Faculty of Manufacturing Engineering

THE APPLICATION OF STRATEGIC COOLING TECHNIQUE IN BOBBIN FRICTION STIR WELDING TO IMPROVE WELD STRENGTH

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Master of Manufacturing Engineering (Industrial Engineering)

2021

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A thesis submitted
in fulfilment of the requirements for the degree of Master in Manufacturing Engineering (Industrial Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled “The Application of Strategic Cooling Technique in Bobbin Friction Stir Welding to Improve Weld Strength” 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 : SYAIDATUL SYAKIRAH BINTI SALEHUDDIN

Date : 1 FEBRUARY 2021

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 fulfilment of Master of Manufacturing Engineering (Industrial Engineering).

Signature : ______________________________

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Date : 1 FEBRUARY 2021

DEDICATION

To my beloved father, Salehuddin bin Idrus, my appreciated mother, Norizam binti Ismail, my adored sister and brothers, Nasyatul Natasya, Muhammad Nufail Syakir and Muhammad Nafiz Syazmi, thank you for giving me moral support, money, cooperation, encouragement and also understandings. Love you all forever.

ABSTRACT

Bobbin Friction Stir Welding (BFSW) is a welding technique which utilizes welding (travel) and spindle speed of the tool by passing it through the welding plates to form a weld joint. The bobbin tool is a unique tool which has upper and lower shoulders, which results in a better weld joint as compared to Conventional Friction Stir Welding (CFSW). However, BFSW process still generates a lot of heat due to high frictional force from the spinning Bobbin tool. Such condition reduces the overall strength of the weld joint. In this research, an experiment will be conducted to study the effects of introduction of coolant during the welding process using Minimum Quantity Lubricant (MQL) concept. By introducing small amounts of liquid in the form of mist, it was expected to increase the strength of the weld joints. 2 constant parameters, which are spindle speed and welding (travel) speed were kept at 1250 rpm and 110 mm/min respectively. A varying parameter, liquid flow rate, have 3 different levels of 1, 3 and 7 mL/min. It was found that using a liquid flow rate of 7 mL/min gives the best result overall result. The temperature during the welding process dropped the most when compared to the other 2 sets. The ultimate tensile strength obtained was very high, which is 189.11 MPa. This means that crystallization in the stir zone is better when the weld joint was cooled, as heat was less likely to dissipate to other places. However, the average microhardness was 48.8 HV, which is the lowest among the 3 flow rates. On the other hand, using liquid flow rate of 1 mL/min produces the least ultimate tensile strength at 94.52 MPa. The average microhardness is the highest at 49.0 HV. It can be concluded that using higher amounts of liquid introduction during BFSW will help strengthen the weld joints.

ABSTRAK

Bobbin Friction Stir Welding (BFSW) adalah teknik kimpalan yang menggunakan kelajuan kimpalan (perjalanan) dan gelendong alat tersebut dengan melalukannya menerusi plat-plat kimpalan untuk membentuk sambungan. Alat bobbin adalah alat unik yang mempunyai bahu atas dan bawah, dimana ia mampu menghasilkan sambungan kimpalan yang lebih baik berbanding Conventional Friction Stir Welding (CFSW). Namun, proses BFSW masih menghasilkan banyak haba yang disebabkan oleh daya geseran yang tinggi dari alat Bobbin yang berputar. Keadaan sedemikian menyebakan kekuatan keseluruhan sendi kimpalan berkurangan. Dalam penyelidikan ini, sebuah eksperimen akan dilakukan bagi mengkaji kesan pengenalan penyejuk semasa proses kimpalan menggunakan konsep Minimum Quantity Lubricant (MQL). Dengan memperkenalkan sejumlah kecil cecair dalam bentuk kabus, diharapkan dapat meningkatkan kekuatan sendi kimpalan. 2 parameter tetap, iaitu kelajuan gelendong dan kelajuan kimpalan (perjalanan) telah ditetapkan pada 1250 rpm dan 110 mm/min. Parameter yang berbeza, iaitu kadar aliran cecair, mempunyai 3 tahap berbeza pada 1, 3 dan 7 mL/min. Ujikaji ini mendapati bahawa penggunakan kadar aliran cecair 7 mL/min memberikan hasil keseluruhan terbaik. Suhu yang turun semasa proses kimpalan adalah yang paling banyak jika dibandingkan dengan 2 set yang lain. Kekuatan tegangan utama yang diperoleh sangat tinggi, iaitu 189.11 MPa. Ini bermaksud bahawa penghabluran di zon pengadukan lebih baik sekiranya sendi kimpalan disejukkan kerana haba kurang merebak ke tempat lain. Walau bagaimanapun, kekerasan mikro rata-rata adalah 48.8 HV, dimana ia merupakah yang terendah jika dibandingkan dengan 3 kadar aliran cecair yang lain. Sebaliknya, menggunakan kadar aliran cecair 1 mL/min menghasilkan kekuatan tegangan paling sedikit, iaitu 94.52 MPa. Purata kekerasan mikro adalah yang tertinggi pada 49.0 HV. Secara kesimpulan, menggunakan jumlah cecair yang tinggi sebagai pengenalan semasa proses BFSW dapat membantu untuk menguatkan sendi kimpalan.

