UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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THE INFLUENCE OF FRICTION STIR WELDING PARAMETERS ON MECHANICAL PROPERTIES OF 6061-T6 ALUMINUM ALLOY

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DECLARATION

I declare that this thesis entitled “The Influence of Friction Stir Welding Parameters on Mechanical Properties of 6061-T6 Aluminum Alloy” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	………..…………..………
Name	:	Mohsin Hameed Atiyah
Date	:	……………..……………..

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Manufacturing System Engineering).

Signature : ………..………………….

Supervisor Name : Associate Prof. Dr. Zulkifli Bin Mohd Rosli

Date : …………………………..

DEDICATION

To the sake of Allah, my Creator and my Master, My great teacher and messenger, Mohammed (peace be upon him), who taught us the purpose of life. My parents, for their endless love, support and encouragement along my life. My dearest wife, who leads me through the valley of darkness with light of hope and support, my beloved kid: Ahmed. To all my family, the symbol of love and giving. My friends who encourage and support me. All the people in my life who touch my heart. I dedicate this research.

ABSTRACT

Aluminum alloy 6061 is frequently utilized for construction of aircraft structures, such as aerostructures and wings, which is the most common in home built aircraft than commercial or military aircraft. It is generally present low weldability by conventional fusion welding process. The advancement of Friction Stir Welding (FSW) has provided an alternative improved means of suitably producing weld joint of AA6061-T6. Unlike in conventional fusion welding, friction stir welds will not confront troubles like distortion, porosity and cracking, and welds are produced with good surface finish. The welding parameters rotational speed and welding speed play a key role in determining the joint characteristics. This experimental study presents the effect of welding parameters (rotational speed and welding speed) on hardness, tensile strength, bending strength and microstructure of 6061-T6 aluminum alloy joints produced by FSW. In this study, FSW is performed using CNC vertical milling machine with three different welding speeds of (50, 100, 150 mm/min) and three different tool rotation speeds of (800, 1000, 1200 rpm). Tool made of steel (H13) consisting of 12 mm diameter shoulder and 4 mm diameter pin with an overall height of 2.8 mm making it little shorter than the plate thickness (3mm). The outcomes refer that the best tensile strength of FSW joints is 163 MPa and joint efficiency is 72% which were welded with welding parameters of (1200 rpm and 50 mm/min). It was observed that the tensile strength, joint efficiency, hardness, and bending strength of the weldments increased with increasing the tool rotation speed and decreasing travel speed. The microstructure of the welded specimens has been studied by using optical microscopy. The formation of fine equiaxed grains and very fine strengthening precipitates (Mg_2Si) in the stir or weld region are the reasons for higher tensile strength, bending strength and hardness of FSW joints.

ABSTRAK

Aluminium Aloi 6061 sering digunakan untuk pembinaan struktur kapal terbang seperti aerostruktur dan sayap serta digunakan dalam pembinaan kapal terbang sendiri lebih daripada pengiklanan atau pesawat tentera. Ia mempunyai tahap boleh kimpalan yang rendah sekiranya menggunakan gabungan proses kimpalan konvensional. Kemajuan oleh Kimpalan Adunan Geseran (KAG) memberikan alternatif penambahbaikkan untuk membuat sambungan kimpalan jenis AA6061 – T6. Tidak seperti kimpalan konvensional, kimpal adunan geseran tidak akan mengalami pengasingan,keretakan keliangan dan kimpalan dihasilkan mempunyai kemasan permukaan yang baik. Parameter kimpalan adalah kelajuan putaran dan kelajuan kimpalan memainkan peranan penting dalam mengenal pasti ciri – ciri gabungan. Eksperimen membentangkan kesan parameter kimpalan (kelajuan putaran dan kelajuan kimpalan) atas kekerasan, daya tegang, kekuatan lenturan dan mikrostruktur pada gabungan aluminium aloi 6061 – T6 dihasilkan oleh KAG. Dalam kajian ini, KAG dijalankan dengan bantuan mesin CNC pengilangan menegak pada tiga kelajuan kimpalan iaitu (50,100,150 mm/min) dan tiga jenis alat kelajuan putaraan iaitu (800, 1000 dan 1200 rpm) Alat ini mempunya diameter selebar 12 mm dan diameter pin selebar 4 mm serta tinggi keseluruhan ialah 2.8 mm dimana lebih pendek daripada ketebalan plat (3 mm). Alat ini dibuat oleh besi (H13). Hasilnya merujuk kepada daya tegang oleh KAG adalah 163Mpa dan tahap efisien gabungan adalah pada 72% yang telah dikimpalkan dengan parameter kimpalan (1200rpm dan 50mm/min). Dapat dilihat, daya tegang, effisien gabungan, kekerasan dan daya lentur daripada kimpalan dapat meningkatkan kelajuan putaran mata alat dan mengurangkan kelajuan bergerak. Mikrostruktur pada spesimen kimpalan telah dikalji menggunakan mikroskopik optik. Pembentukan halus berbentuk selari pada bijirin, dan mendakan pengukuhan yang sangat halus (Mg_2Si) dalam pengadunan atau kawasan kimpalan adalah penyebab daya tegang, daya lentur dan kekerasan tinggi oleh gabungan dihalsilkan oleh KAG.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGUERS

