid welding process. The similarity of the parameter ensured the comparison to be done equally.

3.2.2 TIG MIG Hybrid Welding Process

Pure argon gas is utilized as a shielding gas for both MIG and TIG welding, and the control unit is pre-programmed welding operations with MIG welding leading and TIG welding trailing to start the process. For this study, the MIG and TIG power sources are operated in DCEP (Direct Current Electrode Positive) and DCEN (Direct Current Electrode Negative) settings, respectively.

3.3 Welding Parameter

The parameters used in this experiment for both TIG-MIG hybrid welding and MIG welding are shown in Table 3.3. Bead-on-plate welding method is used throughout.

Table 3.3: The experimental parameters of MIG welding and TIG-MIG hybrid welding

Parameter	MIG Welding	TIG-MIG Hybrid Welding
Current (A)	70A, 80A, 90A, 100A	MIG: 100A TIG: 70A, 80A, 90A, 100A
Polarity	DCEP	TIG: DCEN MIG: DCEP
Welding speed (mm/s)	4 mm/s	
Wire feed speed	500 cm/min	
Voltage	11V	MIG: 11V TIG: 10V
Contact tip work distance (mm)	10mm	
TIG arc length (mm)	None	TIG: 5mm
Tungsten size	None	TIG: 2.4 mm
Torch angle (°)	65°	TIG: 60° MIG: 65°
Wire size	MIG: 1.2mm	

3.4 Sample Preparation

To examine the weld profile and porosity formation tendency of the of the welded aluminium 5083, are cut using various MIG and TIG MIG hybrid welding currents (70A, 80A, 90A, 100A).

The specimens grinded and polished using grinding machine and silicon carbide (SiC) paper in order to obtain the mirror surface. This phase is crucial for demonstrating superior observation.

Etching is used after the grinding and polishing procedures. Unetched specimens will have an impact on the results of metallography since they will highlight flaws. The hydrofluoric etchant used in this investigation was made up of 200ml H2O and 1ml HF. The samples are then submerged for 15 to 20 seconds each sample, and it should be noted that the experiment is carried out within a vacuum chamber. After dipping, the sample surface was promptly dried and rinsed with distilled water to eliminate any surplus solution. Welded metals will be split apart and observed using metallurgical tools like an optical microscope (OM) for the examination of porosity creation.

3.5 Hardness Vickers Testing

Vickers hardness testing in aluminum welding is a vital method for evaluating the material's resistance to penetration and one of distructive testing. The process involves pressing a square-shaped diamond indenter into the material's surface under a known load, with resulting indentation size determining the hardness value. Aluminum alloys, comprising different elements, exhibit varied hardness levels, influenced by alloy composition and heat treatments.

The welding process introduces thermal cycles, impacting the microstructure of the aluminum, particularly in the heat-affected zone (HAZ) and weld metal. Welding parameters such as current, voltage, and heat input play a role in determining the final hardness. Post-weld heat treatment may be employed to refine the microstructure and enhance hardness, evaluated through Vickers hardness testing. Careful preparation of test specimens is essential, and interpreting results involves considering application-specific requirements. Vickers hardness testing serves as a crucial aspect of quality control, ensuring compliance with industry standards and optimizing welding processes to achieve the desired mechanical properties in aluminum welded joints.

3.6 Research Flow

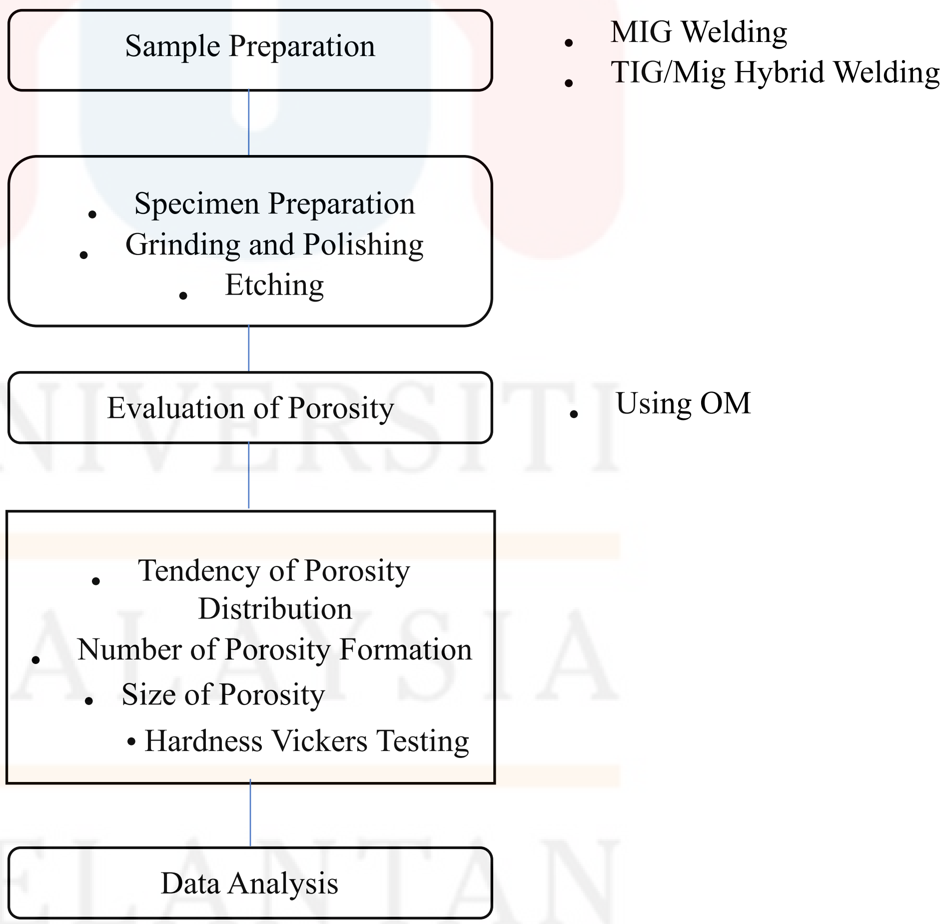


Figure 3.1: Research Process of the sample preparation and welding process

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 Weld Specimen and Profile

Under the same torch angle (degrees) and wire feeding speed (metre per minute), the following table illustrates the visual appearance of weld specimens for TIG-MIG hybrid welding and MIG welding at different welding currents of 70A, 80A, 90A, and 100A.

Table 4.1: Visual Appearance of MIG Welding Process

Torch Angle (°)	Welding Speed (mm/s)	Current (A)	Weld Specimen
15	4	70	
		80	
		90	
		100	

Table 4.2: Visual Appearance of TIG MIG Hybrid Welding Process

Torch Angle (°)	Welding Speed (mm/s)	Current (A)	Weld Specimen
15	4	70	
		80	
		90	
		100	

4.2 Porosity Evaluations

4.2.1 Welded Aluminium 5083

The typical MIG welding process has a tendency to create a significant amount of porosity in the 5083 series of welded aluminium. As a consequence of the hybridization effect that TIG and MIG arcs have, the high porosity problems that are associated with welded aluminium 5083 might be brought under control. With the help of an optical microscope and the Capture 2.2.1 software, the researchers were able to examine the development of porosity in welded aluminium 5083 by measuring its tendency, number of porosities, percentage of porosity, pore size, and position. A cross-sectional view of the welded bead is shown in Figure 4.1. This picture is displayed for both the classic MIG welding method and the TIG MIG hybrid welding technique.

However, with the use of an optical microscope (OM), a cross-section of the porosity production in welded bead aluminium 5083 was displayed below. This cross-section represented the porosity generation for both standard MIG and TIG MIG hybrid welding processes at different welding currents of 70A, 80A, 90A, and 100A.

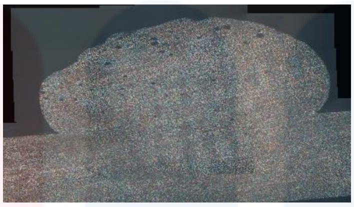
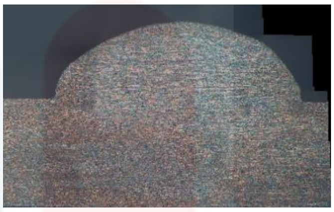
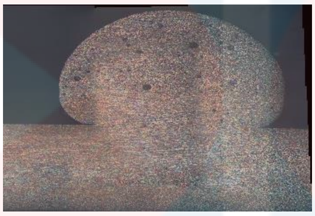
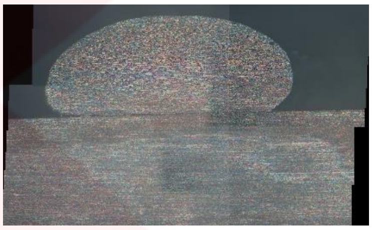
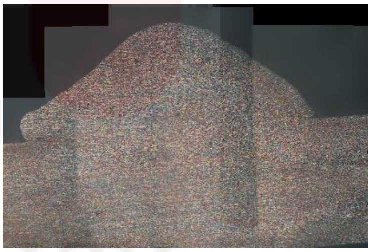
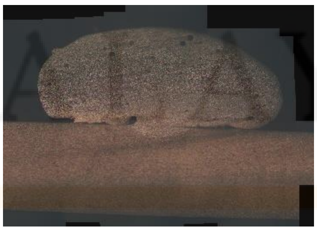
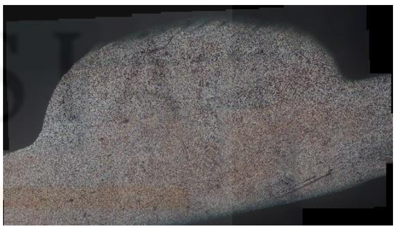
Current (A)	MIG Welding	TIG-MIG Hybrid Welding
70A	 (a)	 (b)
80A	 (c)	 (d)
90A	 (e)	 (f)
100A	 (g)	 (h)

Figure 4.1: Cross-section of Porosity Formation in Welded Aluminium 5083 Using MIG Welding and TIG-MIG Hybrid Welding