ACKNOWLEDGEMENTS

All praises to Allah S.W.T., the most gracious, the most merciful, with the highest praise. All praises to Allah for allowing me to complete Master Project II with flying colours. All the good ones came from Allah, and the bad ones came from myself.

Thank you very much to my respected supervisor, Ts. Dr. Mohammad Kamil bin Sued for guiding and encouraging throughout the period of completing this project. I would like to express my gratitude for your kind supervision as well as exposing me to meaningful new knowledge and experiences.

Last but not least, I would like to thank all of my friends who have been also supporting me to complete the project. Thank you very much to Imah, Syazana, Sabrina, Rawdhah, Kasyah, Gogulan, and Afiqah for giving me continuous motivation and support which allows me to brave through all of the hard times. They had given me hope and great suggestions to advance further with this research.

Finally, thank you very much to each and every one of the important personnel that has supported me throughout my project. Thank you very much Mr. Hanafiah, Mr. Hairolisham, and Mr. Wan for helping with the lab experiments. Apologies since I am unable to mention every single name here.

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LIST OF ABBREVIATIONS

AA	-	Aluminium Alloy
Al	-	Aluminium
AS	-	Advancing side
RS	-	Retreating side
ASTM	-	American society for testing and materials
BFSW	-	Bobbin Friction Stir Welding
CFSW	-	Convention Friction Stir Welding
UFSW	-	Underwater Friction Stir Welding
CNC	-	Computer numerical control
FSW	-	Friction Stir Welding
HAZ	-	Heat affected zone
SEM	-	Scanning electron microscope
XRD	-	X-ray Diffraction
OM	-	Optical Machine
SZ	-	Stir zone
TMAZ	-	Thermo-mechanically affected zone
WNZ	-	Weld nugget zone
MQL	-	Minimum Quantity Lubrication

LIST OF SYMBOLS

GPa	-	Giga Pascal
HV	-	Hardness Vickers
Kg	-	Kilograms
K	-	Kelvin
MPa	-	Mega Pascal
kN	-	Kilo newton
mm/min	-	Millimetre per minute
mm	-	Millimetre
rpm	-	Revolution per minute
nm	-	Nanometre
W/mK	-	Watt per metre per Kelvin
Wt. %	-	Weight percent
℃	-	Degree Celsius
%	-	Percent
mL/min	-	Millilitre per minute
µm	-	Micrometre

CHAPTER 1

INTRODUCTION

1.1 Background Study

Friction Stir Welding (FSW) was classified under the solid state welding category. There are two categories of FSW, which were separated in terms of the technology used. These categories are Conventional Friction Stir Welding (CFSW) and Bobbin Friction Stir Welding (BFSW). The main difference between these two FSW categories lie in their tool design. In BSFW, the welding process uses an equipment known as bobbin tool. Its main ingredient is H13 steel, which is highly durable when both low and high temperatures, as well as pressures were imposed on it. Other conventional welding techniques are placed under the fusion welding category. Examples of fusion welding techniques are Gas Metal Arc Welding (GMAW), Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG). Their working principle was quite different from BFSW. In fusion welding, the welding process may use the base material as weldment, where they were heated to the melting point then joined. Compared to FSW, the welding process uses frictional heat generated by a rotating non-consumable tool to join materials. In this case, the rotating tool is the bobbin tool. An obvious benefit of using bobbin tool is that it only requires a rectangular-shaped prepared zone in the work piece, as opposed to the more commonly used triangular-shaped prepared zone, which was often used in outlines for ordinary contact mix welding apparatus. To top it off, the work piece has a net hub drive almost equivalent to zero. This condition serves a critical and valuable aftermath in machine outline and cost.

