THE EFFECTS OF PIN PROFILE ON JOINING ALUMINIUM ALLOY BY USING FRICTION STIR WELDING TECHNIQUE

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ABSTRACT

The main objectives of this project are to investigate the effects of tool pin profile and rotational speed towards the joint strength, hardness value, microstructural changes and defects on aluminium AA1100 welded joint. The welding process was done by using friction stir welding technique (FSW) using cylindrical tool pin and cylindrical threaded tool pin. The weld quality was evaluated by mechanical test and metallurgical analysis. Microstructural analysis was done by using optical microscope while Vickers hardness tests and tensile test was conducted to analyze the mechanical properties of weld joint. From the cross sectional area of the weld region, it is found that a wormhole defect occur throughout the weld region. The threaded pin profile produce the highest hardness value which is 68.09 HV at 1700 rpm while highest tensile strength is 113.02 MPa at 1600 rpm. The analysis from both microstructural and mechanical test shows that cylindrical threaded tool pin profile produce better weld quality compared to cylindrical pin samples.

ABSTRAK

Objektif utama projek ini adalah untuk mengkaji kesan daripada reka bentuk “tool pin” dan kelajuan pusingan “tool” terhadap kekuatan, ketahanan, perubahan mikrostuktur dan kecacatan daripada kimpalan aluminium AA1100. Proses kimpalan dilakukan menggunakan teknik geseran dan gaulan menggunakan “tool pin” silinder dan silinder beralur. Kualiti cantuman ini diuji dengan menggunakan ujian mekanikal dan analisis metalogi. Analisis mikrostruktur telah dilakukan dengan menggunakan mikroskop optik manakala ujian kekerasan Vickers dan ujian tegangan telah dijalankan untuk menganalisis sifat-sifat mekanik sambungan kimpalan. Daripada potongan bahagian kawasan kimpalan, didapati terdapat kecacatan lubang disepanjang kawasan kimpalan. Kajian mendapati “tool pin” silinder beralur menghasilkan nilai kekerasan tertinggi iaitu 68.09 HV pada kelajuan pusingan 1700 rpm manakala kekuatan tegangan tertinggi ialah 113.02 MPa pada kelajuan pusingan 1600 rpm. Analisis daripada ujian kedua-dua mikrostruktur dan mekanikal menunjukkan bahawa “tool pin” silinder beralur menghasilkan kualiti kimpalan yang lebih baik berbanding sampel pin silinder.

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LIST OF SYMBOLS

σ	True Stress, local stress
F	Force
A	Area
ε	Normal stain
HV	Vickers Hardness value
L	Length
rpm	Revolutions per minute
d	Diameter
Mpa	Mega Pascal
r	Radius
μm	Micrometer
N	Newton
Kp	Kilo Pascal

LIST OF ABBREVIATIONS

FSW	Friction Stir Welding
CNC	Computer Numerical Control
AA	Aluminium alloy
Al	Aluminium
HAZ	Heat Affected Zone
BM	Base Metal
TMAZ	Thermo-mechanical Affected Zone
NZ	Nugget Zone
ASTM	American Society for Testing and Material

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Welding is one of the techniques to join two or more pieces of metal. Nowadays, welding has been used as the most important process in the metalworking process and almost all metal is joint using welding. The applications of welding technique have been used to produce automobile, ship, jet engines and etc. Some advantages of welding are it is the lowest cost for the permanent joining method and it also provide design flexibility. FSW appears as a solution to diminish material waste and to avoid radiation with harmful gas emissions that occur during fusion welding process since FSW as productive and clean weld method (Leitao et al., 2008).

1.2 PROJECT BACKGROUND

Friction stir welding (FSW) is the solid state joining technique which means the process is done without reaching the melting point. Deformation of the material occurs at temperature below melting point during this process (Shitong et al., 2006). This technique involves joining similar and dissimilar metal using rotating tool. FSW is a technology that allows weld to be made of aluminium alloys that cannot be readily fusion arc welded. Compared to traditional welding techniques, FSW reduces the presence of distortions and residual stresses and is being targeted by modern aerospace industry for high performance structural applications. Nowadays FSW is widely used in many manufacturing sectors such as aircraft aerospace, automotive, and shipbuilding.

