UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE INVESTIGATION OF WELD DEFECT REPAIR USING FRICTION STIR ADDTIVE MANUFACTURING

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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Date : 2 July 2020

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

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Dr. Mohammad Kamil bin Sued

ABSTRACT

Weld repair is a common technique in which cracked material is removed by arc gouging, and the components are then welded together to rejoin the material on either side of the crack. The welding process is divided into two categories: fusion welding and solid-state welding. Welding is defined as melting materials together and coalescing by heating. Heat the material at the seam to a molten state and solidify it. Due to the participation of the molten state and solidification, fusion welding has various limitations in the form of metallurgical defects, such as shrinkage, porosity, cracking, deformation, and corrosion. Weld repair is used to repair defects caused by fusion welding. The use of friction stir additive manufacturing (FSAM) for welding repair is the scope of this study. The purpose of this study is to analyze the available literature of FSAM in welding repair, use the literature results to predict the welding performance of FSAM, and conduct a pilot test of FSAM in a laboratory environment. The material used in this study was AA1100. To simulate welding defects, grinding will be performed on AA1100 to produce samples. After comparing the literature and making predictions, the tensile strength of FSAM repair welding is predicted to be 121.01 MPa, which is 10.01% higher than the original tensile strength. The microhardness of the FSAM repair weld predicted is 49.79 HV, which is 1.42% lower than the original microhardness. All literature studies have shown that repair welding successfully repaired and improved the microstructure. The pilot test of FSAM repair welding successfully welded the workpiece. However, in the second pilot test, the tool was broken in FSAM. After observing the microstructure, the actual reason should be revealed. In order to suggest the next study, it is best to perform FSAM repair welding on AA1100 to prove the predicted results. In the research process, the literature research on FSAM repair welding, especially AA1100, is very limited. It shows the novelty of this research.

ABSTRAK

Pembaikan kimpalan adalah teknik umum di mana bahan retak dikeluarkan dengan busur busuk, dan komponennya kemudian dikimpal bersama untuk menyatukan semula bahan di kedua sisi retak. Proses pengelasan terbahagi kepada dua kategori: pengelasan gabungan dan kimpalan keadaan pepejal. Kimpalan ditakrifkan sebagai bahan lebur bersama dan penyatuan dengan pemanasan. Panaskan bahan pada jahitan ke keadaan lebur dan padatkan. Kerana penyertaan keadaan lebur dan pemejalan, pengelasan peleburan mempunyai pelbagai batasan dalam bentuk kecacatan metalurgi, seperti pengecutan, keliangan, keretakan, ubah bentuk, dan kakisan. Pembaikan kimpalan digunakan untuk memperbaiki kecacatan yang disebabkan oleh pengelasan fusi. Penggunaan pembuatan aditif geseran geseran (FSAM) untuk pembaikan kimpalan adalah skop kajian ini. Tujuan kajian ini adalah untuk menganalisis literatur FSAM yang ada dalam pembaikan kimpalan, menggunakan hasil literatur untuk meramalkan prestasi pengelasan FSAM, dan melakukan uji coba FSAM di persekitaran makmal. Bahan yang digunakan dalam kajian ini adalah AA1100. Untuk mensimulasikan kecacatan kimpalan, pengisaran akan dilakukan pada AA1100 untuk menghasilkan sampel. Setelah membandingkan literatur dan membuat ramalan, kekuatan tegangan kimpalan pembaikan FSAM diprediksi 121.01 MPa, yang 10.01% lebih tinggi daripada kekuatan tegangan asal. Kekerasan mikro kimpalan pembaikan FSAM yang diramalkan adalah 49.79 HV, yang 1.42% lebih rendah daripada mikrohardness asal. Semua kajian literatur menunjukkan bahawa kimpalan pembaikan berjaya memperbaiki dan memperbaiki struktur mikro. Ujian rintangan kimpalan pembaikan FSAM berjaya mengimpal bahan kerja. Walau bagaimanapun, dalam ujian rintis kedua, alat itu rosak di FSAM. Setelah memerhatikan struktur mikro, alasan sebenar harus dinyatakan. Untuk mencadangkan kajian seterusnya, lebih baik melakukan pengelasan pembaikan FSAM pada AA1100 untuk membuktikan hasil yang diramalkan.

DEDICATION

TO MY MOTHER AND SISTER,

Lee Mui See, Lee Hung Ling, Lee Yuan Ling and all of my family members.

