THE EFFECTS OF SINGLE-PASS/DOUBLE-PASS TECHNIQUE ON FRICTION STIR WELDING OF ALUMINIUM

NUR AIN AMELIA BINTI SATHARI

This thesis is submitted as a partial fulfilment of the requirements

for the award of Bachelor in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG

ABSTRACT

Friction stir welding is a solid state welding that use the idea of frictional heat to soften stirred materials without the need of melting. This study is focusing in the effects of single-pass/ double-pass technique on friction stir welding of aluminium. Two pieces aluminium alloy (AA1100) with the same thickness of 6mm were friction stir welded using CNC milling machine. Three different rotational speeds of 1400 rpm, 1600 rpm and 1800 rpm respectively were used for both groups of single-pass and double-pass. Microstructure observation of welded area was studied using metallurgy microscope. All the specimens were tested by using tensile test and Vickers hardness test to evaluate its mechanical properties. Results indicated that at low rotational speeds (rpm) due to defects such as ‘surface lack of fill’ and tunnel in the welded area contributed to the decreases the result in mechanical properties of the specimens. Welded specimens using double-pass technique shows increasing value of tensile strength and hardness value. Therefore, the optimum parameters in FSW process were double-pass technique with rotational speed of 1800 rpm.

ABSTRAK

Kimpalan geseran kacauan adalah kimpalan pepejal yang menggunakan idea haba geseran untuk melembutkan bahan yang dikacau tanpa memerlukan keadaan bahan itu lebur. Kajian ini member tumpuan dalam kesan terhadap teknik satu-laluan / dua-laluan kimpalan geseran kacauan terhadap aluminium. Dua keping aloi aluminium AA1100 dengan ketebalan yang sama iaitu 6mm dikimpal dengan cara kimpalan geseran kacauan dengan menggunakan mesin pengilangan CNC. Tiga kelajuan putaran yang berbeza iaitu 1400 rpm, 1600 rpm dan 1800 rpm digunakan untuk kedua-dua kumpalan teknik satu-laluan dan teknik dua-laluan. Pemerhatian mikrostruktur di kawasan kimpalan telah dikaji menggunakan mikroskop metalurgi. Semua specimen diuji dengan ujian tegangan dan ujian kekerasan Vickers untuk menilai sifat-sifat mekanikal bahan. Hasil kajian menunjukkan penurunan hasil terhadap sifat mekanikal pada kelajuan putaran rendah (rpm) oleh kerana kecacatan ‘ kekurangan isi di permukaan’ dan terowong di dalam kawasan specimen yang dikimpal. Spesimen yang dikimpal menggunakan teknik dua-laluan menunjukkan peningkatan nilai kekuatan tegangan dan nilai kekerasan. Oleh itu, parameter optimum dalam FSW proses adalah dengan menggunakn teknik dua-laluan dengan kelajuan putaran 1800 rpm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FSW	Friction Stir Welding
HAZ	Heat Affected Zone
TMAZ	Thermo-mechanically Affected Zone
AA1100	Aluminium alloy 1100
CNC	Computer Numerical Control
Mg	Magnesium
C	Carbon
Cr	Chromium
Mn	Manganese
Fe	Ferum
N	Nickel
Si	Silicon
Cu	Copper
S	Sulphur
P	Phosphorus

LIST OF SYMBOLS

rpm	Rotation per minute
HV	Hardness Value
MPa	Mega Pascal
F	Applied Force
d	Diameter
A	Area cross-section
mm	millimeter

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will describe about the process background, problem statement, objectives and scope of the study. From the background of the study, it comes out the problem statement and from the problem statement; the purpose of this study can be identified. This study will be based on the objective that have been determined and is limited by the scopes.

1.2 PROJECT BACKGROUND

Welding is a materials joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure. Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. Welding involves localized coalescence or joining together of two metallic parts at their faying surfaces. The faying surfaces are the part surfaces in contact or close proximity that are to be joined. In some welding processes, filler material is added to facilitate coalescence. The assemblage of parts that are joined by welding is called a weldment (Groover, 2010).