1.3 PROBLEM STATEMENT

As commonly known, fusion welding of aluminium alloys is accompanied by the defects like porosity, solidification and cracks. FSW is free from this defect since there is no melting taking place during the welding process. Even so, there are still drawbacks that need to be overcome in FSW. The drawbacks are due to the improper plastic flow of materials such as severe softening in Heat Affected Zone (HAZ) and defects like pinhole and cracks (Shitong et al., 2006). This defect can lead to the decrease of tensile properties and ductility strength of welded material. As welding parameters such as tool pin profile and rotational speed play a major role in deciding weld quality, this project looks into the effect of using different tool pin profile and rotational speed on the strength of weld joint and defects that may occur during the welding process of aluminium sheets. This project also investigates the mechanical properties of the weld joint.

1.4 OBJECTIVES OF THE PROJECT

Corresponding to the project background and problem statements, it is decided that the objectives of the project are:

(i) Fabrication of welded aluminium plate using different pin profile and tool rotational speed (rpm).
(ii) Investigate the weld strength and defects.
(iii) Investigate mechanical properties of the joints.

1.5 SCOPES OF THE PROJECT

This project is focusing on designing tools and analyzing the quality of the weld joint. This focus area is done based on the following aspect:

(i) Fabrication of aluminium plate using the different pin profile and tool rotational speed by using CNC Milling machine.
(ii) Analyze the microstructure changes of the weld region microstructure in aluminium alloy using optical microscope.
(iii) Investigate the specimen’s mechanical properties of the weld joint using tensile test and the Vickers hardness test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Welding is the process of joining materials by heating them to the proper temperature. The process can be either with or without the application of pressure, and with or without filler metal. Welding process not only functions to joint similar materials, but dissimilar materials also possible to do.

There are many types of welding process that are commonly used such as Shielded Metal Arc welding, Gas Metal Arc welding, Flux Cored Arc welding, Gas Tungsten Arc welding and Friction Stir welding (FSW).

This chapter also represents the review of FSW. This chapter begins with a general review of processes by giving a simple definition of what FSW actually is and the role of tool in this project.

2.2 FRICTION STIR WELDING

FSW is a process of emerging solid state joining process where the material being welded does not melt and recast which means the joining process is done without reaching the melting point. The processes also occur without the use of a brazing filler metal. This works through the use of pressure (Shitong et al., 2006). FSW is a continuous process, hot shear, autogenously process involving non- consumable rotating tool and the tool consists of material harder than the substrate material (Elangovan and

Balasubramaniam, 2007). In FSW, parameters such as welding speed, tool shoulder diameter, pin length, pin diameter and rotational speed play important roles in producing the best weld quality. Design consideration is important to be analyzed in order to get the best design producing the best weld quality.

The welding process involves a rotating tool to perform with a shoulder and a pin that functions to generate heat and facilitate the flow of the softened solid alloy behind the tool where the welded joint forms along the weld line (Elangovan and Balasubramaniam, 2007). Material flow pattern and temperature distribution are the result from design consideration. This implies that good design consideration will produce better strength of the weld joint. As mentioned earlier, the tool has two primary functions, that are localized heating and material flow. In the initial stage of tool plunge, the heating results primarily from the friction between tool pin and work piece. Meanwhile, the rotating and non- consumable welding tool locally softens a work piece through the heat produced by friction and plastic works, thus allowing the tool to “stir” the joint surfaces.

Welding parts, such as parameters, tool geometry, and joint design influence towards significant effect on the material flow pattern and temperature, thus affect the microstructural properties of materials (Mishra and Ma, 2005).During the FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The fine microstructures in friction stir welds produce good mechanical properties (Mishra and Ma, 2005).