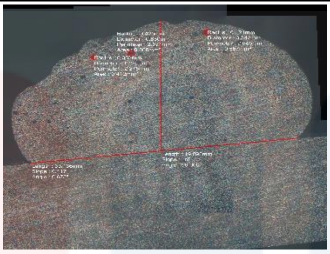
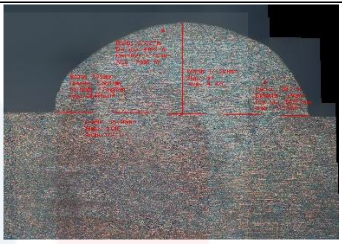
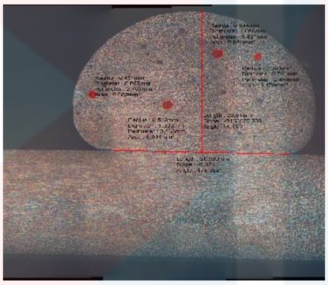
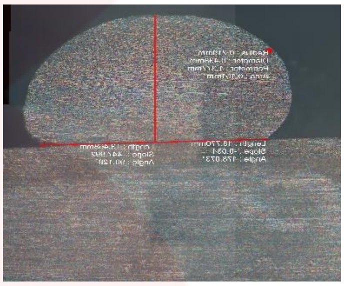
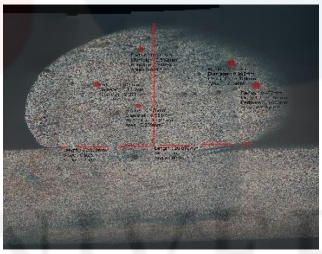
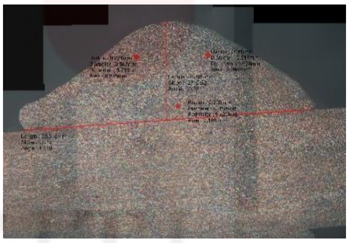
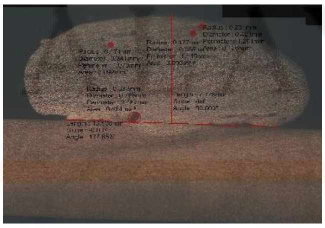
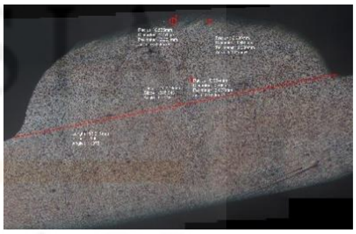
Current (A)	MIG Welding	TIG MIG Hybrid Welding
70A	 (a)	 (b)
80A	 (c)	 (d)
90A	 (e)	 (f)
100A	 (g)	 (h)

Figure 4.2: Measure Cross-section of Porosity Formation in Welded Aluminium 5083 Using MIG Welding and TIG-MIG Hybrid Welding

4.2.2 Number of Porosity Distribution in Welded Aluminium 5083

Each sample show different tendency of porosity distribution in welded Aluminium 5083 for both MIG Welding and TIG-MIG hybrid welding process.

I. Sample Welding 70A

The sample for 70A demonstrates two separate welding processes MIG and TIG-MIG hybrids. In accordance with the data shown in the table 4.3 and the figure 4.3, the sample of 70A MIG welding has a total porosity of 71. The formation -1 state, in which the porosity value is 13, is the most porous condition that may be seen. When the porosity value of the MIG welding sample for 70A is 4, it reaches its lowest point at the location where the porosity creation 2 occurs. Porosities totalling 36 were discovered in the sample of 70A TIG-MIG Hybrid Welding that was examined. The largest amount of porosity is seen during the creation of 1.5 porosity, which occurs when the porosity value is 7. The TIG-MIG Hybrid Welding sample for 70A displays the least degree of porosity; this is the case when the porosity formation is -0.5 and the porosity value is 0.

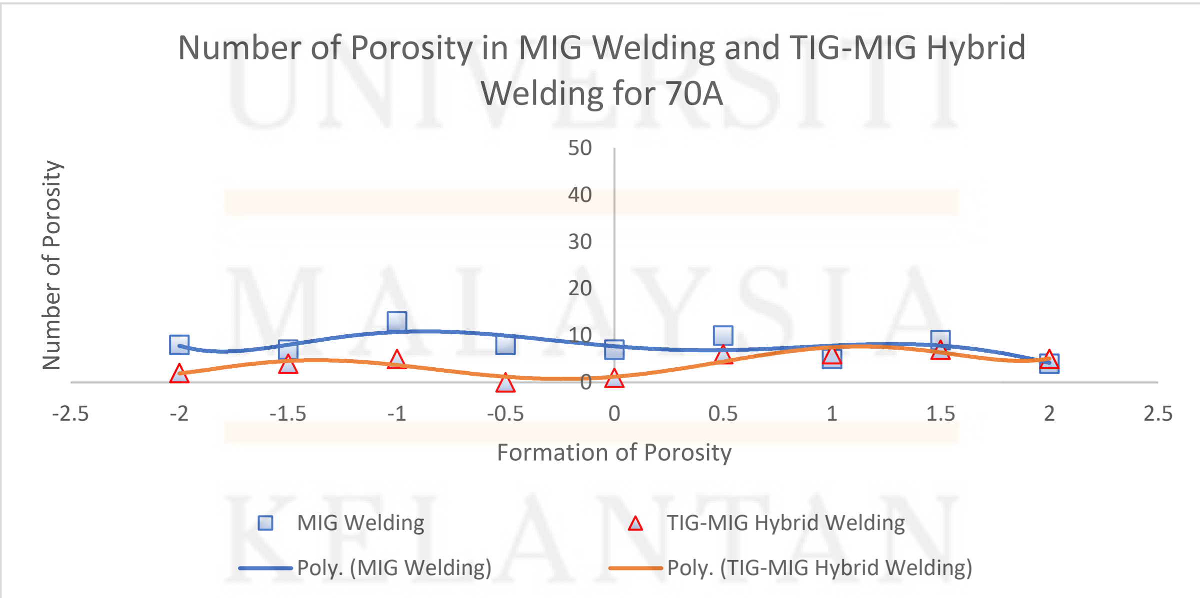


Figure 4.3: Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 70A

II. Sample Welding 80A

MIG welding and TIG-MIG hybrid welding are two of the 80A welding methods that are examples of the techniques described in the sample. It can be seen from both the table 4.4 and the figure 4.4 that the sample of 80A MIG welding has a total porosity of around 102. A porosity grade of 22 indicates that the largest amount of porosity results from a value of 1.5. It was determined that the sample of 80A MIG welding had the least amount of porosity, with a porosity generation of 0.5 and a porosity value of 4. Within the 80A TIG-MIG Hybrid Welding sample, on the other hand, there is a total of 15 porosity. The porosity value in the 2 formation is 4, which refers to the highest possible value. By virtue of its porosity rating of 0, the TIG-MIG Hybrid Welding sample for 80A demonstrates the least amount of porosity among all the samples.

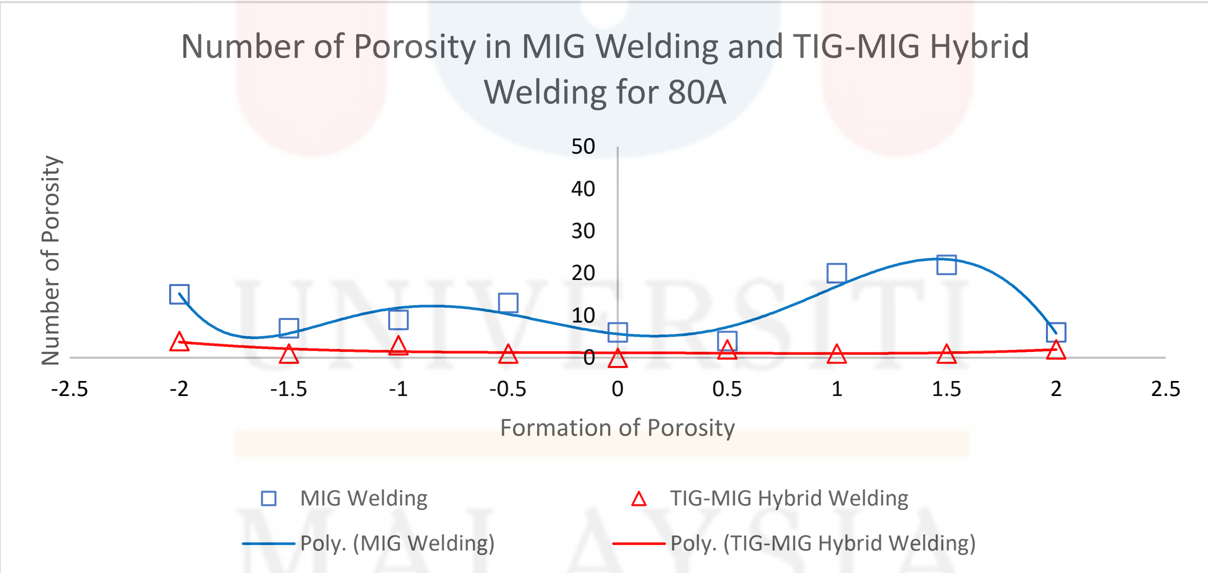


Figure 4.4: Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 80A

III. Sample Welding 90A

The MIG and TIG hybrid welding techniques are two of the 90A welding procedures that are shown in the sample. The overall porosity of the 90A MIG Welding sample turns out to be 128 according to the table 4.5 and the figure 4.5. At porosity formation-2, which is the most porous region, the porosity value is 28. The MIG Welding sample for 90A has the least amount of porosity overall, with a porosity value of 8 and a porosity formation of 2. The 90A TIG-MIG Hybrid Welding sample, on the other hand, has a total of 27 porosities. At a porosity formation strength of -0.5, the maximum amount of porosity, which has a value of 7, is achieved. For 90A, the TIG-MIG Hybrid Welding sample displays the least amount of porosity when the porosity formation is set to 2, and the porosity value is set to 0.

