ANALYSIS OF WELDING PERFORMANCE THIN MATERIAL ALUMINIUM ALLOY 1100 SERIES USING BOBBIN FRICTION STIR WELDING

MOHAMMAD KHAIRUL AZMI BIN MOHD KASSIM

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A thesis submitted
In fulfillment of the requirements for the degree of
Doctor of Philosophy

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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2023

DECLARATION

I declare that this thesis entitled “Analysis of Welding Performance Thin Material Aluminium Alloy 1100 Series Using Bobbin Friction Stir Welding” is the result of my own research excepted as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

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Name : Mohammad Khairul Azmi Bin Mohd Kassim

Date : 3 October 2022

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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Doctor of Philosophy.

Signature : __________________________________

Name : Ts Dr Mohammad Kamil Bin Sued

Date : 4 October 2022

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DEDICATION

To my only wife and beloved family,

Fly me to the moon,

And let me play among the stars,

Let me see what spring is like on Jupiter and Mars,

In other words,

Hold my hand,

In other words,

I love you.

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ABSTRACT

Bobbin Friction Stir Welding (BFSW) is a solid-state welding technique combining heat and pressure to complete the process. With the advancement of technology, many industries opt for thin materials in their production thus making the joining process more difficult especially when involving BFSW technique. This is due to lack of study focusing on joining thin materials using BFSW technique. Therefore, this study is carried out to investigate the welding performance of thin material Alumium Alloy 1100 series using fixed BFSW process. 3mm thickness of Aluminium Alloy 1100 series is used in this study. 2 types of tool designs are used to ensure that the joining can be achieved with zero defect. Both tools are used in a pilot test to identify the suitable range of process parameter and the best tool is selected for this study. The test results showed that the tool having two convex angles (Tool 2) produced better joining compared to the other one. Therefore, Tool 2 is selected as the main tool for the rest of this study. There are only 2 process parameters used in this study which are rotational speed and welding speed. Based on the pilot test results, the suitable range of parameters used in this study are 1500 – 1600 rpm for rotational speed and 150 – 210 mm/min for welding speed. Design of Experiment (DoE) software is used in designing the study model. After the experiment is conducted, it is found out that the rate of error of this study model is below 10% and all the analysis by DoE can be accepted. During the process, 4 different responses were recorded which were temperature, vibration, current and force. Then, all the welded parts were cut for the tensile and microhardness testing. After that, the welded parts were divided into 3 different areas which were Entry Side (EN), Middle Side (MD), and Exit Side (EX). Each area was analyzed based on the best and worst mechanical properties for joining. The analysis showed that the EN of the welded parts had higher tensile and microhardness strength, while EX showed the weakest tensile and microhardness strength. Apart from that, Advancing Side (AS) had higher temperature generation compared to Retreating Side (RS) due to the tool direction. Then, it was also found that all the vibration, current and force were unstable at the EN and becoming more stable towards the EX. This is believed to be due to heat generation that occurs towards the end of the material. Last but not least, all the joining specimens were analyzed based on the microstructure of each area focusing on Heat Affected Zone (HAZ) and Stir Zone (SZ). The founding showed that HAZ encompassed bigger microstructure area compared to the SZ due to the higher heat experience without any mechanical movement. Due to that, there were a few defects that occurred on the welded parts which were incomplete joining and keyhole defects. All of these findings show that the difficulties of joining thin materials using BFSW technique can be solved by maintaining the temperature within acceptable value during the process, lowering the vibrancy during the process, and using suitable tool design to transport the soft material from AS to RS during the process.

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ANALISIS PRESTASI KIMPALAN BAHAN NIPIS ALUMINIUM ALOI SIRI 1100 MENGGUNAKAN KIMPALAN PUTARAN GESERAN BOBBIN