The dependence on friction and plastic work for the heat source precludes significant melting in the work piece, avoiding many of the difficulties arising from a change in the state, such as changes in gas solubility and volumetric changes, which often plague fusion welding processes. FSW is considered to be the most significant development in metal joining in a decade and is green technology due to its energy efficiency, environmental friendliness, and versatility. As compared to the conventional welding methods, FSW consumes less energy. There is no cover gas or flux is used to process, thus making the process environmentally friendly and safe. Since the joining does not require any use of filler metal, therefore the compatibility of composition no need to be concerned and any aluminium alloy can be joined easily(Mishra and Ma, 2005).

FSW is a new technology that allows weld to be made of aluminium alloys that cannot be readily fusion arc weld. Compared to the traditional welding techniques, friction stir welding improved cosmetic appearance of the joint part. The root side of conventional friction stirs weld has been shown to be extremely smooth and flat in a variety of materials and thicknesses. After painting, the root side of the joint can be virtually invisible. This has played a big role in the justification of the use of the process over other joining processes in commercial shipbuilding, in aircraft manufacture, and also in the production of food trays (Lohwasser and Chen, 2010).

2.2.1 Friction Stir Welding Machining

Since FSW is a relatively new technology introduced locally and currently no industries in Malaysia that used this technique in production line, the machine is still not available in Malaysia. This may be due to the less exposure to the advantage of FSW usage and high machining cost. However, there still other ways or method that can be used to practice the FSW process. Computer Numerical Control (CNC) Milling is an alternative to apply this FSW process since the process is similar to the milling process. However, there are some limitations of variable parameter to be controlled from CNC machine.

2.2.2 Friction Stir Welding Process

The basic concept behind the FSW process is remarkably simple to work (Mishra and Ma, 2005).Three primary functions that involve in FSW are the heating of the work piece, movement of the materials to produce the joint and containment of the hot metal beneath the tool shoulder. The basic principle of FSW is a non-consumable rotating tool that has a pin and shoulder is inserted to the abutting edged of plates to be joined and subsequently traversed along the joint line. The heating is done by friction between the tool and the work piece and plastic deformation of work piece. The localized heating from the friction softens the material around the pin. From the combination of tool rotation and translation contribute to the movement of material that is elastic properties from the front of the pin to the back of the pin. As a result, a joint is produced in solid state (Mishra and Ma, 2005).

The time taken to finish a process is more on the computerized system design and time process due to dependence on tools. The process cannot be done too fast since it requires cooling time to avoid tool from breaking out during the process. However, FSW still can be considered as a faster weld processing compared to traditional welding method. Compared to arc welding, friction stir welding can be done in a single pass although with increasing thickness of work piece. There is no need to rotate the work piece since the plates is weld completely by friction stir process although by a single pass. This show that FSW require less processing time compared to conventional method (Lohwasser and Chen, 2010).Figure 2.1 illustrates a process definition for the tool and the work piece.