Figure 1.1 summarizes the two major groups of welding processes that is fusion welding and solid-state welding.

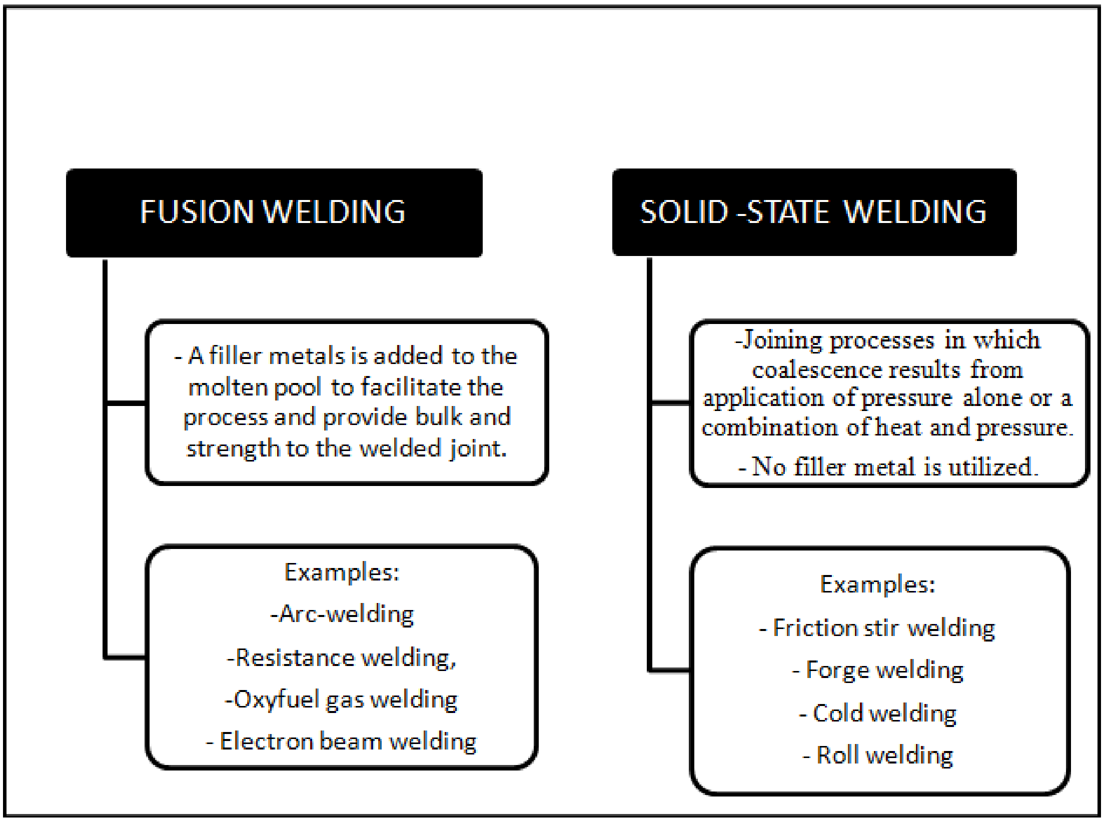

Figure 1.1: Types of welding processes

Source: Principles of Modern Manufacturing book (2010)

Friction Stir Welding is categorized in solid-state welding group. FSW is a welding technology that has been a very comprehensive method for joining non-ferrous material such as aluminium alloys. It is a solid-state process, occurring below the solidus temperature of the metals being joined. FSW does not need any filler material as required in conventional welding process such as MIG welding which require filler material to weld and is relatively easy to perform.FSW also produces welds that are strength and high in quality. The other main advantage is that FSW produces no fumes during process and is energy efficient (Naidu, 2003).However, to perform FSW process, the workpiece should be rigidly clamped to ensure the fixed joint position of the workpiece.