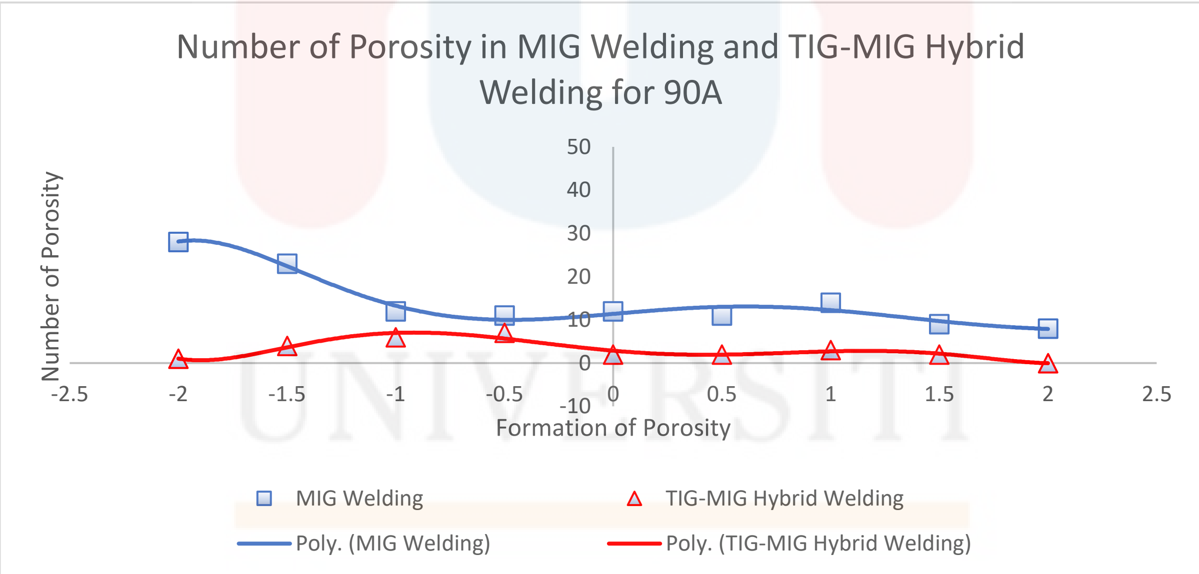


Figure 4.5: Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 90A

IV. Sample 100A

The MIG welding and the TIG-MIG hybrid welding methods are two of the 100A welding techniques that are shown in the sample. It can be seen from both the table 4.6 and the figure 4.6 that the sample of 100A MIG welding has a total porosity rate of 130. Based on the porosity score of 39, it can be concluded that formation 2 has the highest level of porosity. In the case of 100A, the MIG Welding sample displays the least amount of porosity possible when the porosity formation is 0.5 and the porosity value is 4. 40 is the overall porosity of the sample that was welded using 100A TIG-MIG hybrid welding. When the porosity value is 11, the highest amount of porosity that may be seen is at the formation porosity on of -0.5. At 100A, the TIG-MIG Hybrid Welding sample has the lowest amount of porosity, with a formation porosity of 2, -1.5, -2 is 0.

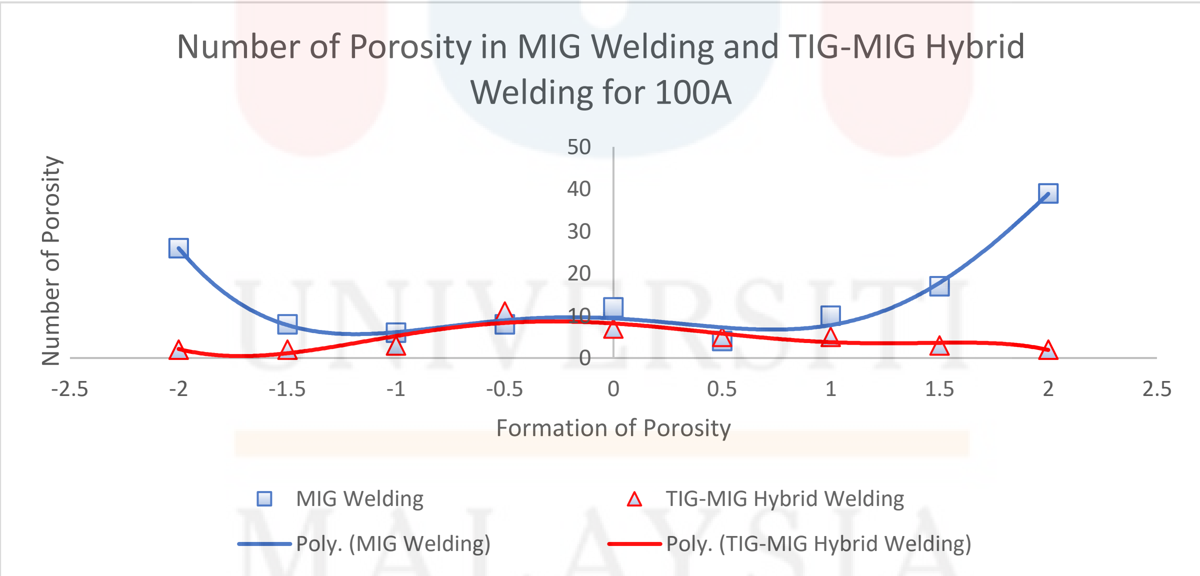


Figure 4.6: Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 100A

V. Total Number of Porosity

The total count of weld bead porosity is shown for each and every sample in both Table 4.7 and Figure 4.7 simultaneously. After going through the MIG Welding process, the sample's porosity increased from 71 at 70A current to 130 at 100A current. This was a significant increase. There is a rise of 59 Porosity. There is a direct correlation between the quantity of current and the degree of porosity that is produced in the weld bead. Inducing this effect is the act of increasing the current. At a current of 70A, the TIG-MIG Hybrid Welding sample has a porosity value of 36, which is considered to be rather high. Nevertheless, when subjected to 80A current, its porosity decreased from 36 to 15 porosity. A decrease in porosity is seen. The generation of porosity in the welding bead has been seen to have increased to a noteworthy degree. The porosity rises from 15 to 27 when the current is 90A, and it continues to grow from 27 to 40 when the current is 100A. By increasing the porosity by 25 Porosity, the current may be increased from 80A to 100A. The conclusion is that TIG-MIG Hybrid Welding has the potential to dramatically reduce porosity and weld bead defects when the current setting is adjusted appropriately for the sample. These observations are in accord with recent research carried out by Chen et al. (2017) and Zhan et al. (2018). According to these researchers, the formation of that coarse pore in the upper molten pool is the result of a combination of the small pores that occur during the movement of the gas pores upwards. In conclusion, TIG-MIG Hybrid Welding can reduce porosity in the weld pool due to a delay in the solidification process in the molten weld pool.

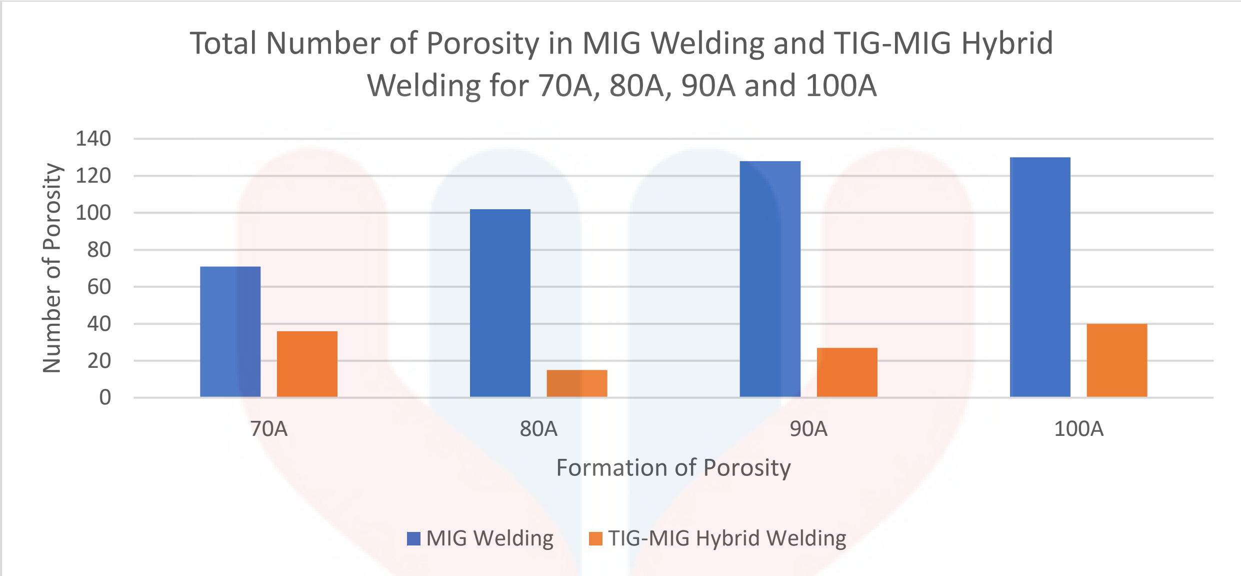


Figure 4.7: Total Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

4.2.3 Size of Porosity less than 0.5mm in Welded Aluminium 5083

In addition to size of porosity less than 0.5mm, MIG Welding and TIG-MIG Hybrid Welding process interactions also influenced the size of porosity in welded Aluminium 5083. Figure 4.8, 4.9, 4.10, 4.11 and 4.12 imply the size of porosity less than 0.5mm in both MIG welding and TIG MIG hybrid welding process.

I. Sample 70A

MIG welding and TIG-MIG hybrid welding are both shown in the sample welding processes for 70A. The sample welding methods also include varied quantities of size porosity that is less than 0.5. There were 13 of the 70A MIG welding samples that had overall porosity sizes that were less than 0.5mm, according to the study of the table 4.8 and figure 4.8. A porosity value of three is present at the point of formation -1, which is the point at which porosity is at its highest. The MIG Welding sample, which has a porosity value of zero, displays the least amount of porosity at porosity formations of -0.5 and 1, respectively. By comparison, only 19 of the samples that were subjected to 70A TIG-MIG Hybrid Welding had total porosities that were less than 0.5 millimetres. With a porosity score of 4, the formation 1 is by far the most porous of all the formations. A porosity formation of 0.5 and 0 is seen in the TIG-MIG Hybrid Welding sample, which has a porosity value of 0. This sample displays the least amount of porosity.