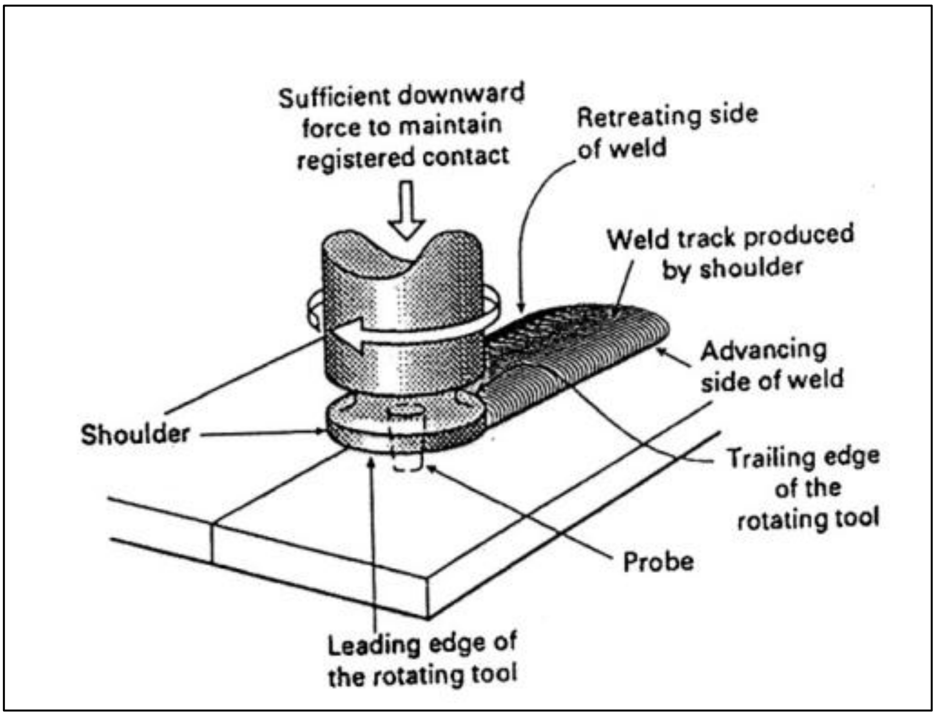


Figure 2.1: Schematic sketch of FSW process

Source: Elangovanet.al (2007)

After all set up had been made, the welding process was run. For the welding process, the tool will start to rotate in a clockwise direction at the selected speed above the plates to create sufficient heat before an axial force is applied to merge the pin inside the plates. Once the pin is rotating in between plates, it will move along the joining line at a constant welding speed perpendicular to the rolling direction, thus performing friction stir welding. During the process of FSW, the heat generated is often assumed to occur predominantly under the shoulder, due to its greater surface. Material on the retreating side never enters into the rotational zone near the pin, but the material on advancing side forms fluidized bed near the pin and rotates around it. The surface of the work piece came in contact in the shoulder, and the insertion of the rotating tool was stopped, after a generation of frictional heating was waited enough, the tool moved along the joint line and welded (Vural et al., 2007).

2.2.3 Friction Stir Welding Tool

Parameters play a very important role in producing good quality on the welding process. The parameters including the welding speed, tool shoulder diameter, pin length, pin diameter and rotational speed. To succeed in the FSW process, it was found that the tool, consisting of a rotating round shoulder and a pin that heats the work piece by friction are critically the main factor (Rai et al., 2011). Since there are not yet any standards for running the FSW process, try and error is the option to get the best parameter that can produce good weld quality joint. The operational principle of FSW differs completely from those of fusion welding processes; the existing welding standards cannot be applied to FSW (Lohwasser and Chen, 2010).Below are some definition of each part in FSW tool and parameters:

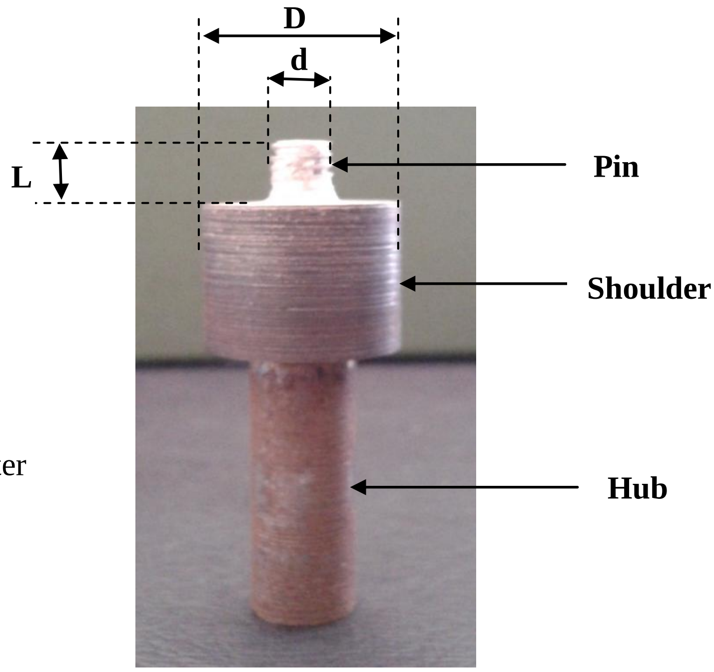
(i) Pin – is a tool that will insert to the abutting edge of the plates and traverse along the joint line after sufficient heat is produced by friction.
(ii) Shoulder – is the main part that generates heat during the friction process due to its greater surface attach to the plates.
(iii) Hub – act as a holder that connected to the CNC machine.
(iv) Rotational speed – is a speed of the tool to rotate in order to produce friction so that sufficient heat can be produced.