During FSW process, a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint as shown in Figure 1.2.The tool perform two primary functions; (a) heating a workpiece, and (b) the movement of material to produce the joint (Mishra and Ma, 2005). After entry of the of the pin tool to almost the thickness of the material and to allow the tool shoulder to just penetrate into the sheets, the rotating tool is transitioned along the joint line. The rotating tool develops frictional heating of the material, causing it to plasticize where it cools and consolidates to produce high integrity weld (Vural et al., 2007). Figure 1.2 shows the schematic presentation of the FSW process where the tool is rotated and traversed along the joint to produce weld (Muhsin et al., 2012).

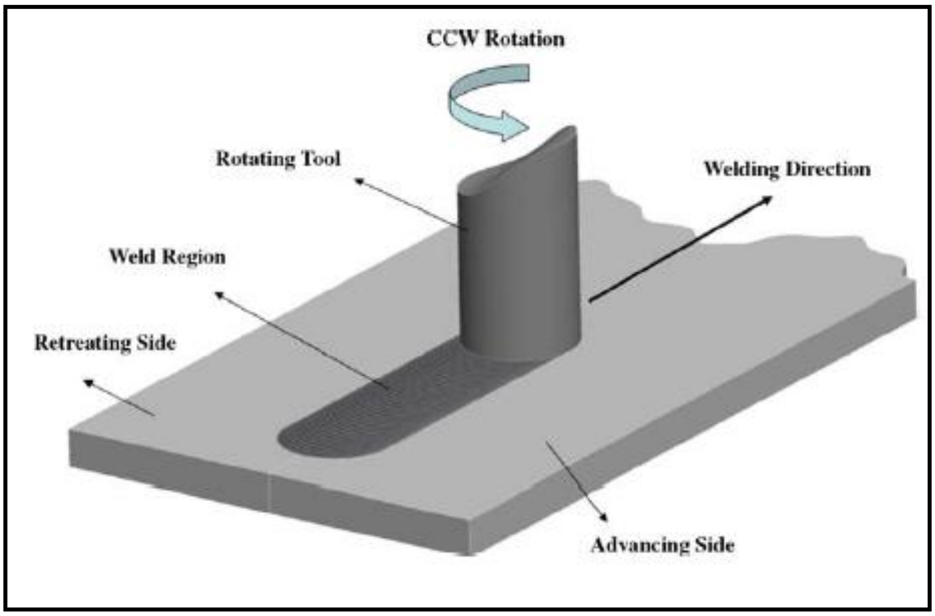

Figure 1.2: Schematic diagram of Friction Stir Welding process

Source: Applied Surface Science 255 (2009)

1.3 PROBLEM STATEMENT

This project is mainly about the development of Friction Stir Welding (FSW) process in Malaysia, where conventional welding methods such as tungsten inert gas (TIG) welding are still widely used. However, the real FSW machine is expensive and from reviewed paper it was found that FSW process can be performed by using CNC machine which is available in Malaysia and cheaper cost compared to the real FSW machine (Hussain et al., 2010).

Even so, from preliminary experiments, there are still several drawbacks that need to be addressed in FSW, such as the occurrence of voids and cracks at welded specimen using the same type of aluminium alloy if a judicious selection of the welding parameters is not done. This defect can lead to the degraded of tensile properties and decreases the ductility strength of welded material. As weld joint is the crucial area and heavily affected by the proper selection of parameters, the single/double- pass techniques of FSW and the rotational speed is taken into consideration. This project looks into the effects of using single-pass or double-pass technique on the quality of the weld joint and defects that may occur during the welding process of aluminium sheets. The mechanical properties of the weld joint are also investigated.

1.4 PROJECT OBJECTIVES

The objectives of this project are;

i. Fabrication of welded aluminium sheets using single-pass/double-pass techniques.
ii. Investigate the weld strength and defect, and also the mechanical property of the welded joints.
iii. Investigate the single-pass/double-pass techniques to be used to joint aluminium sheets.

1.5 PROJECT SCOPE OF WORK

The scopes of this project are as follows:

i. Fabrication of welded aluminium sheets using single-pass/double-pass techniques by CNC Milling machine.
ii. Analyzed the microstructure changes of welds in aluminium alloys using optical microscope.
iii. Investigate the specimen's mechanical properties of the welds using tensile test and Vickers hardness test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the basic knowledge which related to the Friction Stir Welding process will be described in it. Besides, the important parameters of FSW will be define and lastly, some journals regarding to direction techniques and tool rpm of FSW which are highly related to this study will be summarized. The idea and dimension used to applying in designing the pin tool,backing plate and workpiece have been referred back to the previous study.