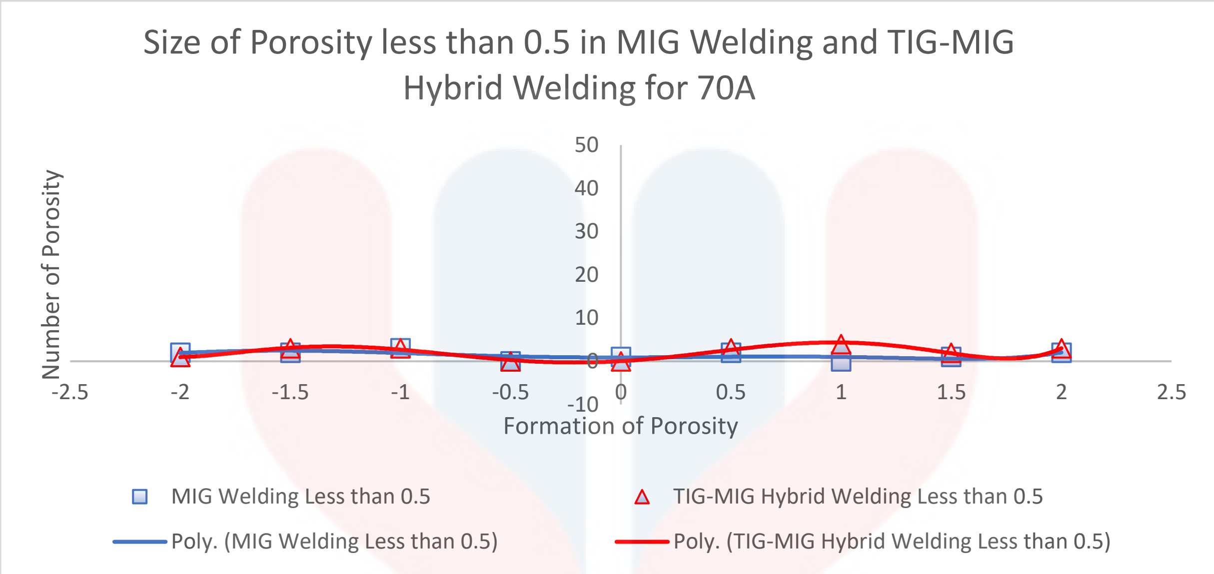


Figure 4.8: Size of Porosity less than 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 70A

II. Sample 80A

MIG welding and TIG-MIG hybrid welding are two of the welding processes that may be used for 80A. The sample demonstrates that there are various quantities of size porosity below 0.5mm within these procedures. It can be seen from both the table 4.9 and the figure 4.9 that out of the 80A MIG Welding sample, there are a total of 22 porosity that are smaller than 0.5mm. At formation-2, where the porosity value is 5, what is considered to be the greatest amount of porosity is found. The MIG Welding sample demonstrates the least amount of porosity for 90A when the porosity formation is between 0 and 0.5 and the porosity value is 0. On the other hand, there are 14 porosity of 80A TIG-MIG hybrid welding that have total porosities that are less than 0.5mm. Formations -2 and -1 include the most porous region, with a porosity rating of 3, which is the highest of any formation. When the porosity value is 0, it shows that there is 0 porosity present in the sample of 80A TIG-MIG Hybrid Welding.

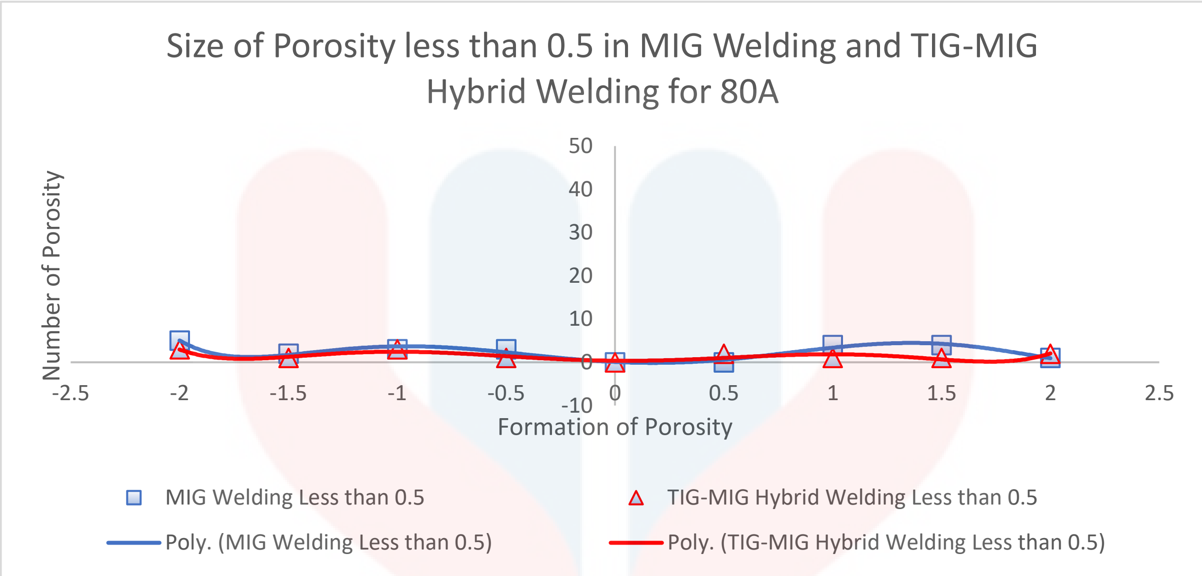


Figure 4.9: Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 80A

III. Sample 90A

Both MIG Welding and TIG-MIG Hybrid Welding are examples of welding processes that may be used for 90A. Both of these procedures have a range of size porosities that are lower than 0.5, as shown in the sample. Both the table 4.10 and figure 4.10 demonstrate that the 90A MIG Welding sample has a total of 30 porosity sizes that are less than 0.5mm. The formations that have a porosity of -2 and -1.5 are the most porous, with porosity values 9 porosity. The sample of MIG welding, which has a porosity value of 0, displays the least amount of porosity at porosity formations of 0.5 and 2, respectively. While this is going on, there are 19 porosities of 90A TIG-MIG hybrid welding that have total porosities that are less than 0.5 mm. The largest level of porosity that may be found in a material with porosity formations of -1 and -0.5 is 4 porosity. There is a difference between the porosity formation value of 90A MIG-TIG Hybrid Welding, which is 2, and the porosity value, which is 0.

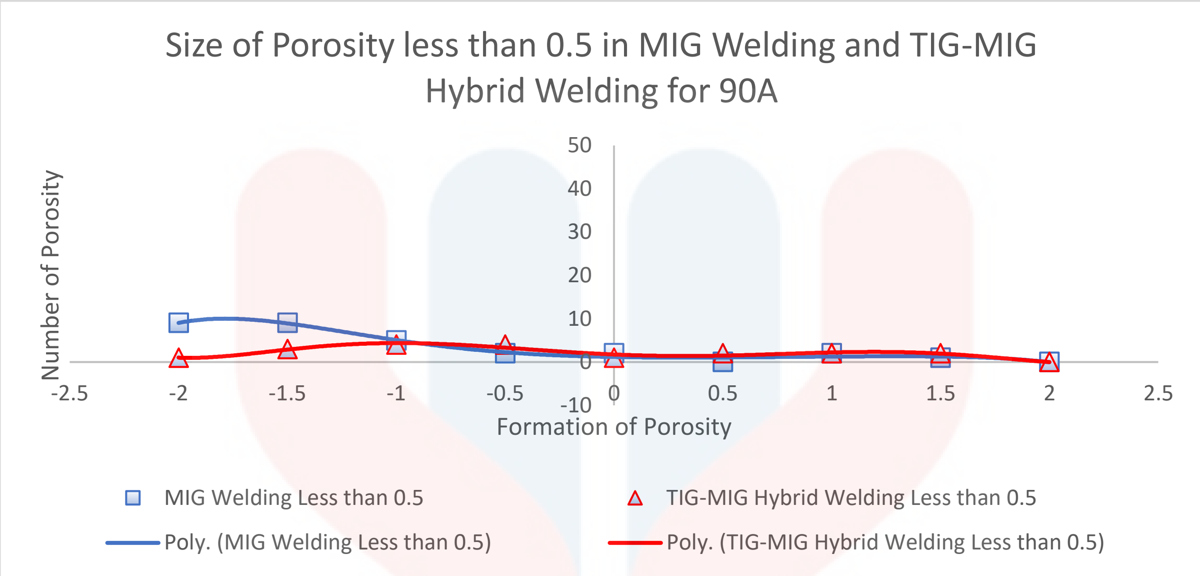


Figure 4.10: Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 90A

IV. Sample 100A

The sample shows the different welding processes for 100A are MIG Welding and TIG-MIG Hybrid Welding with different quantity of size porosity less than 0.5. Based on the figure 4.11 and table 4.11, the MIG Welding sample for 100A has 41 total porosity sizes less than 0.5mm. At porosity formation -2 has the highest amount of porosity with a porosity value of 11. For the lowest amount of porosity in the MIG Welding sample for 100A is at porosity formation 0.5 with a porosity value of 0. On the other hand, the TIG-MIG Hybrid Welding sample for 100A has 26 total porosity less than 0.5mm. At porosity formation -0.5 has the highest amount of porosity with a porosity value of 7. For the lowest amount of porosity in the TIG-MIG Hybrid Welding sample for 100A is at a porosity formation of -2 and -1 with a porosity value of 1.

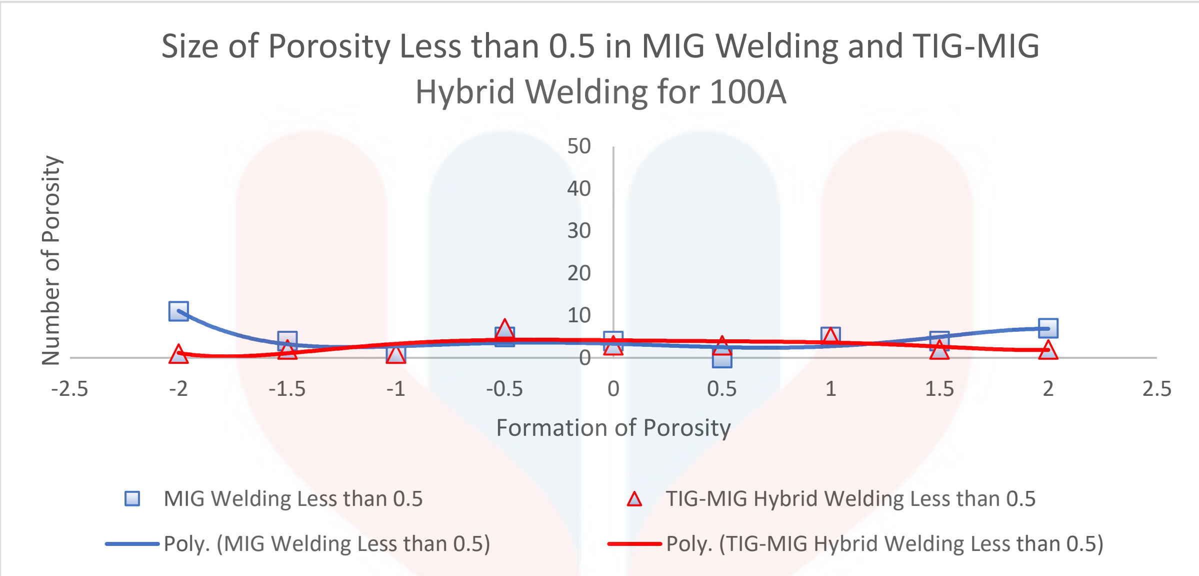


Figure 4.11: Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 90A

V. Total of Number Porosity less than 0.5mm

Both table 4.12 and Figure 4.12 illustrate the total number of pores in the weld bead for each sample. For the MIG Welding sample, it can be seen that porosity has increased from 13 porosity at 70A current to 41 porosity at 100A current. The increase is 28 pores. It can be concluded that when the current increases, then it will increase the amount of porosity formed in the weld bead. As for the TIG-MIG Hybrid Welding sample, at 70A current, the porosity value is quite high which is 19 porosity. But at 80A current it experienced a decrease in porosity from 19 porosity to 14 porosity. Porosity reduction. However, when the current is 90A the formation of porosity in the welding bead starts to increase from 14 porosity to 19 porosity and at a current of 100A, it continues to increase from 27 porosity to 26 porosity. Increase from 80A current to 100A by 12 Porosity. In addition, Miao et al. (2017) have investigated the formation of porosity during the hybrid laser/MIG welding process. They discovered that an increase in welding speed reduces the size of pores on the surface of the weld bead. In 2018, Zhan et al. investigated the porosity distribution in hybrid laser/MIG welding at various welding speeds. With a welding speed of 3 m/min, less porosity and better penetration can be achieved, according to their findings. It can be concluded, when using TIG-MIG Hybrid Welding at the right current and the right welding speed for the sample, it can drastically reduce the amount of porosity as well as reduce defects that occur on the weld bead.