(v) Welding speed – is the movement of the tool from a point to another point.

(vi) Axial force – is the downward force exerted on the plates to support in producing enough heat during friction stir process.

Tool rotational speed plays important role in producing the most heat during friction in between the tool pin and the materials. When the rotational speed increases, the temperature will also increase thus causing the increment in heat input. When high heat is generated, the material flow will occur to be in slow cooling rate which produce fine grain structure of the weld area.

Furthermore, the increase in rotational speed will increase peak temperature in the weld zone and at the same time reduce the time duration for material to experience elevated temperature. However, too high rotational speed of the tool can result in defects such as release of material to upper surface which cause the formation of voids in weld area (Rajakumar and Balasubramaniam, 2011). It is important to ensure that appropriate heat input is supplied by applying suitable rotational speed of the tool, weld speed along the joint line and also pin profile. The Figure2.2below demonstrates the FSW tool dimension.



D = shoulder diameter

d = pin diameter

L = pin length

Figure 2.2: FSW tool dimensions

Figure 2.2demonstrates the main operating tool in FSW process that is pin length and diameter, and shoulder length and diameter with a hub. Based on reviews, mostly stated that the pin length must be approximately 0.5 mm less than the thickness of weld plates. Pin accomplishes the breakup of original faying surfaces of the joint. So the pin must penetrate to within 0.5mm of the back of the work piece to ensure complete penetration of the weld through the work piece (Lohwasser and Chen, 2010). In addition, the best shoulder diameter to be used is 18 mm. Shoulder tool with 18 mm diameter produce no defect and good quality of the weld consolidation (Elangovan and Balasubramaniam, 2007).

The pin profile and all other parameter consideration are very important in getting good weld quality because to get sufficient heat generated during the friction process so that the flow of the metal is well elastically before being welded together. It is important to note that there should be a limitation of the heat input so that there is enough heat generated during friction stir processing (Rui et al., 2012). The Figure 2.3 below shows the types of pin profile that may be used in FSW process.

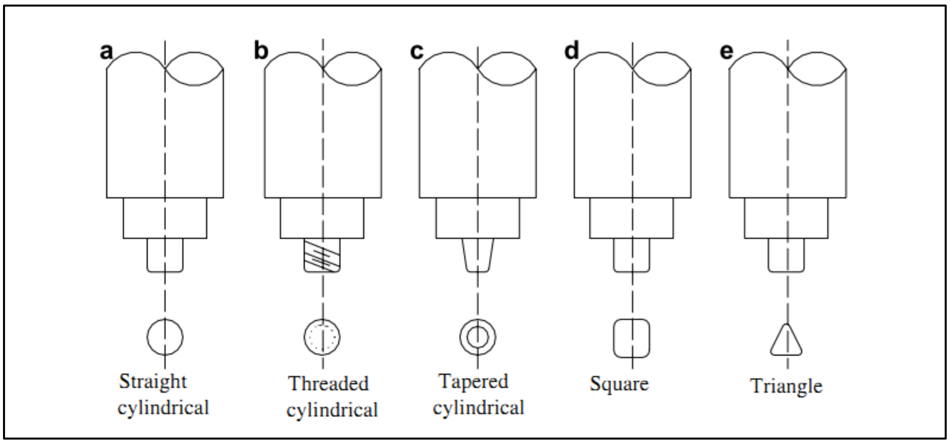


Figure 2.3: FSW tool pin profiles

Source: Elangovan (2007)

There consist of several types of pin profile in friction stir welding. The different pin profile can result in different weld quality. This is because each profile can cause into a different flow of softening plasticized material during the welding process. The threaded pin profile is found to have the mixing of material flow around the weld region. The threaded tool pin profile can ensure the retention of the material flow in the weld region which can cause improve strength of the weld joint. As stated by Lohwasser and Chen, (2010), the threaded shape features have the ability to push the surrounding work piece material downward the weld joint, thus assisting in the retention of material within the weld zone.