2.2 WELDING PROCESS

Welding is a relatively new process and it is commercial and has its technological importance. This process provides a permanent joint where the welded parts become a single entity. The welded joint can be stronger than the parent materials if proper welding techniques are used. Welding is usually the most economical way to join components in terms of material usage and fabrications costs (Groover, 2010).

2.3 FRICTION STIR WELDING

FSW is a solid state welding process in which the base metal does not melt during the process. During FSW, a rotating tool moves along the joint interface, generates heat and results in recirculating flow of plasticised material near the tool surface. The tool usually has a large diameter shoulder and a smaller threaded pin.Heat generated at and near the interface between the tool and the work piece is transported into the workpiece and the tool. In addition,the properties of the metal change depending on the temperature and the strain rate. The motion of the plasticised metal depends on both the material properties and the welding variables such as the rotational and the translational speeds of the tool and the tool design. The rotational and the translational speeds determine the local values of the relative velocities between the tool and the workpiece. As a result, the local heat generation rates differ between the advancing and the retreating sides of the workpiece (Nandan et al., 2006).

The FSW process is based on a very simple concept. Soundararajan et al., (2009) state that rotating tool with a pin stirs the material across the joint line forming a sound bond of similar and dissimilar materials. The heat generated between the rotating tool and the workpiece will plastically soften the workpiece material without melting it. The obtained joint will be characterized with the fine microstructure resulting in its high mechanical properties. In contrast, fusion welding techniques are characterized with a cast microstructure that will lead to severe degradation in the mechanical and physical properties of the joint. Originally, the FSW has been developed for joining high strength aluminum alloys and advanced aluminum alloys produced by powder metallurgy.

FSW technique can be used to produce butt, corner, lap, T, spot, fillet and hem joints as well as to weld hollow objects, such as tanks and tube, and parts with 3-dimensional contours. However, it cannot be used for the traditional tee fillet joint configuration that is commonly used in many fusion welding applications. Typical applications are butt joints on large aluminium parts. Other metals, including steel copper, and titanium, as well as polymers and composites have also been joined using FSW. Apart from producing joints, FSW is also suitable for repair of existing joint. Thick FSW was also used to produce butt joints between metals of different thicknesses and between tapered sections. FSW can be performed in all positions such as horizontal and vertical, and it can produce or repair joints utilizing equipment based on traditional machine tool technologies (Khaled, 2005). In this study, the FSW process of a butt joint between aluminium sheets will be produced.

Friction stir welds have been produced in a wide variety of metals, all requiring different energy inputs and different types of tooling. The energy input per unit length in FSW is primarily a function of the variables of tool rotational speed and traverse speed, requiring that these welding parameters be modulated for each alloy to input sufficient energy to form a solid joint (Mishra and Ma, 2005). Welding dense, strong materials requires very high energy input and consequently higher power machinery. Because of the low density and strength of aluminum, FSW in aluminum requires a lower input energy than FSW in other common aerospace and transportation materials such as titanium and steel. The low strength of aluminum permits steel tooling to be used, further lowering the cost of implementing FSW manufacturing solutions for aluminum (Kwon et al., as cited in Richard, 2002).

2.4 ROTATIONAL SPEED

Hussain et al., (2010) found that the rotational speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (rpm). The preferred speed is determined based on the material being cut. Excessive spindle speed will cause premature tool wear, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct rotational speed for the material and tools will greatly affect tool life and the quality of the surface finish. The speed at any point on the outside edge of a cutter must always be equal to the ideal speed for the material for it to work at its optimum performance. The best speed depend on the following condition;

i. Weld strength and quality of the weldment required - Higher quality of weld and strength can be obtained at high speed operations.
ii. Material to be welded - Hard material requires high speed operation.
iii. Size of weld. Large welds require low speed operation.
iv. Thickness of the work piece to be welded.