The invention of BFSW was considered extremely critical in the history of weld plate intermixes. It receives such a reputation because of its user-friendliness and energy efficiency, which was highly contributed from its material composition. When compared with previous methods such as GMAW, FSW is more likely to deplete less energy since the process does not require non-consumable tool such as a cover gas or flux. This would mean that no harmful emissions will be created during the welding process. Likewise, this method also requires no utilization of filler metals as well as liquefying in low temperature. Therefore, any aluminium compound can be intermixed together without having to worry about dissimilarities of material organization or cementing splitting issues related with combination welding. Materials of low melting point or completely dissimilar may be joined with ease as there will likely to be precipitation issues (Rai *et al.*, 2011). Unique materials such as aluminium steel and composites may also be joined easily regardless of any issues. Among all the other welding techniques to date, FSW techniques are most likely to be environmental-friendly since it applies a technology that can be considered as green technology.

Welding has been extensively applied in various fields, which included the marine industry for the production of ships and boats (Exploring the Hull Material Used in Modern Boat Design - SHM Blog, 2018). Arc welding was commonly used for joining the body of a ship. However, considering that the traditional arc welding has many limitations, a new and more viable method is necessary to be produced. This contributes to the idea of using BFSW technique to quickly repair damaged ships and boats at the harbour. Considering the condition at the harbour may be humid and misty at times, this sparked the exploration of using BFSW technique alongside Minimum Quantity Lubrication (MQL). By spraying mist using MQL, the condition at the harbour may be closely replicated. However, the use of MQL in welding itself was not that extensive, let alone in BFSW. It was still relatively unknown whether using mist as coolant will affect the weld strength of the material. Therefore, this research will experiment BFSW using mist as coolant in an attempt to weld Al-Alloy 1XXX.

AA1XXX Aluminium is advantageous in terms of its characteristics. The metal possesses high strength and corrosion resistance, as well as an attractive appearance. Other equivalently vital properties required for BFSW welding aside from its material composition is its good electrical and thermal conductivity, as well as high reflectivity. Aluminium is being continuously improved by a wide range of industries, thus making it highly acceptable as an option greater than steel in various applications. Many researchers and developers involved with aluminium development projects are trying to make aluminium more recognizable within its material group. The 1000 series alloy, as according to The Aluminium Association, were classified under the heat-treatable alloys alongside its other members such as the 6000 and 2000 series alloys. These alloy series were proven to have excellent weldability together with high corrosion resistance, which is highly useful to the transportation industries despite its high cost. In terms of its composition however, they are far more reasonable to be used compared to the 5000 series. This makes the above alloys widely used in aerospace constructions and other industrial companies.

Following the various benefits of BFSW technique, it was suggested for the technique to be further implemented in the manufacturing industry as compared to CFSW. In this research, the recommended parameter to conduct FSW process is to utilize a non-consumable turning device consisting of a stick and a shoulder known as bobbin tool, where the tool helps to outline the AA1XXX plate. On the other hand, the idea of BFSW sparks a few points of interest related to the combination of welding strategies. One of it is related to cooling the welding process with coolant fluid while being placed at a strategic distance from the weldment. Intriguingly, issues such as porosity and solidification splitting does not occur in the welding process. This explains why this new welding method is way superior than previous ones since the possible numbers of problem that may occur during the welding process was drastically minimized.

1.2 Problem Statement

Continuous research on the topic of Bobbin friction stir welding has often revolve around finding the best process parameters and tool dimensions. Multiple studies were conducted by experimenting with different welding and spindle speeds. The same goes for the Bobbin tool designs, where different designs on the shoulders and pins were created and tested out. The best design choice for Bobbin tool were often investigated along with the process parameters. All in all, these studies were conducted with the objective of obtaining higher quality weld joints. However, even with the different process parameters and tool dimensions investigated, the heat generated during the experiment was still very high. In BFSW, the heat generated was still high since having both upper and lower shoulders in the tool concentrates the heat in the stir zone. Zhao, Wang and Dong (2018) mentioned in their study that the deterioration of precipitates caused by having high welding heat input is the main reason for having softening mechanism in the weld joints. The authors also found that the lowest hardness in the weld joints are actually located in the heat affected zone. When the welding heat input was decreased, the area with lowest hardness as well as the tensile strength of the weld joint was actually improved. This means that lowering the heat input during the welding process improves the weld joint strength.