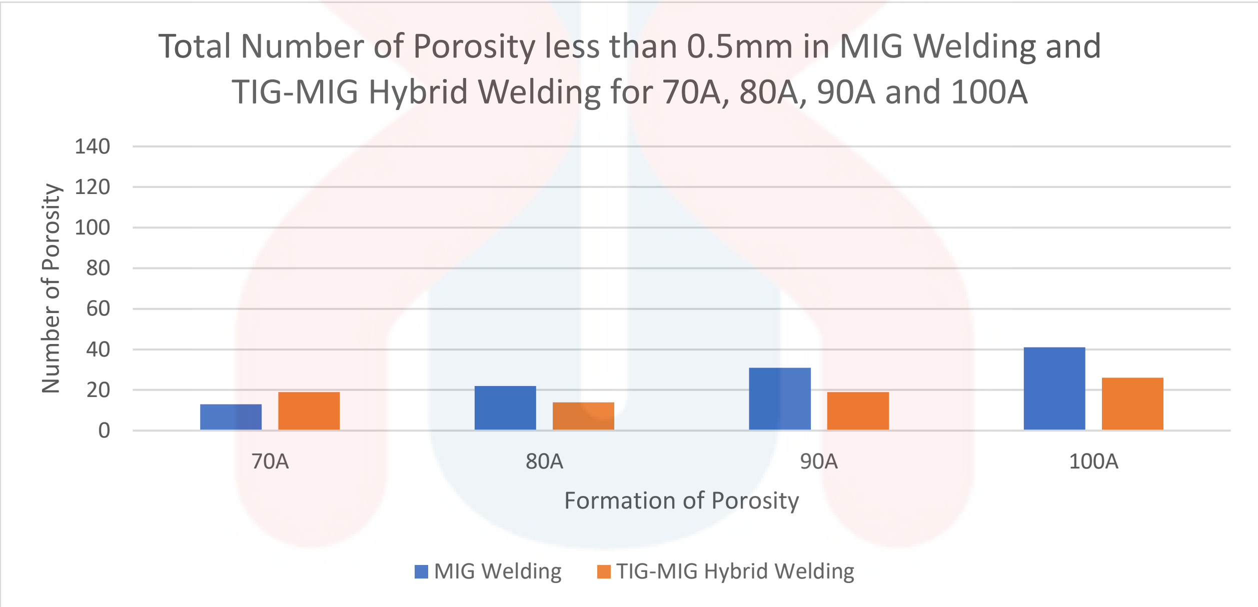


Figure 4.12: Total Number of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

4.2.4 Size of Porosity above than 0.5mm in Welded Aluminium 5083

In addition to size of porosity above than 0.5mm, MIG Welding and TIG-MIG Hybrid Welding process interactions also influenced the size of porosity in welded Aluminium 5083. Figure 4.13, 4.14, 4.15, 4.16 and 4.17 imply the size of porosity less than 0.5mm in both MIG welding and TIG MIG hybrid welding process.

I. Sample 70A

The sample shows the different welding processes for 70A are MIG Welding and TIG-MIG Hybrid Welding with different quantity of size porosity above than 0.5. Based on the figure 4.13 and tabl 4.13, the MIG Welding sample for 70A has 58 total porosity sizes above than 0.5mm. At porosity formation -1 has the highest amount of porosity with a porosity value of 10. For the lowest amount of porosity in the MIG Welding sample for 70A is at porosity formation 2 with a porosity value of 2. On the other hand, the TIG-MIG Hybrid Welding sample for 70A has 17 total porosity above than 0.5mm. At porosity formation 1.5 has the highest amount of porosity with a porosity value of 5. For the lowest amount of porosity in the TIG-MIG Hybrid Welding sample for 70A is at a porosity formation of -0.5 with a porosity value of 0.

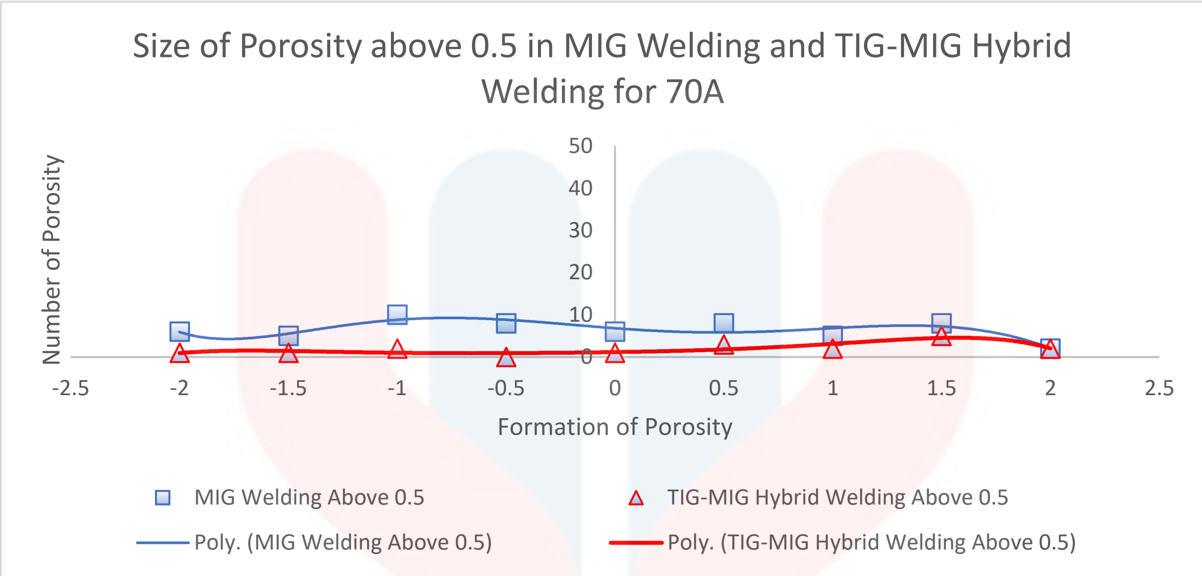


Figure 4.13: Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 70A

II. Sample 80A

The sample shows the different welding processes for 80A are MIG Welding and TIG-MIG Hybrid Welding with different quantity of size porosity above than 0.5. Based on the figure 4.14 and table 4.14, the MIG Welding sample for 80A has 80 total porosity sizes above than 0.5mm. At porosity formation 1.5 has the highest amount of porosity with a porosity value of 18. For the lowest amount of porosity in the MIG Welding sample for 80A is at porosity formation 0.5 with a porosity value of 4. On the other hand, the TIG-MIG Hybrid Welding sample for 80A has 1 total porosity above than 0.5mm. At porosity formation -2 has the highest amount of porosity with a porosity value of 1. For the lowest amount of porosity in the TIG-MIG Hybrid Welding sample for 80A is at a porosity formation of all but -2 with a porosity value of 0.

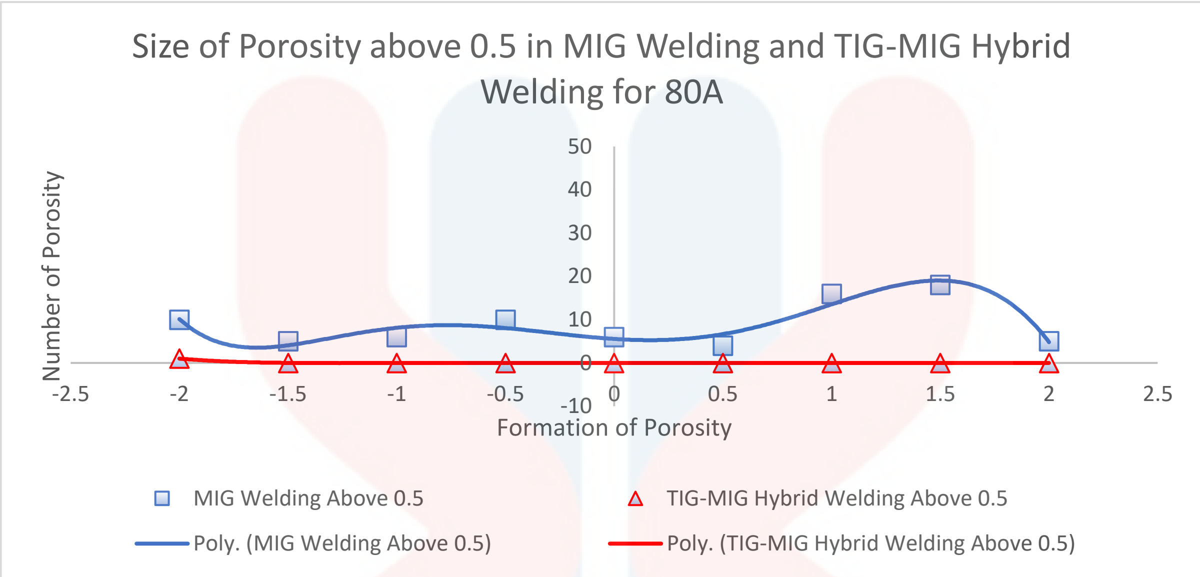


Figure 4.14: Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 80A

III. Sample 90A

The sample shows the different welding processes for 90A are MIG Welding and TIG-MIG Hybrid Welding with different quantity of size porosity above than 0.5. Based on the figure 4.15 and table 4.15, the MIG Welding sample for 90A has 98 total porosity sizes above than 0.5mm. At porosity formation -2 has the highest amount of porosity with a porosity value of 19. For the lowest amount of porosity in the MIG Welding sample for 90A is at porosity formation -1 with a porosity value of 7. On the other hand, the TIG-MIG Hybrid Welding sample for 90A has 8 total porosity above than 0.5mm. At porosity formation -0.5 has the highest amount of porosity with a porosity value of 3. For the lowest amount of porosity in the TIG-MIG Hybrid Welding sample for 90A is at a porosity formation of -2, 0.5, 1.5, and 2 with a porosity value of 0.