ABSTRAK

Kimpalan Putaran Geseran Bobbin (BFSW) merupakan kimpalan bahan pejal yang berlaku menggabungkan haba dan tekanan bagi menjayakan proses tersebut. Namun begitu, dengan kemajuan teknologi di industri yang menggunakan bahan nipis dalam pengeluaran mereka, menyebabkan kesukaran bagi memastikan proses ikatan menggunakan teknik BFSW berjaya. Terdapat banyak kekurangan kajian yang khusus dalam ikatan bahan nipis menggunakan teknik BFSW. Oleh itu, kajian ini dijalankan untuk mengkaji prestasi kimpalan bahan nipis Aluminium Aloi siri 1100 menggunakan proses BFSW kekal. Ketebalan 3mm bagi Aluminium Aloi siri 1100 digunakan bagi kajian ini. 2 jenis rekabentuk alat digunakan dalam memastikan ikatan boleh dijayakan dengan kosong kecacatan. Kedua-dua alat digunakan dalam ujian rintis bagi mengenal pasti julat parameter proses dan alat terbaik akan dipilih bagi menjalankan keseluruhan kajian.didapati alat yang mempunyai 2 sudut cembung (Alat 2) menghasilkan ikatan yang baik dibandingkan alat lain. Oleh itu, Alat 2 dipilih sebagai alat utama untuk keseluruhan kajian ini. Terdapat hanya 2 parameter proses yang dikhususkan dalam kajian ini iaitu kelajuan pusingan dan kelajuan kimpalan. Berdasarkan keputusan ujian rintis, julat yang sesuai bagi parameter kajian ini adalah 1500-1600 rpm bagi kelajuan pusingan dan 150-210 mm/min bagi kelajuan kimpalan. Perisian reka bentuk eksperimen (DoE) digunakan bagi merekabentuk model kajian. Selepas eksperimen dijalankan, didapati kadar ralat bagi model kajian ini dibawah 10% dan semua analisis oleh DoE diterima. Semasa proses dijalankan, 4 respon berbeza telah direkodkan iaitu suhu, getaran, arus elektrik dan daya tekanan. Kemudian, semua bahagian sudah dikimpal dipotong bagi ujian tegangan dan kekerasan mikro. Seterusnya, bahagian yang sudah dikimpal dibahagi kepada 3 bahagian berbeza iaitu bahagian masuk (EN), bahagian tengah (MD), dan bahagian keluar (EX). Setiap bahagian dianalisis berdasarkan keputusan yang terbaik dan terburuk bagi sifat mekanikal ikatan. Didapati EN bagi bahagian kimpalan mempunyai tegangan dan kekerasan mikro paling tinggi, manakala EX menunjukkan tegangan dan kekerasan mikro terlemah. Selain itu, sisi dimajukan (AS) mempunyai kenaikan suhu paling tinggi berbanding sisi berundur (RS) disebabkan arah pusingan alat. Ia juga menunjukkan kesemua getaran, arus elektrik, dan daya tekanan tidak stabil di EN dan semakin stabil kearah EX. Ini dipercayai disebabkan kenaikan suhu yang berlaku ke penghujung bahan. Akhirnya, semua spesimen ikatan dianalisis berdasarkan struktur mikro di setiap bahagian fokus terhadap bahagian zon terjejas haba (HAZ) dan zon kacauan (SZ). Ia didapati bahagian HAZ mempunyai struktur mikro yang lebih besar berbanding di SZ disebabkan berdepan dengan suhu yang tinggi tanpa pergerakan mekanikal. Oleh itu, terdapat beberapa kecacatan yang berlaku di bahagian kimpalan seperti ikatan tidak berjaya, dan kecacatan lubang kunci. Semua dapatan ini menunjukkan kesukaran ikatan bahan nipis menggunakan teknik BFSW boleh diselesaikan dengan memastikan suhu semasa proses mencapai tahap diterima, getaran yang rendah semasa proses, dan rekabentuk alat yang sesuai bagi membawa bahan lembut dari AS ke RS semasa proses.

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LIST OF ABBREVIATIONS

FSW - Friction Stir Welding

TIG - Tungsten inert gas

MIG - Metal inert gas

BFSW - Bobbin Friction Stir Welding

CFSW - Conventional Friction Stir Welding

AA - Aluminium alloy

SZ - Stir zone

HAZ - Heat affected zone

TMAZ - Thermo mechanical affected zone

BM - Base material zone

AS - Advancing side

RS - Retreating side

RFSSW - Refill Friction Stir Spot Welding

rpm - revolution per minute

kN - kilo Newton

mm/min - millimeter per minute

ν - welding speed

ω - rotational speed

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CHAPTER 1

INTRODUCTION

This chapter elaborates the background of this study, problem statements, objectives, scopes, and significance of this study.

1.1 Background of study

Nowadays, welding industry has increasing demands in zero defect products. In fact, Friction Stir Welding (FSW) is probably the only solution to overcome the usual problems that occur in fusion welding such as material wastage and radiation produced by the harmful gas emissions during fusion welding (Leitão et al., 2009). Moreover, expansion and development in automotive and aerospace industries results in the application of lightweight materials such as magnesium alloy and aluminum alloy. The application of these materials is to improve fuel economy and it is more environmentally sustainable (Cao and Jahazi, 2009). However, the application of lightweight material such as aluminum alloys invites challenges that required to be resolved. This is because of aluminum properties which are very sensitive in the sense that they need to be taken into consideration such as having a low melting point, higher strength to weight ratio, low density, and easy to be formed and machined. As mentioned by Ghosh et al. (2010) and Cao and Jahazi (2011), the applications of fusion welding such as tungsten inert gas (TIG) welding and metal inert gas (MIG) welding are creating many defects such as voids, hot cracking, distortion in shape and loss of work hardening.

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FSW is known as the solid-state welding. This process occurs with the combination of heat and pressure (Boumerzoug and Helal, 2017). The need of heat in this process is important since the heat is the only source that creates the joining. The heat in this process is generated from the mechanical friction between two surfaces which are the tools and the materials used. During this process, the temperature of the joint area generally rises between 0.80 to 0.90 from the melting point of the material used. However, the process is maintained without exceeding the melting point and the material stays in the solid phase (Gibson et al., 2014). This process is energy efficient, environmentally friendly and versatile thus it aligns with the objectives of green manufacturing (Mishra and Ma, 2005). In addition, the applications of FSW can easily eliminates defects associated with fusion welding such as shrinkage, solidification cracks and porosity (Bussu and Irving, 2003). The elimination of defects is needed in improving joined industries. In FSW, the joining can be used for different applications such as butt, lap or angle joints. However, the approaches to use FSW are different in every application. It is because, in FSW, the joining setup is complicated due to the availability of back anvil to support the downward force by the tool. Other than that, the capability of FSW is various in term of complexity and the size of the material.

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There are two different types of FSW which are Conventional Friction Stir Welding (CFSW) and Self-Support/Bobbin Friction Stir Welding (BFSW). The main difference for both types of FSW is the tool design. In CFSW, there is only a single shoulder used while two shoulders are used in BFSW. Figure 1.1 shows the difference between CFSW and BFSW. With tool difference, it gives BFSW more advantages (Threadgill et al., 2010). This is because of the heat generation by the shoulders. The good heat generation in BFSW ensures that the material is ready before the stirring process. The readiness of material is important in FSW to improve