For their supports and love throughout my life

TO MY HONOURED SUPERVISOR,

Dr. Mohammad Kamil Bin Sued

For his advices, support, motivation, patience and care throughout this project

TO ALL STAFF& TECHNICIANS,

For their cooperation, motivation and advices upon completing this project

Thank you so much.

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Next, I would like to express my appreciation to my family, Lee Mui See, Lee Hung Ling, and Lee Yuan Ling for the endless love and support throughout my life. Thank you for understanding that I am unable to spend a lot of time with you on this final year. Lastly, I would like to express my gratitude to all people that directly or indirectly contribute in this project. I believe without the help, supports and motivation from all of that I mentioned above, I will not manage to reach this far. May God bless all of you and repay your kindness and good deeds.

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CHAPTER 1

INTRODUCTION

The introduction of this project means to elaborate the main idea of the project. This chapter explains the significant of the study in exploring the repair of the damaged weld. It introduces the title, background, problem statement, objective, the significance and the scope that are going to be focused in this final year project.

1.1 Background of Project

Welding is the process of joining together two pieces of metal so that bonding takes place at their original boundary surfaces. When two parts to be joined are melted together, heat or pressure or both is applied and with or without added metal for formation of metallic bond. Manufacturing industry such as automotive, aerospace, ship building have high demand in welding process.

Welding process can be applied in production and maintenance for large and small scale. Welding provides permanent joint with good strength compared to mechanical joint as it has lower strength and need extra cost to buy additional parts like bolts and nuts, and it requires additional process like assembling.

Repair welding is a common technique in which cracked material is removed by arc gouging and the components are then welded to rejoin the material on either side of the crack. Although extra care is usually required, repair welding is in principle no different from ordinary welding. This is because welding may have to be done under unfavourable conditions, or because repairs may have to correct welding failures. In this case, you should know the cause of the failure to avoid repeating the failure.

In heavy industry, the field welding process is very important. At any time in the industry, if the welding of any critical component fails, it usually results in a loss of production or, in extreme cases, a complete shutdown of the production process. When this happens, the quickest way is needed to fix the system and get it back into use. The pressure to fix the weld quickly and efficiently is increasing.

The welding process is divided into two major categories: Fusion Welding and Solid State Welding. Fusion welding is defined as melting together and coalescing materials by means of heat. The material at the joint is heated to a molten state and allowed to solidify. Solid state welding is joining that takes place without fusion at the interface of the two parts to be welded. In solid state welding, no liquid or molten phase is present in the joint. In this process, pressure or friction is used to heat metal to plastic state.

The most common processes on site are shielded metal arc welding (SMAW) and manual metal arc welding (MMA). Industrial welding is usually carried out under exposed cold conditions, in the wind, and sometimes even in the rain. These environmental factors make welding very difficult (Thomas, 2016). Beside the environment factors, fusion welding has its limitations on forming defects.

Due to the involvement of molten state and solidify, fusion welding has various limitations in the forms of metallurgical defects such as shrinkage, porosity, cracking, deformation and corrosion. These defects could cause the welded pieces to be unusable. This problem can be eliminated by solid state welding like Friction Stir Welding (FSW) since it does not involve molten state. Therefore, using a FSW-based technology, Friction Stir Additive Manufacturing to do repair welding has become the objective of this research.

The principle of FSW is based on the fact that if the two surfaces rub against each other, frictional heat is generated, causing the temperature to rise below the melting point temperature of the material. At this temperature, the material softens and the rotation and lateral movement of the tool causes mixing and consolidation of the material to form a joint at the interface.

FSAM is a fusion of layer-by-layer Additive Manufacturing (AM) and FSW processes. FSAM has the unique ability to modify and significantly improve the microstructure of the parts being manufactured. Due to its unique engineering and ability to control microstructures, it can help customize the microstructure to meet customer needs. It produces a fine-grained structure which in turn significantly improves the ductility and structural properties of the part being produced compared to the base material. FSAM can be successfully used to manufacture high strength metal alloys.

The working process of FSAM is a non-consumable rotary tool with special pins and shoulders is slowly inserted into the overlapping surface of the panel/sheet and then moved forward along the bond line to be joined. The side in which the direction of rotation is the same as the direction in which the tool travels is referred to as the traveling side (AS). The side in which the direction of rotation of the tool is opposite to the direction of travel of the tool is referred to as the retreating side (RS). At the RS, the material flow is smoother than the forward side because the rotation of the tool supports the backward flow of the material. Due to the friction and plastic deformation of the working material, the heat required for the layer connection is obtained.