Rotational speed also plays a crucial role in performing FSW process which some interesting developments of microstructure and properties occurred in the weldments and the tensile strength is affected by the rotational speed and states that the rotation of tools results in stirring and mixing of material around the rotating pin and the translation of tools moves the stirred material from the front to the back .The higher the tool rotation rate generates higher temperature because of higher friction heating and result in more intense stirring and mixing of materials (Mishra and Ma, 2005). The rotational speed that will be used in this study are 1500 ,1600 and 1800 rpm in order to get the best welds joint result in FSW process.

Anyway, the FSW technology requires more of understanding of the process and consequent mechanical properties of the welds in order to be used in the production of high performance components. The effects of welding parameters (rotational speed and feed rate), tool geometry and position of the pin axes were investigated in order to obtain high quality welds (in terms of ultimate tensile strength, weld microstructure, hardness, fatigue resistance). Actually, the design of the tool geometry is still one of the most important aspect to assure a good quality weld and to reduce the load during the process (D'Urso et al., 2009).

2.5 WELDING TOOLS

The welding tool design, including both its geometry and the material from which it is made, is critical to the successful use of the process.Welding tool geometry development led to the first sound welds made in aluminium alloys, and this field of study has led to higher weld production speeds, higher workpiece thickness, improved joint properties, new materials and new welding equipment. Welding tool material development has enabled welding of high melting point materials and has improved productivity in aluminium welding (Lohwasser and Chen, 2010).

Mishra and Ma, (2005) states that tool geometry is the most influential aspect of process development of FSW. The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which FSW can be conducted. An FSW tool consists of a shoulder and a pin as shown schematically.As mentioned earlier, the tool has two primary functions: (a) localized heating, and (b) material flow. In the initial stage of tool plunge, the heating results primarily from the friction between pin and workpiece. Some additional heating results from deformation of material. The tool is plunged till the shoulder touches the workpiece. The friction between the shoulder and workpiece results in the biggest component of heating. From the heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical. The shoulder also provides confinement for the heated volume of material. The second function of the tool is to ‘stir’ and ‘move’ the material. The uniformity of microstructure and properties as well as process loads are governed by the tool design.

The pin generally has cylindrical plain, frustum tapered, threaded and flat surfaces. Pin profiles with flat faces which is square and triangular are associated with eccentricity. This eccentricity allows imcompressible material to pass around the pin profile. Eccentricity of the rotating obect is related to dynamic orbit due to eccentricity (Thomas et al., 1997). The type of tool pin geometry that will be used in this study is cylindrical plain.

2.6 ALUMINIUM 1100 SERIES

Depending on alloying elements and heat treatment, aluminum grades can exhibit a wide variety of properties, from good appearance, ease of fabrication, good corrosion resistance, to high strength-to-weight ratio, good weldability and high fracture toughness. Selection of the proper aluminum grade ultimately depends on the application needed and working conditions.As in this study, the aluminium from 11xx series were chosen as it is addressed by it good property. These grades of aluminum (1050, 1060, 1100, 1145, 1200, 1230, 1350 etc.) are characterized by excellent corrosion resistance, high thermal and electrical conductivities, low mechanical properties, and excellent workability. Moderate increases in strength may be obtained by strain hardening. Iron and silicon are the major impurities (Hatch, 2006). Aluminium alloy of AA1100 was chosen as the workpiece to be welded.

2.7 CNC MILLING MACHINE

The process of Friction Stir Welding (FSW) could also be performed by using CNC Milling Machine. From the reviewed paper, experiments were conducted on AA6351 Aluminium alloy in a CNC Vertical Machining Centre (Hussain et al., 2010).

2.8 MICROSTRUCTURE REGION

Friction stir welds on Al alloy display several microstructural distinct regions including the stir zone (along the weld centerline), the heat-and deformation-affected zone (HDAZ) or thermomechanically affected zone (TMAZ) (surrounding the stir zone), and a true heat-affected zone (HAZ). Microstructural development in the different areas of the weld zone is linked with the local thermomechanical cycle experienced during the joining process and important parameters of the thermomechanical cycle that affects in the growth of microstructure are the total strain, the strain rate, and the temperature .

