WELD QUALITY COMPARISON BETWEEN FUSION WELDING AND SOLID STATE WELDING ON AA1100

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

By

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DECLARATION

I hereby, declared this report entitled "Weld Quality Comparison between Fusion Welding and Solid State Welding on AA1100" is the results of my own research except cited in reference.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

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Dr. Mohammad Kamil bin Sued

ABSTRACT

AA 1100 is widely used in many fields of engineering such as marines, aerospace and automobile. This is because, AA1100 portrays unique properties such as resistance to corrosion, high strength, lightweight, good conductor of electricity and heat and many others. Many types of welding have been proposed by industry in order to join this metal, either from fusion welding or solid state welding. From literature review, one best welding from each type has been compared and selected to be compared on its weld quality on AA1100. The properties of wrought alloy AA1100 that is best undergoes cold worked makes BFSW welding is the best welding to be performed on joining AA1100 rather than TIG welding. Taguchi design of experiment was develop using Minitab software to develop weld run parameter, optimization, regression and validation error. TIG welding parameter which were current (180, 200, and 230 A) and weld speed (12, 13, and 15 cm/min) were selected by previous study and pilot test. While BFSW welding parameter which were rotation speed (800, 900 and 1000 rpm) and weld speed (90, 105 and 150 mm/min) were also selected by previous study and pilot test. The weld quality was compared after optimization parameter weld run by the results on mechanical strength from tensile strength, hardness and weight of weld. Also, the defects and weld time were observed. Throughout the welding process, the weld response which was temperature was recorded using thermocouple to observe the behavior of weld response during the welding process. The optimize parameter for TIG were 230 A and 15 cm/min, while BFSW welding optimize parameter were 800 rpm and 90 mm/min. BFSW wins at every test except for hardness due to filler metal addition in TIG weld. The result was approved by validation error below than 10% which are 7.10% and 0.07% for TIG welding and BFSW welding respectively.

ABSTRAK

AA1100 digunakan dengan sangat meluas di dalam bidang kejuruteraan seperti marin, aeroangkasa dan automobil. Ini adalah kerana, AA1100 mempunyai ciri ciri yang unik seperti tahan karat, kekuatan yang tinggi, ringan, konduktor yang bagus untuk elektrik dan haba dan sebagainya. Terdapat banyak jenis kimpalan yang telah diusulkan oleh industri untuk mencantumkan besi ini, samada daripada kimpalan gabungan atau kimpalan pepejal. Menurut kajian literatur, satu jenis kimpalan terbaik dari setiap jenis telah dibandingkan dan dipilih untuk dibandingkan dari segi kualiti kimpalan pada AA1100. Ciri-ciri aloi tempa AA1100 yang lebih sesuai melalui kerja sejuk membuatkan kimpalan BFSW menjadi yang terbaik untuk dilakukan bagi mencantumkan AA1100 berbanding kimpalan TIG. Reka bentuk experiment Taguchi telah dilakukan menggunakan perisian Minitab untuk menjana parameter bagi melakukan eksperimen kimpalan, regresi dan pengesahan ralat. Parameter kimpalan TIG ialah arus elektrik (180, 200, dan 230 A) dan kadar kelajuan kimpalan (12,13 dan 15 cm/min) telah dipilih berdasarkan kajian literatur dan ujian perintis. Sementara itu, parameter kimpalan BFSW ialah kelajuan putaran (800, 900 dan 1000 rpm) dan kadar kelajuan kimpalan (90, 105 dan 150 mm/min) juga dipilih melalui kajian literatur dan ujian perintis. Kualiti kimpalan telah dibandingkan selepas pengoptimuman parameter kimpalan daripada hasil kekuatan mekanikal dari ujian tegangan, kekerasan dan berat kimpalan. Selain itu, kecacatan pada kimpalan dan kadar masa yang diambil juga diperhatikan. Sepanjang proses kimpalan berlangsung, kadar suhu sebagai tindak balas kimpalan diambil menggunakan pengesan haba untuk memerhatikan tindak balas suhu semasa proses kimpalan. Parameter optimum bagi kimpalan TIG ialah 230 A dan 15 cm/min, sementara parameter optimum bagi kimpalan BFSW ialah 800 rpm dan 90 mm/min. Kimpalan BFSW memberi hasil terbaik bagi setiap ujian kecuali pada ujian kekerasan atas sebab penambahan logam pengisi pada kimpalan TIG. Hasil telah dibuktikan dengan pengesahan ralat bawah daripada 10% iaitu 7.10% dan 0.07% untuk kimpalan TIG dan kimpalan BFSW masing-masing.