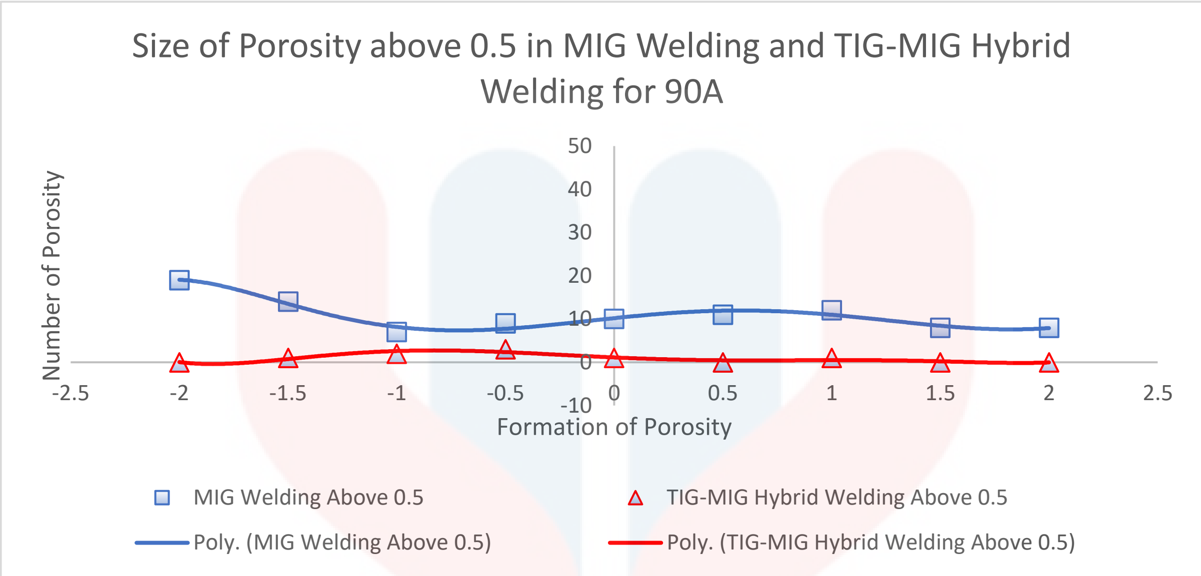


Figure 4.15: Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 90A

IV. Sample 100A

The sample shows the different welding processes for 100A are MIG Welding and TIG-MIG Hybrid Welding with different quantity of size porosity above than 0.5. Based on the figure 4.16 and table 4.16, the MIG Welding sample for 100A has 89 total porosity sizes above than 0.5mm. At porosity formation 2 has the highest amount of porosity with a porosity value of 32. For the lowest amount of porosity in the MIG Welding sample for 100A is at porosity formation -0.5 with a porosity value of 3. On the other hand, the TIG-MIG Hybrid Welding sample for 100A has 15 total porosity above than 0.5mm. At porosity formation -0.5 and 0 has the highest amount of porosity with a porosity value of 4. For the lowest amount of porosity in the TIG-MIG Hybrid Welding sample for 100A is at a porosity formation of -1.5, 1 and 2 with a porosity value of 0.

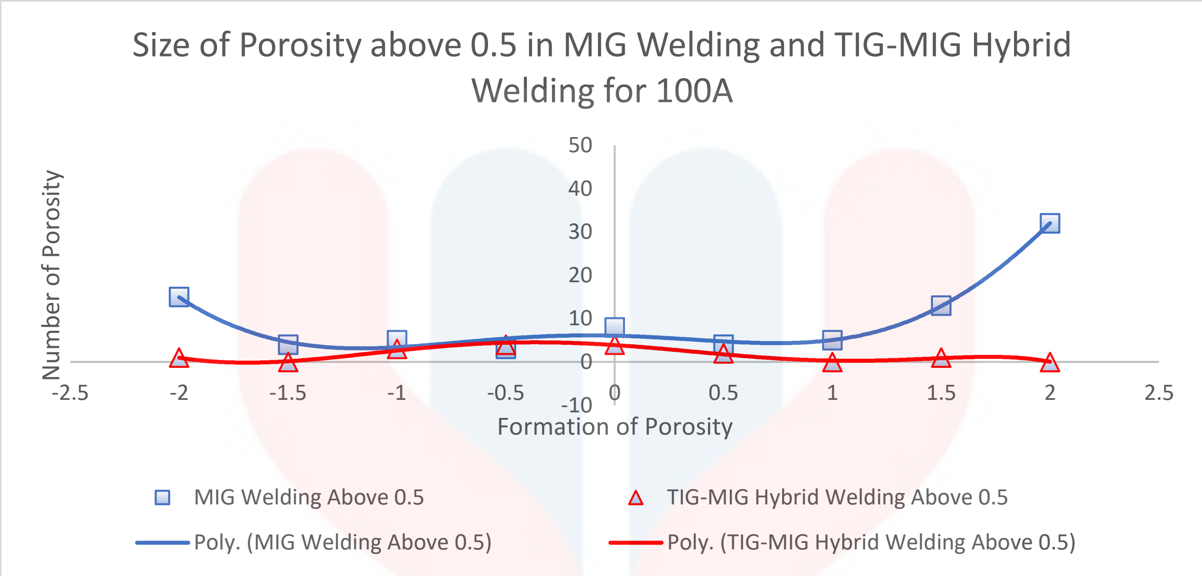


Figure 4.16: Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 100A

V. Total Number of Porosity Above 0.5mm

Both table 4.17 and Figure 4.17 illustrate the total number of pores in the weld bead for each sample. For the MIG Welding sample, it can be seen that the porosity has increased from 58 porosity at 70A current to 98 porosity at 90A current. The increase is 40 porosity. But at a current of 100A it experienced a decrease in porosity from 98 porosity to 89 porosity. The decrease is 9 porosity. It can be concluded that when the current increases, it will increase the amount of porosity formed in the weld bead. But when the temperature is relatively high, it can reduce the porosity that is larger than 0.5. For the TIG-MIG Hybrid Welding sample, at a current of 70A, the porosity value is quite high which is 17 porosity. But at a current of 80A it experienced a decrease in porosity from 17 porosity to 1 porosity. However, when the current is 90A the formation of porosity in the weld bead starts to increase from 1 porosity to 8 porosity and at a current of 100A, it continues to increase from 8 porosity to 15 porosity. Increase from

80A current to 100A by 14 Porosity. It can be concluded, when using TIG-MIG Hybrid Welding at the right current for the sample, it can drastically reduce the amount of porosity as well as reduce the defects that occur in the weld bead.

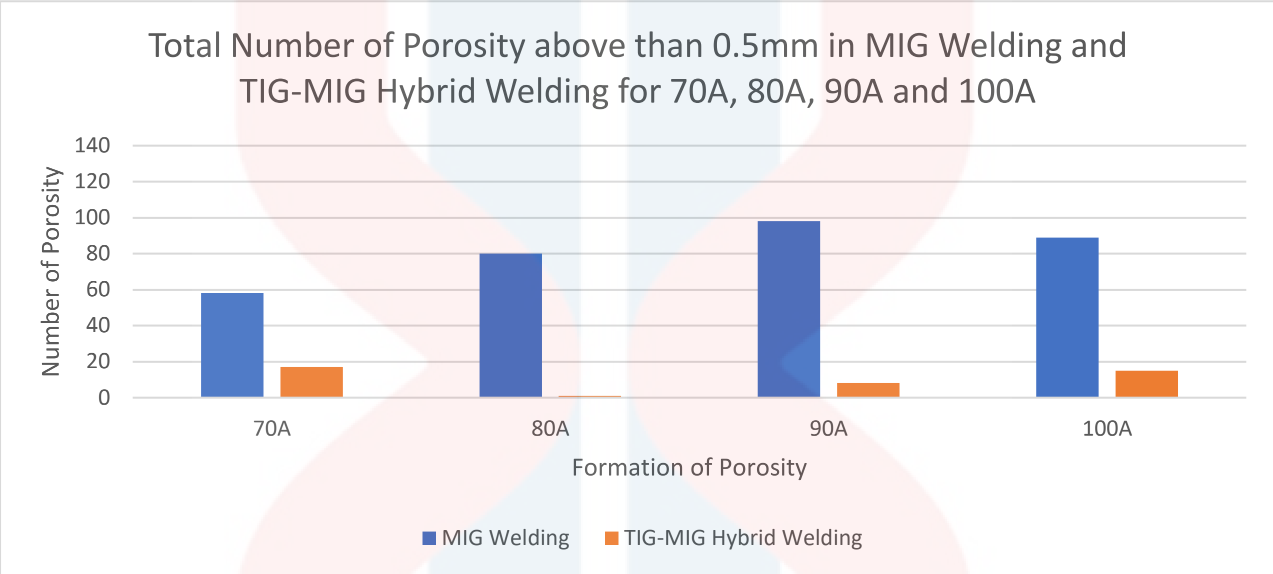


Figure 4.17: Total Number of Porosity above than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

4.2.5 Vickers Hardness in Welded aluminium 5083

I. Vickers Hardness in MIG Welding and TIG-MIG Hybrid Welding for 90A

Samples showing different welding processes for 90A are MIG Welding and TIG-MIG Hybrid Welding with vickers hardness test. Based on the table 4.19 and figure 4.19, the MIG Welding sample for 90A has a peak at the weld with a value of 100HV. At point -3 which is the base metal, the value is 92HV and starts to increase to 93HV at point -2 which is in the HAZ area. It is due to welding causing changes in the microstructure of the material, such as the formation of the heat affected zone (HAZ). This transformation can affect the hardness profile along the weld joint. Because of this, the HAZ area receives very little temperature from MIG Welding which makes the value slightly higher than in the base metal area. Then it continues to increase from 93HV to 100HV from point -2 to point 0. It is because in that area the heat input during the MIG welding process plays a big role in determining the hardness of the weld joint. High heat input can result in changes to the microstructure of the material, affecting its hardness. For this reason, the highest hardness value is in the middle of the weldment metal. And it starts decreasing from 100HV to 88HV. It starts from point 0 to point 88. For the TIG-MIG Hybrid Welding sample, for 90A has its peak value at weldment metal which is point 0 with a value of 76HV. At point -3 which is the base metal, the value is 67HV and starts to increase to 69HV at point -2 which is in the HAZ area. The microstructure of the material undergoes changes during welding, including the creation of heat-affected zones (HAZ). The hardness profile across the welded joint may be affected by these changes. Because of this, the HAZ area receives very little temperature from TIG-MIG Hybrid Welding which makes the value slightly higher than in the base metal area. Then it continues to increase from 69HV to 76HV from point -2 to point 0. It is because in that area the heat input during the MIG welding process plays an important role in determining the hardness of the welded joint. Higher heat input can result in changes to the microstructure of the material, affecting its hardness. For this reason, the hardness value is the highest in the middle of the weldment metal. However, the rate of evaporation after the welding process affects the hardness. Fast evaporation may produce a harder microstructure, while slower evaporation may produce a softer structure. This is the reason why the Vickers hardness value for MIG Welding is higher than TIG-MIG Hybrid Welding because when cooling in the weldment metal area causes the sample for MIG Welding to be harder than TIG-MIG Hybrid Welding. And it started to decrease from 76HV to 67HV. It starts from point 0 to point 3.