While lowering the heat input shows improvement in weld strength and hardness, optimizing only the process parameters are actually limited since it will give effects to the formation of the weld joints. These effects refer to the defects that may happen when the parameters were changed. If the tool speed is too low, or the welding speed is too high, weld defects will form since the softened material cannot be sufficiently mixed together. This means that an external source of cooling must be used to lower the heat input, whilst maintaining the adequate welding and spindle speed. Therefore, in order to effectively lower the heat input without compromising the process parameters, an external water source to act as cooling agent can be applied. Some studies have used this technique on conventional FSW experiments to investigate the welding effects. The way the experiment was conducted was by applying mists of water on the top of the work piece surface. In those studies, the tensile strength has seen improvements when water was used to cool the work piece during the experiment. This means that using water cooling can be used to improve the mechanical properties of the weld joints.

Since water can be used to cool down the work piece during BFSW process, it was intended to use water as cooling agent, but only for small amounts. The previous experiment uses quite a large amount of mist to be sprayed in order to study the effects of coolant usage. However, this particular study will be conducted by only introducing small amounts of water mists. The effects of the mist introduction will be investigated on by conducting mechanical tests such as tensile strength and microhardness tests. Based on the acquired results, the best volume of liquid used to spray the mist will be proposed as the optimum parameter.

1.3 Objectives

The objectives of this research are:

1. To develop a test rig for BFSW with liquid introduction using CNC milling machine.
2. To evaluate the effects of liquid introduction on BFSW weldment formation through tensile and microhardness tests.
3. To propose the best amount of liquid introduction in BFSW.

1.4 Scope of Research

This research requires the investigation and collection of data using the AA1XXX series rolled plates. The rolled plates were used to find the best parameters in BFSW that will result in a better weld quality. The BFSW technique has previously been proven to counter the limitations of the conventional single-sided FSW, thus making it a highly relevant choice. The material used to make the bobbin tool is the H13 steel, with the threaded tool pin and scrolled shoulder design. The tool was attached to the chuck of CNC milling machine, and set up using the suggested coding parameters to run the process. This weld process was then introduced to liquid by spraying with minimum amounts of tap water acting as the coolant. The spraying of tap water was to emphasize the cooling attack effects and evaluate its reactions on the AA1XXX series rolled plates. Exposure to tap water during the process will affect the deformation of the rolled plate weldment. The microhardness and tensile strength at different regions of the weldment was evaluated. Different grain sizes, coarse precipitations and dislocating density may result in a better performance compared to typical FSW techniques.

Butt welding was used in this welding technique since it was commonly used both in manual and automated welding. This research also applied the latter by using an automated

CNC Milling machine and bobbin tool to weld two rolled plates. The output of BFSW interpreted were the corrosion and weld strength of the AA1XXX series. Mechanical tests were conducted to study the tensile strength and micorhardness of the weldment. Such tests were conducted to investigate the measurements on AA1XXX and compare with the different profiles of other aluminium alloy series.

1.5 Project Significance

a) Discover the impacts of using coolant on weld material appearance and microstructure properties of BFSW at different work piece regions.

b) Compute more knowledge and enhance understanding on the cooling impacts imposed on the AA1XXX series when welded using either BFSW or CFSW.

c) Develop a new opportunity to discover new knowledge and data on the 1000 series aluminium alloys with the use of BFSW as compared to the traditional FSW.

d) Adopt a new and unexposed approach in underwater welding which was tested using tap water.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The Friction Stir Welding technique was developed by Wayne Thomas in early 1991 at The Welding Institute (TWI) Ltd in England (Thomas, Johnson and Wiesner, 2003). This FSW technique was then used to examine new ways of welding aluminium in 1992. Ever since the technique was improved, it has gained a worldwide attention, and now applicable in various fields. FSW technique were commonly applied in multiple transportation industries such as aviation, railroad and shipbuilding. This technique was also highly applicable for welding materials such as aluminium composites, copper and magnesium, as well as other metals with low and high dissolving temperatures.

The FSW concept involves a rotating tool penetrating into two firmly placed work pieces. The work pieces may have their positions fixed with the help of an anvil or a backing plate. The rotating tool will travel and follow the edges of the two work pieces to be joined. During this process, the work pieces will undergo plastic deformation at a very high temperature in the stir zone (SZ). The material structure will be recrystallized, and new fine grains will be produced in the microstructure. FSW has been used in practices to refine grain, alter structure and achieve superplasticity with the help of constant and consistent