2.2.4 Friction Stir Welding Area

In friction stir process, not all parts of the plate being affected by the heat generated. Only a few parts are becoming elastically plastic and joined together before becoming solid state. This material flow is affected by the tool profiles, diameter and other parameters. The area affected by this FSW process is known as a region. From the FSW joint, there usually consist of four different regions as a result from the welding process (Elangovan and Balasubramaniam, 2007). The regions are:

a) Unaffected base metal (BM)
b) Heat affected zone (HAZ)
c) Thermo-mechanically affected zone (TMAZ)
d) Friction stir processed zone (FSP) or Nugget Zone (NZ)

Figure 2.4 shows the welded region from friction stir welding process.

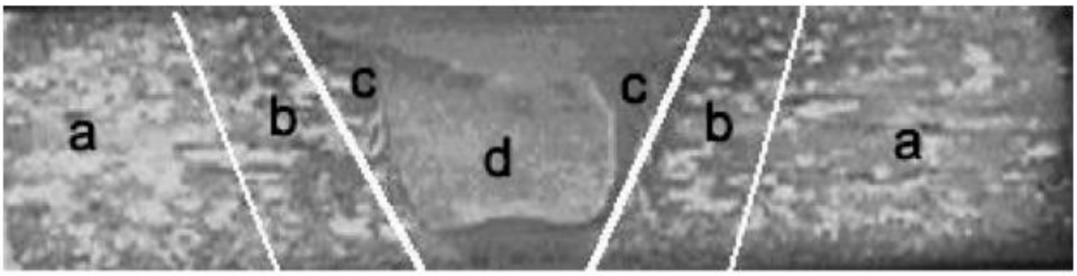


Figure 2.4: FSW welded region

Source: Elangovanet.al (2007)

From the welded region, it shows that FSP zone is the area that is affected most during the welding process while Unaffected Base Metal is the area that is unaffected by the heat produced from the friction. It's best to get a wide range of area for an FSP zone since this region perform high strength welded joint. In the weld region, there are few defects that may occur such as burr, groove, surface streaks, and also melting. This may be due to loss or excessive heat input.

Currently, there are few literature reviews available for focusing on the effect of pin profile and tool rotational speed on the weld joint quality of AA 1100 aluminium alloy. Hence, in this investigation, an attempt has been made to investigate the effect of pin profile and tool rotational speed on the joint strength by using FSW technique.

2.3 ADVANTAGES AND DISADVANTAGES OF FRICTION STIR WELDING

The major advantages of FSW in aluminium alloy when compared to conventional fusion welding are the elimination of cracking evaporative loss of alloying elements. This is due to solid state joining and weld zone with fine worked generated by stirring and forging during the FSW process. In addition, the use of FSW can eliminate and minimize the sealant and locking compounds. FSW is very beneficial compared to traditional techniques because it is more environmentally friendly as well as a cleaner process that produce no smoke, fumes, glare and also have higher mechanical properties (Lohwasser and Chen, 2010).

Besides that, these advantages of FSW also includes; good mechanical properties of weld joint, avoidance of toxic fumes, warping, shielding issues, and other problems associated with arc welding, little distortion or shrinkage, good weld appearance, and improve static strength and fatigue properties (Groover, 2010).

However, there are still drawbacks using this FSW technique. The disadvantages include; an exit hole is produced when the tool is withdrawn from the work, and heavy-duty clamping of the parts is required (Groover, 2010). Other than that, FSW processes are also prone to other defects such as piping defect, kissing bond, cracks and tunnel defect due to improper plastic flow and insufficient consolidation of metal in friction stir process zone (Elangovan and Balasubramaniam, 2007).Modification on the backing plate is used in this FSW such as flow through the pass along weld line, so that the backing plate can still be used as a clamp and the pin can rotate until the end of the weld line.