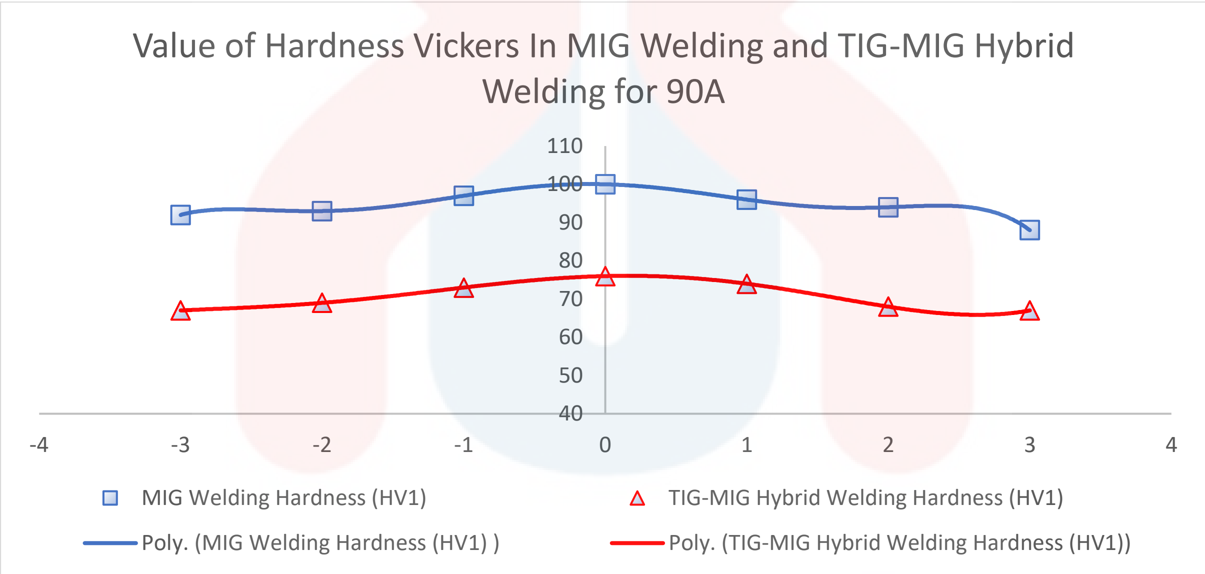


Figure 4.18: Value of Hardness Vickers in MIG Welding and TIG-MIG Hybrid Welding for 90A

II. Vickers Hardness in MIG Welding and TIG-MIG Hybrid Welding for 90A

Samples showing different welding processes for 90A are MIG Welding and TIG-MIG Hybrid Welding with vickers hardness test. Based on the table 4.20 and figure 4.20, the MIG Weld sample for 100A has a peak at the weld with a value of 103HV. At point -3 which is the base metal, the value is 74HV and starts to increase to 80HV1 at point -2 which is in the HAZ area. It is due to welding causing changes in the microstructure of the material, such as the formation of the heat affected zone (HAZ). This transformation can affect the hardness profile along the weld joint. Because of this, the HAZ area receives very little temperature from MIG Welding which makes the value slightly higher than in the base metal area. Then it continues to increase from 80HV to 103HV from point -2 to point 0. It is because in that area the heat input during the MIG welding process plays a big role in determining the hardness of the weld joint. High heat input can result in changes to the microstructure of the material, affecting its hardness. For this reason, the highest hardness value is in the middle of the weldment metal. And it started decreasing from 103HV to 68HV. It starts from point 0 to point 3. For the TIG-MIG Hybrid Welding sample, for 100A has its peak value at weldment metal which is point 0 with a value of 80HV. At point -3 which is the base metal, the value is 70HV and starts to increase to 73HV at point -2 which is in the HAZ area. The microstructure of the material undergoes changes during welding, including the creation of heat-affected zones (HAZ). The hardness profile across the welded joint may be affected by these changes. Because of this, the HAZ area receives very little temperature from TIG-MIG Hybrid Welding which makes the value slightly higher than in the base metal area. Then it continues to increase from 73HV to 80HV from point -2 to point 0. It is due to the fact that in that area the heat input during the MIG welding process plays an important role in determining the hardness of the welded joint. Higher heat input can result in changes to the microstructure of the material, affecting its hardness. For this reason, the hardness value is the highest in the middle of the weldment metal. However, the rate of evaporation after the welding process affects the hardness. Fast evaporation may produce a harder microstructure, while slower evaporation may produce a softer structure. This is the reason why the Vickers hardness value for MIG Welding is higher than TIG-MIG Hybrid Welding because when cooling in the weldment metal area causes the sample for MIG Welding to be harder than TIG-MIG Hybrid Welding. And it starts to decrease from 80HV to 59HV. It starts from point 0 to point 3.

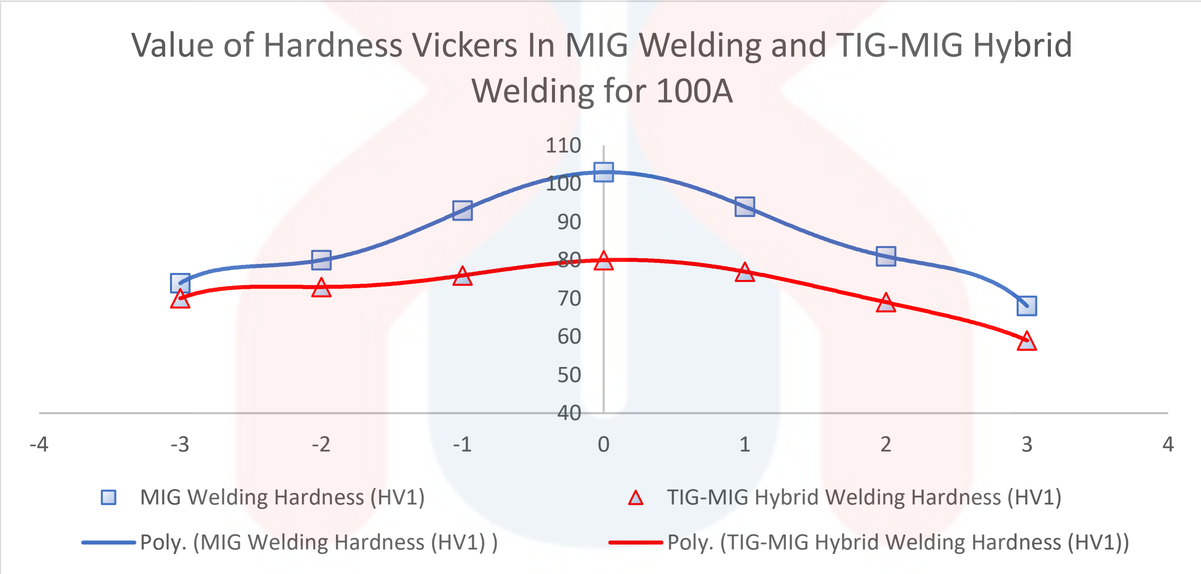


Figure 4.19: Value of Hardness Vickers In MIG Welding and TIG-MIG Hybrid Welding for 90A

III. Relationship between porosity and Vickers Hardness testing in aluminium welding

The relationship between porosity and Vickers Hardness testing in aluminum welding, especially with MIG welding (Metal Inert Gas) and TIG-MIG hybrid welding (Tungsten Inert Gas - Metal Inert Gas), involves several factors related to porosity in aluminum welding. Effect of Porosity on Hardness Vickers porosity introduces cavities or gas pockets in aluminum structures. These cavities act as stress concentrators and can result in a decrease in Vickers hardness. Porosity, or the presence of gas voids in aluminum weld joints, can negatively affect Vickers hardness. These voids act as weak points in the structure, causing a decrease in hardness and the material's ability to withstand penetration. In addition, it is also caused by the influence of the welding process itself. In MIG welding, the use of a constant wire feed and high welding speed can contribute to variations in heat input, affecting the formation of porosity. Therefore, that can happen when hydrogen is absorbed during the welding process. Porosity often indicates the presence of hydrogen, and its retarding effect will affect the Vickers hardness of aluminum welding. Hybrid TIG-MIG welding, which combines the precision of TIG welding with the efficiency of MIG welding, provides better control of heat input and reduced porosity compared to MIG welding. So, the goal is to create a strong weld with minimal porosity for an accurate Vickers hardness test. Overall, the relationship between porosity and Vickers hardness test in aluminum welding, whether produced by MIG welding or hybrid TIG-MIG welding, emphasizes the importance of controlling welding parameters and reducing porosity. The presence of porosity can compromise the structural integrity and hardness of aluminum welds, emphasizing the need for accurate welding practices and careful quality control measures.

4.3 The Effect of Welding Process Towards Porosity Formation

The mode of solidification, rate of cooling, degree of convective fluid flow, welding parameters, bead shape, shielding gas mixture, and pressure outside the weld determine the size, shape, position, and amount of hydrogen pores. Welding parameters like current, power density, arc length, speed, flow rate, and shielding gas composition affect the width and depth of the fusion zone, which affects hydrogen absorption and porosity formation. The proportion of porosity in welds may also be affected by a variety of parameters that are particular to a specific welding method. In the following paragraphs, these comprehensive parameters will be presented for each reviewed procedure.