DEDICATION

TO MY BELOVED PARENT AND GRANDPARENT,

Nor Aslan Bin Abd. Hamid, Mashithah Binti Maarof, Maarof Bin Jamaluddin and Normah Binti Ujang and all of my family members.

For their supports and prayers throughout my life

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LIST OF ABBREVIATIONS

AA1100	–	Aluminium Alloy 1100
TIG	–	Tungsten Inert Gas
BFSW	–	Bobbin Friction Stir Welding
SMAW	–	Shielded Metal Arc Welding
MIG	–	Metal Inert Gas
GTAW	–	Gas Tungsten Arc Welding
GMAW	–	Gas Metal Arc Welding
FSW	–	Friction Stir Welding
CNC	–	Computer Numerical Control
DOE	–	Design Of Experiment
$Al_2 O_3$	–	Aluminium Oxide
HAZ	–	Heat Affected Zone
UV	–	Ultra Violet
AC	-	Alternating Current
DCEN	–	Direct Current Electrode Negative
DCEP	–	Direct Current Electrode Positive
Ar	-	Argon
He	-	Helium
TWI	–	The Welding Institute
NDT	–	Non- Destructive Test

LIST OF SYMBOLS

A	-	Ampere
Cm/min	–	Centimetre per minute
Rpm	–	Revolution per minute
Mm/min	–	Milimetre per minute
%	-	Percent
Mm	-	Milimetre
°	-	Degree
˚C	–	Degree Celcius
KN	–	Kilo Newton
HV	–	Hardness Vickers
δ	-	Stress
β	-	Beta
Cm	-	Centimetre
N/mm^2	–	Newton per milimetre square
G	-	gram

LIST OF EQUATIONS

CHAPTER 1
INTRODUCTION

The introduction of this project means to elaborate the main idea of the project by introducing its title, background, problem statement, objective, the significance and the scope that are going to be focused in this final year project.

1.1 Background of Project

Nowadays, many manufacturing industry such as automotive, aerospace, ship building and others find it useful to use welding process to join materials for many application such as for production process or maintenance. It provides permanent joint and good strength rather than mechanical joint that needs additional part like bolts and nuts, have low strength and also need additional cost to buy parts and assemble.

However, it depends on the function and requirement of the product to choose either welding or mechanical joint. In most critical area like ships, aerospace and automotive, they face high pressure, heavy loads and force that needs permanent and good joint that can sustain the loads and pressure, have longer life spent with lower maintenance cost. Welding also can be applied on field where it can be used on-the-go without specific area of working.

Beside steels, aluminium alloy like Aluminium Alloy 1100 (AA1100) have started to be used widely in welding because of its excellent ductility, corrosion and chemical resistance, high strength, high machinability and easy to weld properties. It is also been widely applied in aerospace, marines and automotive because of its good strength, ductile and light weight properties (Ankur and Rakesh, 2018).