List of Abbreviations

FSW	-	Friction Stir Welding
TWI	-	The Weld Institute
2xxx	-	Aluminum-Copper (Al-Cu) Alloy Series
6xxx	-	Aluminum-Magnesium-Silicon (Al-Mg-Si) Alloy Series
T3	-	Solution Heat Treatment, Cold Worked, and Naturally Ageing
T6	-	Solution Heat Treatment, and Artificial Ageing
NZ	-	Nugget Zone
TMAZ	-	Thermo-Mechanically Affected Zone
HAZ	-	Heat Affected Zone
BM	-	Base Metal
HSS	-	High Speed Steel
ASTM	-	American Society for Testing and Materials
AS	-	Advancing Side of the Weld
RS	-	Retreating Side of the Weld

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Welding is defined as a process of joining two or more materials at their respective contacting surfaces via the suitable application of heat and/or pressure (Groover, 2007). Aluminum welding is a crucial, mostly owing to its complexity and the presence of numerous defects at the joint, due to high chemical reactivity with oxygen, high thermal conductivity, and high hydrogen solubility at high temperature. All these factors can cause the presence of defects on the weld bead (Maggiolino and Schmid, 2008). Welding can be represented by three major methods; fusion welding, solid state welding, and adhesive bonding (Kalpakjian, 1997).

Friction stir welding (FSW) is characterized as a solid- state joining, which was invented at The Welding Institute (TWI) in 1991. Over time, it has been proven itself to be a suitable joining method in cases of aluminum alloys. The utilization of FSW results in superior mechanical properties within the weld zone, as opposed to the conventional welding process. This technique is attracting intense research interest (Mishra and Mahoney, 2007). The advantages of FSW technique are that it is environment friendly, energy efficient, and the lack of need for filler materials or gas shielding for welding aluminum. Additionally, the mechanical properties are confirmed by fatigue, the tensile tests results are excellent, the lack of fume, spatter, cracking, porosity, distortion, and low shrinkage of the metal from welding in the solid state of metal, all of which render this method as a stellar approach of joining dissimilar and previously non-weldable metals (Mishra and Mahoney, 2007). It is also suitable for welding heat treatable aluminum alloys, especially for the 2xxx and 6xxx series, both of which are regarded as challenging to weld via conventional welding processes (Aydin et. al., 2009). This method has piqued considerable amount of interest, especially for applications in aerospace, automotive, marine, railway, and construction (Babu, 2008 and Lim, 2004).

FSW can be utilized to weld numerous sorts of materials and metals, which work at the manufacturing temperature of the work pieces. The process has been utilized to make butt welds, overlap welds, T-sections, and corner welds. For each of these joint, geometries' particular tool designs are required, which are being further evolution and optimized (Awang et. al., 2011 and Vural et. al., 2007).

Friction stir welding (FSW) is a solid-state joining process where a rotating tool, made up of a shoulder and a pin, moves along the butting surfaces of two rigidly clamped plates put on a support plate. The shoulder stays in contact with the top surface of the workpiece. A portion of the heat originates from the rubbing between the shoulder and workpiece, while others are the consequence of material stirring. This heat will certainly soften the materials that are to be welded. This will lead to intense plastic distortion and the plasticized metal will stream toward of the welding.

Friction stir welding joint is comprised of numerous microstructures and contrasting mechanical properties. The heat affected zone (HAZ) is found the farthest from the joint's centerline. It stays unaffected amid the entire procedure, nonetheless, the microstructure do change, for the most part attributable to the welding thermal cycles influencing the mechanical properties. Both the thermo-mechanically affected zone (TMAZ) and weld nugget will be highly deformed from material rotational stream (Deplus et. al., 2011).

The temperature through friction stir welding falls between 0.7 and 0.9 of the melting point, which is the maximum temperature of the system (Attallah et. al., 2007). This basically means that the metal reaches a temperature that is high enough to soften, but not melt them, which results in the minimization or elimination of the welding defects and large distortion that is characteristic of fusion welding (Vepakomma, 2006).