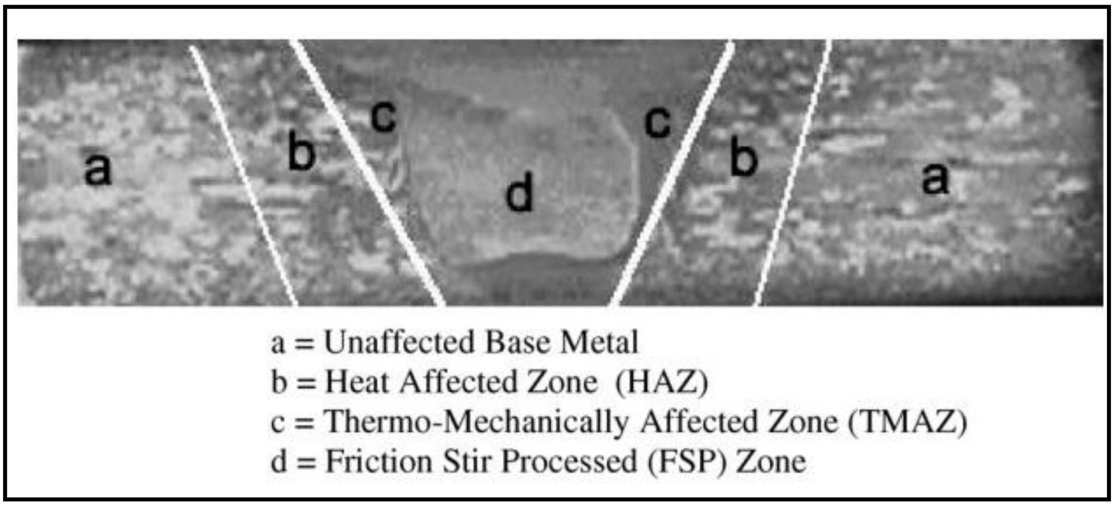

Figure 2.1: FSW microstructural region

Source: Elangovan and Balasubramaniam, (2007)

The micro structure of friction stir welding depends in detail on the tool design, the rotation and translation speeds, the applied pressure and the characteristics of the material being joined. There are a number of zones. The heat-affected zone (HAZ) is as in conventional welds. The central nugget region containing the onion-ring flow-pattern is the most severely deformed region, although it frequently seems to dynamically recrystallize, so that the detailed microstructure may consist of equated grains. The layered (onion-ring) structure is a consequence of the way in which a threaded tool deposits material from the front to the back of the weld. It seems that cylindrical sheets of material are extruded during each rotation of the tool, which on a weld cross-section gives the characteristic onion-rings.The thermo mechanically-affected zone lies between the HAZ and nugget; the grains of the original microstructure are retained in this region, but in a deformed state. The top surface of the weld has a different microstructure, a consequence of the shearing induced by the rotating tool-shoulder (Hussain et al., 2010).

2.9 ADVANTAGES OF FSW PROCESS

The FSW process is used in the aerospace, automative, railway, and shipbuiling industries. FSW also offers a variety of advantages over traditional welding processes. These advantages include (1) good mechanical properties of weld joint, (2) avoidance of toxic fumes, warping, shielding issues, and other problems associated with arc welding, (3) little distortion or shrinkage, (4) good weld appearance, and (5) improve static strength and fatigue properties. Disadvantages include (1) an exit hole is produced when the tool is withdrawn from the work, and (2) heavy-duty clamping of the parts is required.(Groover, 2010)

Other that that, a few of the important advantages of FSW over conventional joining techniques include improved joint properties and performance, low-deformation of the workpieces, a significant reduction in production costs and the freeing of skilled labor for use in other tasks. Compared to the conventional arc-welding of aluminum alloys, FSW produces a smaller heat affected zone, and it also allows the successful joining of aluminum alloys, steel, titanium, and dissimilar alloys with a stronger joint (Soundararajan, 2009).