Because of the advantages in aluminium alloy, many industries work on their research and development to enhanced available welding process or invent a new type of welding to weld aluminium alloys. There are two big family of welding that is fusion welding and solid state welding. Even though fusion welding like Shielded Metal Inert Gas Welding (SMAW), Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) are the most economical way to use in terms of cost than solid-state welding, but it can cause many defects such as shrinkage, porosity, cracking, deformation and corrosion. It also causes hazards like spatters, sparks, fumes and smokes. Fusion welding also needs addition of shielding gas, filler metal, surface cleaning and finishing process that will increase the cost. Thus it can be eliminated by solid state welding like Friction Stir Welding (FSW) and Bobbin Friction Stir Welding (BFSW) (Adam, 2018).

While for solid state welding, there is FSW and BFSW. FSW performs below the melting point of work piece material; the heat is produced by contact friction between the tool shoulder and the work piece to be weld. Then, plastic deformation of material occurs and been mixed and stirred by the thread pin. FSW uses a bar-like tool that is from wear resistance material such as H13, with a shoulder and a threaded pin. It can weld a long material below the melting point, producing fine grain structure, which gives advantage on having a good microstructure and mechanical properties on product. Its distortion and residual stresses are lower than fusion welding. Moreover, it consumes low energy and does not need shielding gas, filler, pre-welding preparation and cleaning process (Prakash and Gurunath, 2018).

BFSW is a solid- state welding that also make joint of materials below the melting point. It use bar like tool from non-consumable tool like H13. The difference from FSW tools is it uses two shoulder tool that give force and one pin that stirred material. This process eliminates need of an anvil and axial forces that needed in FSW (Adam, 2018). BFSW also eliminates weld roots and root defects, lower distortion due to uniform heat input, have simple control process and tolerate to thickness variation. Moreover, BFSW is likely more safe to environment as it consumes low energy that is below the energy consumed by FSW (Sued *et al*, 2017) and it also do not produce ultraviolet light, smokes or fumes during welding process. It also gives better microstructure than fusion welding due to net axial force almost zero, and produce fine grain structure that affects the mechanical properties to have better strength and hardness.

1.2 Problem Statement

Welding of aluminium alloy have been started to be venture in many fields like aerospace, marine, automotive and more. This is because aluminium alloy possess good properties like ductile, good machinability, easy to weld, high strength, lightweight and good corrosion and chemical resistant. Aluminium alloy 1100 is a wrought alloy where it contains 99.00% of aluminium alloy in its composition and it is a non-heat treated alloy where it usually gains strength by strain hardening or cold working (Lincoln, 2016).

Fusion welding possesses many defects such as porosity, crack, deformation and more. It also needs surface preparation and finishing before and after the welding process. In addition, it also needs additional tools such as shielding gas and filler metal that can increase the cost. Moreover, fusion welding is not environmental friendly and safe for the operator. This is because, it produces sparks, fumes, UV light, spatters that can cause harm to environment and operator. It also uses high heat input to produce deeper penetration (Adam, 2018).

However, solid state welding operates below the melting point of material. Thus, it can contribute to finer grain that can enhance the strength of weld. By operating below the melting point, it uses lower parameter input to give full penetration of weld. This weld does not produce hazards that make it safe to be operated by people and environmental friendly. It also gives lower cost as it does not need additional tool, surface preparation and finishing process (Sued *et al*, 2017).

In a nutshell, considering the properties of AA1100 that is better undergoes cold working, solid state welding is proposed to be better than fusion welding. Going ahead to greener technology and optimized cost, quality and time leads to the hypothesis that solid state welding will be better than fusion welding on AA1100.

1.3 Objective

The objectives of this study are:

I. To compare the mechanical properties between Bobbin Friction Stir Welding (BFSW) and Tungsten Inert Gas (TIG) welding.
II. To investigate the microstructure (defect) on AA1100 welded using Bobbin Friction Stir Welding (BFSW) and Tungsten Inert Gas (TIG) welding.
III. To determine weld process time for Bobbin Friction Stir Welding (BFSW) and Tungsten Inert Gas (TIG) welding

1.4 Significant Of Study

Fusion welding like TIG, MIG and SMAW are well known for defects that can occur after the welding, such as porosity, crack, deformation and more. Even though it is more economical than solid state welding, it causes hazard and not eco-friendly to the environment and user. This is because it produces sparks, fumes, smokes and uses high energy. Thus, it is not safe to operate and can contribute to environment pollution. Solid state welding like FSW and BFSW is more eco-friendly and safe to be use by the operator and the environment. It consumes less energy, low cost, do not need for surface preparation, good degree of cleanliness and do not produce spatter, sparks, smokes and fumes. It also gives good mechanical strength and microstructure since it happens below the melting point, which reduces the microstructure change that will directly affect the mechanical strength to be better than fusion welding.