The probe is a little bit shorter than the thickness of the work piece. In a FSW process, the advancing side (AS) is the side where the direction of the tool rotation and traverse movement direction are the same, while the side where the rapidity vectors (of tool rotation and traverse movement) are opposite is referred to as the retreating side (RS). The advancing side and retreating side are significant to indicate in the cross section, or plan view, of a weld. This is because of the fact that friction stir welding is innately an uneven process because of the rotational speed and lineaments of the tool. In another meaning, the advancing side is the side of the weld which the rotational rapidity component and traversing velocity component are valuable or additional. The retreating side is the side of the weld which the rotational rapidity component and traversing velocity component are ruinous or subtractive (Cavaliere et. al., 2006), as shown in Figure 1.1.

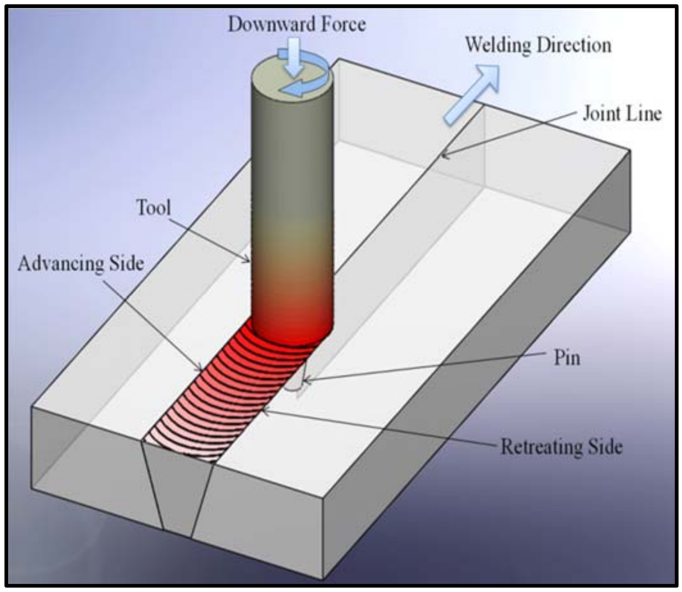

Figure 1.1: Schematic diagram of FSW process (Cavaliere et. al., 2006).

In order to use FSW in critical components, a full understanding of the properties of friction stir welds is necessary. One very common aluminum alloy that could benefit from use of FSW joints is the Al6061 alloy used in the transportation industry. This alloy is relatively inexpensive and has high strength and ductility. Aluminum alloy 6061 is one of the most extensively used of the 6000 series aluminum alloys. It is heat treatable alloy with high strength capabilities. Aluminum alloy 6061 is alloyed with magnesium and silicon. This alloy is beneficial for the production of heavy machineries, aircrafts or aerospace and that is the reason why this alloy is selected for this study.

FSW joins metals are exposed to extended plastic distortion at elevated temperatures that is slightly lesser than the melting point of the metal. The working principle of FSW is quite easy; it consist of a spinning tool equipped with a pin and shoulder that is implanted into the weldable material, traversing by way of the line of interest (Shtrikman, 2008).

So, FSW cycle mainly consists of four stages as shown in Figure 1.2.

1. Plunge phase
2. Dwell phase
3. Welding phase
4. Pull out phase

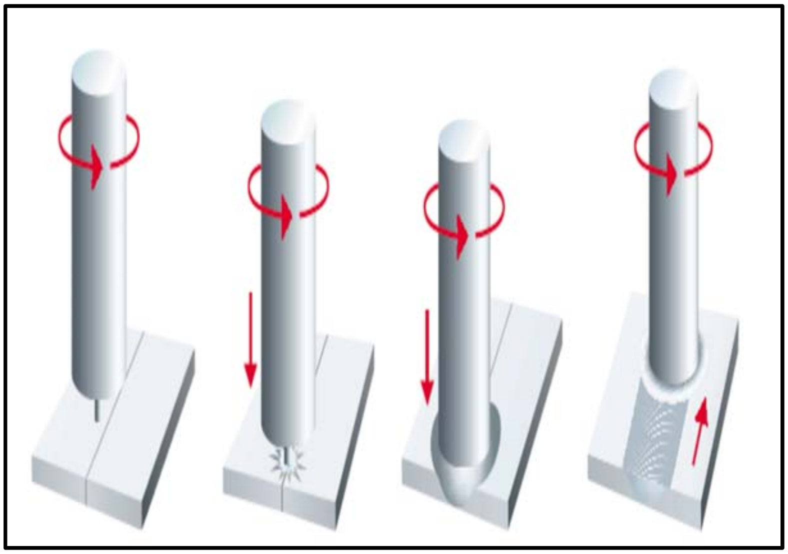

Figure 1.2: Stages of the friction stir welding (Shtrikman, 2008).

The aluminum alloys are designed based internationally approved standards. These alloys can be told apart via a special four digit numeric code, which is pursued by a temper designation code, examples being (2xxx, 6xxx, and 7xxx). The first number represents the principal alloying component, while the second represents the differences of the initial alloy. Both the third and fourth numbers are representative of singular alloy variations. The temper designation code is representative of multiple strengthening techniques, such as AA6061-T6. The heat treatable alloys are drawn from the 2xxx, 6xxx, and 7xxx alloy families.