By cycles of convection or stream flow, gas porosity always forms an annular pattern in the weld pool. The convection on the surface of the weld pool is caused by buoyancy force, electromagnetic force, and surface tension gradient. During this experiment, if the flows upwards, gas bubbles can escape, but they can be caught if the flow moves downwards and solidifies them. Due to the pool's strong magnetic field and relatively modest surface tension gradient, convection flows from the pool's centre to its surface and, in some cases, back up to the fusion boundary. Due to the fact that trapped pores are consistently distributed at the top layer of the fusion zone, gas pores will frequently be found dispersed at the top of the weld pool. According to solidification theory, a sudden increase in solidification rate at the solid-liquid interface will result in a solute-rich band of solidified metal and a porosity-entrapped zone (Kanemaru et al., 2015)

CHAPTER 5

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project was conducted to compare the effect of conventional MIG welding and TIG-MIG welding on the reduction of porosity in welded aluminum, as well as to investigate the formation of porosity during welding. The aim was accomplished, and the following conclusion can be drawn from the results obtained:

1. It was found that the lower current and welding speed could cause more porosity on the Aluminium 5083 specimen.
2. MIG welding process has the highest amount of porosity formation compared to TIG-MIG hybrid welding process.
3. TIG-MIG hybrid welding process could delay the solidification time during welding which contributed to the lowest amount of porosity formation in welded aluminum.
4. During MIG welding process, the bubbles tend to move upwards and some of the pores are disabled to escape sufficiently mainly existed in upper region where pore clusters occurred.
5. The reduction of cooling rate reduce or delay the solidification process on the molten pool which resulting in lowest porosity formation.

5.2 Recommendation

This study provides the first complete TIG MIG hybrid welding assessment on aluminum using leading MIG. Despite this, it's possible that these findings can't yet be implemented in a lot of different fields. Several recommendations for further finding can be made in order to improve the better results such as study the visual appearance (weld toe angle, weld bead size, weld reinforcement height, weld penetration height) for both conventional MIG and TIG MIG hybrid welding process. It can be carried out by using different type of Aluminium grades, as well as different welding parameters to determine the good weld appearance. In future study, the microstructural analysis such as Scanning Electron Microscope (SEM) and x-ray diagram can be used to obtain more accurate and clearer observation of porosity formation. Brunauer-Emmett-Teller (BET) analysis, on the other hand, can be utilized to determine the mechanism of porosity distribution. This is an important approach for determining the specific surface area of materials.

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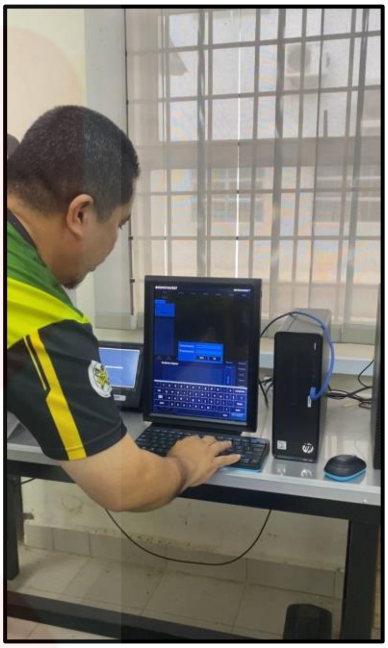
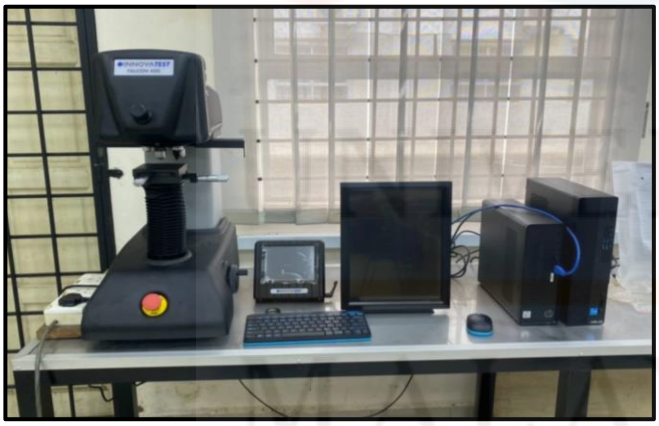
APPENDIX

Do the MIG Welding

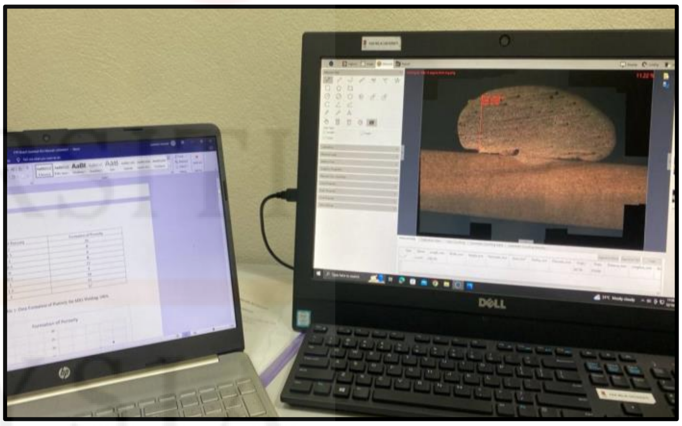
Do the TIG-MIG Welding



Mr Saiful explained about using Machine Hardness Vickers



Machine Hardness Vickers



Do the Optical Microscopy (OM)

Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 70A

Formation of Porosity	MIG Welding	TIG-MIG Hybrid Welding
-2	8	2
-1.5	7	4
-1	13	5
-0.5	8	0
0	7	1
0.5	10	6
1	5	6
1.5	9	7
2	4	5
Total	71	36

Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 80A

Formation of Porosity	MIG Welding	TIG-MIG Hybrid Welding
-2	15	4
-1.5	7	1
-1	9	3
-0.5	13	1
0	6	0
0.5	4	2
1	20	1
1.5	22	1
2	6	2
Total	102	15

Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 90A

Formation of Porosity	MIG Welding	TIG-MIG Hybrid Welding
-2	28	1
-1.5	23	4
-1	12	6
-0.5	11	7
0	12	2
0.5	11	2
1	14	3
1.5	9	2
2	8	0
Total	128	27

Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding for 100A

Formation of Porosity	MIG Welding	TIG-MIG Hybrid Welding
-2	26	2
-1.5	8	2
-1	6	3
-0.5	8	11
0	12	7
0.5	4	5
1	10	5
1.5	17	3
2	39	2
Total	130	40

Total Number of Porosity in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

Current/Type of Welding	MIG Welding	TIG-MIG Hybrid Welding
70A	71	36
80A	102	15
90A	128	27
100A	130	40

Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 70A

Formation of Porosity	MIG Welding Less than 0.5mm	TIG-MIG Hybrid Welding Less than 0.5mm
-2	2	1
-1.5	2	3
-1	3	3
-0.5	0	0
0	1	0
0.5	2	3
1	0	4
1.5	1	2
2	2	3
Total	13	19

Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 80A

Formation of Porosity	MIG Welding Less than 0.5	TIG-MIG Hybrid Welding Less than 0.5
-2	5	3
-1.5	2	1
-1	3	3
-0.5	3	1
0	0	0
0.5	0	2
1	4	1
1.5	4	1
2	1	2
Total	22	14

Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 90A

Formation of Porosity	MIG Welding Less than 0.5	TIG-MIG Hybrid Welding Less than 0.5
-2	9	1
-1.5	9	3
-1	5	4
-0.5	2	4
0	2	1
0.5	0	2
1	2	2
1.5	1	2
2	0	0
Total	31	19

Size of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding for 100A

Formation of Porosity	MIG Welding Less than 0.5	TIG-MIG Hybrid Welding Less than 0.5
-2	11	1
-1.5	4	2
-1	1	1
-0.5	5	7
0	4	3
0.5	0	3
1	5	5
1.5	4	2
2	7	2
Total	41	26

Total Number of Porosity less than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

Current/Type of Welding	MIG Welding	TIG-MIG Hybrid Welding
70A	13	19
80A	22	14
90A	31	19
100A	41	26

Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 70A

Formation of Porosity	MIG Welding Above 0.5	TIG-MIG Hybrid Welding Above 0.5
-2	6	1
-1.5	5	1
-1	10	2
-0.5	8	0
0	6	1
0.5	8	3
1	5	2
1.5	8	5
2	2	2
Total	58	17

Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 80A

Formation of Porosity	MIG Welding Above 0.5	TIG-MIG Hybrid Welding Above 0.5
-2	10	1
-1.5	5	0
-1	6	0
-0.5	10	0
0	6	0
0.5	4	0
1	16	0
1.5	18	0
2	5	0
Total	80	1

Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 90A

Formation of Porosity	MIG Welding Above 0.5	TIG-MIG Hybrid Welding Above 0.5
-2	19	0
-1.5	14	1
-1	7	2
-0.5	9	3
0	10	1
0.5	11	0
1	12	1
1.5	8	0
2	8	0
Total	98	8

Size of Porosity above 0.5 in MIG Welding and TIG-MIG Hybrid Welding for 100A

Formation of Porosity	MIG Welding Above 0.5	TIG-MIG Hybrid Welding Above 0.5
-2	15	1
-1.5	4	0
-1	5	3
-0.5	3	4
0	8	4
0.5	4	2
1	5	0
1.5	13	1
2	32	0
Total	89	15

Total Number of Porosity above than 0.5mm in MIG Welding and TIG-MIG Hybrid Welding in 70A, 80A, 90A and 100A

Current/Type of Welding	MIG Welding	TIG-MIG Hybrid Welding
70A	58	17
80A	80	1
90A	98	8
100A	89	15

Value of Vickers Hardness in MIG Welding and TIG-MIG Hybrid Welding for 90A

Measurement Point	MIG Welding Hardness (HV)	TIG-MIG Hybrid Welding Hardness (HV)
-3	92	67
-2	93	69
-1	97	73
0	100	76
1	96	74
2	94	68
3	88	67

Value of Hardness Vickers In MIG Welding and TIG-MIG Hybrid Welding for 100A

Measurement Point	MIG Welding Hardness (HV)	TIG-MIG Hybrid Welding Hardness (HV)
-3	74	70
-2	80	73
-1	93	76
0	103	80
1	94	77
2	81	69
3	68	59