1.5 Scope

The scope of this project is to perform BFSW welding and TIG welding on AA1100. The BFSW welding will be performed by using 3-axis CNC milling machine and the TIG welding will be conducted by using TIG robot welding machine. Both of this welding will be performed by certified welder to get accurate result. This project will use Taguchi as the design of experiment (DOE) in Minitab software. The parameters variable will be current (180, 200, and 230 A) and weld speed (12, 13, and 15 cm/min) for TIG welding. While parameters variable for BFSW welding are rotation speed (800, 900 and 1000 rpm) and weld speed (90, 105 and 150 mm/min).

Furthermore, the work piece length will be 140 mm x 140 mm x 6 mm. Both welding will be weld with butt joint design. For TIG welding, material will be chamfered to achieve v groove 30˚ and 2 mm root gap. This work piece will be observed on tensile strength, hardness, weight and the microstructure (defect) of the welding quality. Throughout the welding processes, weld time will be observe to determine the time consume for the welding by using stopwatch. Optimization and validation process will be analyze using Minitab software, Taguchi design.

CHAPTER 2
LITERATURE REVIEW

This chapter will discussed about this final year project title from past researches and studies. It will then elaborate and analyze the findings and information regarding this project to gain more understanding and constructing the methodology.

2.1 Aluminium Alloy

On December 1884, Washington Monument was built and it was capped with a 100 oz. of pure aluminium because it is considered as a valuable metal. It was not widely used back then because it is known as reactive metal and always found tightly bound with Aluminium Oxide (Al_2O_3) that also known as bauxite ore. Then, when on 1886, American Charles M. Hall and Frenchman Paul Heroult discovered a process to obtain pure aluminium from aluminium oxide using electrolytic process, aluminium become one of the widely use on many proposes in industry. Because of the massive amount of electric power required to produce aluminium, aluminium have higher cost relative to steel (V. Mohanavel *et al.,* 2018)

Aluminium is widely used in many applications such as to conduct heat and electric slightly good as copper that is used in electrical bus bars and other conductors. It also used in marine and chemical environments because of their good corrosion resistance. In addition, because of the lightweight and high strength makes it a choice to be applied in automobile and aerospace.

Furthermore, aluminium has basic properties that make it a unique material. First, it is lightweight, where its weight is about 1/3 of steel. Second, it has strength that range from 13,000 psi tensile strength for pure aluminium up to 90,000 psi tensile strength for the strongest heat- treatable aluminium alloys. Third, it provides a good resistance towards corrosion from the thin refractory oxide that forms on the surface of aluminium that functions as protective barrier. Fourth, it is a good heat conductor, five times more thermally conductive than steel. Fifth, because of the surface finish on aluminium, it reflects radiant heat. Lastly, it is available in many shapes either extruded shapes or wrought sheet in variety alloy composition (Hui Lee *et al.*, 2017).

Upon welding aluminium, it has difference than welding steel. First, all steel are weldable but some of aluminium alloys is not arc weldable, especially the stronger ones. Second, steels are heat-treatable, but for aluminium, some of them are not, called non-heat treatable aluminium. Even the heat-treatable aluminium alloys have different heat-treating method than steels. Lastly, when welding steels, steel will usually gain more strength than parent material, but aluminium alloys usually not as strong as the parent material, where the difference between weld and heat affected zone (HAZ) usually 30% or more.