The primary alloying elements for the three alloy series are copper (2xxx), magnesium and silicon (6xxx), and magnesium and zinc (7xxx), respectively. Typically, a particular alloy will be strengthened mainly by a single precipitate or multiple precipitate phase. The first step in forming a precipitation-hardened structure is the solution heat treatment (SHT). The SHT is a high temperature step that is meant to place the alloy into a single-phase solid solution condition. Subsequently, the solution heat treated alloy is quenched (normally to room temperature), producing a supersaturated solid solution. After quenching, the supersaturated solid solution is allowed to decompose into a two-phase mixture of the matrix solid solution and a strengthening phase (the precipitate). The decomposition may take place whichever at room temperature (natural aging), or at a somewhat high temperature (artificial aging). The aging time and temperature are chosen in order to develop particular desired combinations of properties. Common temper designations in the heat treatable alloys are (Mishra and Mahoney, 2007):

T6: SHT +artificial aging to the peak strength.

T3: SHT+ cold working + natural aging

The age hardening heat treatment (T6, T3) is commonly utilized for increasing the strength of heat treatable aluminum alloys of 2xxx, 6xxx, and 7xxx series (Abbass et. al., 2011). The tools are made up of three primary functions, which are heating the workpiece, move the materials to obtain the joint, and keep the hot metal under the tool's shoulder (Mishra and Mahoney, 2007).

FSW is regarded as a solid-state process that is advantageous over other fusion welding methods. This is due to the fact that it uses non-consumable tool to generate frictional heat to form sound joints. The tool's rotational and welding speeds are crucial towards the determination of welding quality.

1.2 Problem Statement

Conventional welding processes are unsuitable for welding the heat treatable alloy (AA6061), making it necessary for it be examined by other welding methods such as Friction stir welding (FSW). The friction stir welding technology is being widely considered by the modern aerospace and automotive industry for high performance structural demanding application. The problem arises here is that the heat treatable alloy (AA6061) used in our test is used to in the production of very critical applications or equipment such as aircrafts where there is no space for any compensation. So, this alloy should has the high mechanical properties. This aluminum alloy (6XXX) is challenging to weld via conventional welding processes, mostly owing to the poor solidification microstructure and the presence of porosity in the fusion zone, and the loss of mechanical properties. These factors make the connecting of this alloy via conventional welding processes unattractive. It is known that aluminum alloys are hard to weld, mostly due to its high thermal conductivity and the potential of forming defects, such as porosity and solidification cracking. This makes them unsuitable for aerospace or other similar applications.

1.3 Objectives

The objectives of the present work are:

i- To investigate the effect of two parameters (tool rotation speed and welding speed) on tensile strength, hardness and maximum bending force of the welded joint of AA6061-T6 obtained with FSW, after welding at different welding speeds and tool rotation speeds.

ii- To study the microstructure of welded joints of AA6061-T6 obtained with friction stir welding.

1.4 Significance of the study

AA6061 is classified as a precipitation hardening aluminum, with magnesium and silicon as its major alloying elements. It is usually used for tanks, fuselages, fly fishing reels, small utility boats, aircraft wings, and bicycle frames etc.

This study is based on the friction stir welding process therefore this project is the study of the two main parameters that can affect the welding efficiency directly. These parameters are the tool's rotation and welding speeds. These parameters are imperative towards to obtain the welding efficiency and effect in hardness, tensile strength and the bending strength. So, the significance of the study is just to get the values of these parameters where the welding efficiency percentage will be higher to weld this alloy in a perfect condition, the perfect shaped and good quality of welding.

This study also intends to facilitate modern welding used in the production of heavy machineries, which is beneficial to organizations such as NASA, Airbus, US Navy, Eclipse, Boeing, Kawasaki, and Mitsubishi, which are using friction stir welding for the production of their products.

1.5 Scope of the study

This study includes the welding of similar aluminum alloys (6061-T6) by Friction Stir Welding method. To determine influence of two parameters (Tool rotation speed and welding speed) on hardness, tensile strength, bending strength and the microstructure of welded joints by using variable values for both of the parameters.

The dimensions of the Al 6061-T6 plates were 100 mm in length, 150 mm in width, and 3 mm thickness. These plates were prepared by Laser cut machine. The friction stir welding experiment has been executed utilizing tool made of tool steel (H13) comprising of 12 mm diameter shoulder and 4 mm diameter pin with an overall height of 2.8 mm. It is manufactured in by using (lathe machine gate G-410-TCV). The FSW machine is (CNC vertical milling 3-Axis machine) used for welding of AA6061 in Faculty of Manufacturing Engineering, UTeM (FKP) Laboratory.