Aluminium can be alloyed with different elements to enhance its corrosion resistance, strength and weldability. Primary elements that are generally alloyed with aluminium are silicon copper, magnesium, zinc and manganese. Aluminium alloys can be divided to two families that is wrought alloys or cast alloys and it can be classes to heat-treatable and non- heat treatable. Where heat-treatable alloys will be heat treated to improve its mechanical properties and non-heat treatable alloys will undergo through cold working or strain hardening to increase its strength. The higher the deformation applied on non-heat treatable aluminium alloy, the stronger it will get. But at some point it will gain low ductility and starts to fracture (Lincoln, 2016).

2.1.1 Aluminium Alloy 1100 (AA1100)

Aluminium Alloy 1100 (AA100) is a wrought alloy and non-heat treatable. Figure 2.1 shows the wrought alloy family designation.

Table 1-1: Wrought Alloy Designations

Alloy Family	Main Alloying Elements	Heat-treatable
1xxx	Pure Aluminum	No
2xxx	Copper (sometimes with magnesium)	Yes
3xxx	Manganese (sometimes with magnesium)	No
4xxx	Silicon	No
5xxx	Magnesium	No
6xxx	Magnesium plus silicon	Yes
7xxx	Zinc (sometimes with magnesium & copper)	Yes
8xxx	All others	Normally Yes

Figure 2.1: Wrought Alloy Designation (Lincoln, 2016)

AA1100 is pure aluminium that contains no alloying elements. It is applied in pipe and chemical tanks because of the excellent chemical and corrosion resistance. It also usually used in electrical bus conductor because it conducts electric excellently (Lincoln, 2016). To understand the behavior of AA1100 when it undergoes welding, the composition and properties of aluminium alloy need to be study. Table 1.2 (a) and (b) below shows the composition and properties of AA1100 respectively.

Table 1.2: (a) Composition of AA1100 (Ambriz and Mayagoitia, 2011)

Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr
99	-	0.7	0.25	0.20	0.10	-	0.05	-

Table 1.2: (b) Properties of AA1100 (Ambriz and Mayagoitia, 2011)

Properties	AA1100
Ultimate tensile strength (MPa)	147
Yield Strength (MPa)	69.8
Elongation (%)	24.5
Microharndess (0.2 kg)	50.5

2.2 Shielded Metal Arc Welding (SMAW)

SMAW is also known as stick welding. It is one of the types in fusion welding that joins metals after melting the base metal using the heat that is produced by electric arc. The heat produced will then melts the flux at the tip of electrode and the wire core. The molten material is then transferred to the base metal, goes into the weld pool and solidifies in the base metal. Due to the low density of the flux, make it floats on the surface of the weld pool and solidifies as a layer of slag. The flux is functioned to deoxidize, protect, and stabilize the arc and adding alloy elements. Finally, the flux will form a slag that needs to be removed at the end of the welding process. Shielding gas is used due to high temperature and covers the molten metal, eliminates oxides produced and cleans the weld metal.

Even though SMAW is the most economical welding process among all, but it does not give sufficient degree of cleanliness, have limited deposit rate and the electrode need to be changed continuously because of the short length of electrode that can lead to time consume. It also produce hazards more than MIG and TIG like UV rays, spatters, sparks, fumes and more that is not safe for the environment and user to operate the weld(Ambriz and Mayagoitia, 2011).

2.3 Metal Inert Gas (MIG) Welding.

MIG or also known as Gas metal arc welding (GMAW) is one of the most employed welding processes used in welding of aluminium alloy. It is one of fusion welding where it joins metals by melting between continuous wires that act as electrode and work piece with the heat produced by electric arc. It uses a small diameter of electrode wire that is continuously fed into the arc from a coil. Thus make it have less production time and a neat weld joint. The process is shielded by inert gas such as argon and helium that is usually used when welding an aluminium alloy. The electrode and filler metal is consumable and made from chemical composition that is similar to its base material that