1.2 Problem Statement

Welding of aluminium alloy have been started to be venture in many fields like aerospace, marine, automotive and more. This is because aluminium alloy possess good properties like ductile, good machinability, easy to weld, high strength, lightweight and good corrosion and chemical resistant. Aluminium alloy 1100 is a wrought alloy where it contains 99.00% of aluminium alloy in its composition and it is a non-heat treated alloy where it usually gains strength by strain hardening or cold working (Lincoln, 2016).

As much as the intensive application of welding in different industry sectors, the rate of damage of welded equipment is a major concern for industry. The damaged weldment need to be repaired. Repairs are usually made by eliminating unacceptable weld defects, re-welding and then restoring the original geometry of the part. Repair rate refers to the frequency of repair in a welded components.

According to the online survey of welding repair rates compiled by the The Welding Institute (TWI), the average repair rate in the oil and gas and power industries is in the range of 1-3%. The peak rate at a particular location is as high as 25%, while the peak value of outliers is as high as 55%. Peak repair rates are typically obtained at specific locations in the weld product, such as root welds, fillet welds, and areas where contact is limited (Consonni & Wee, 2012). The results of this survey is presented in Figure 1.1 and Figure 1.2.

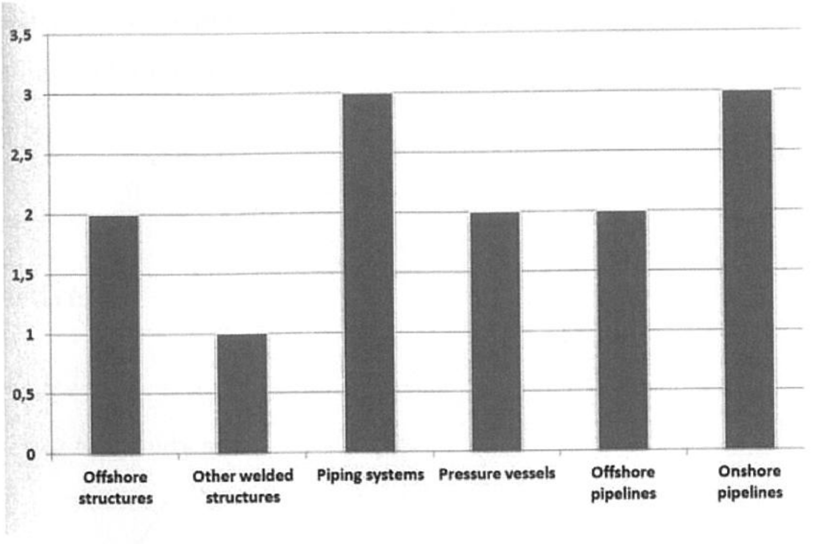

Figure 1.1: Average repair rates (%) for different types of products, considering all material grades (Consonni & Wee, 2012).

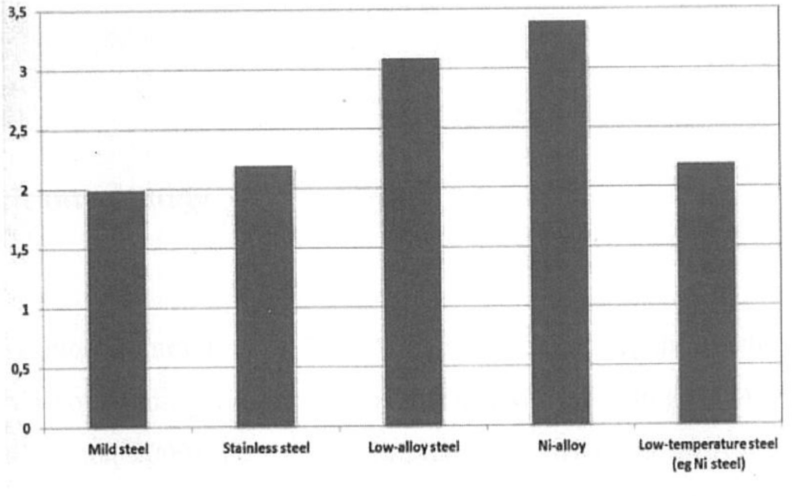

Figure 1.2: Average repair rates (%) for different material grades, considering all type of products (Consonni & Wee, 2012).

Considering the high repair rates in the industrial, the repair welding method is significant. Fusion welding possesses many defects such as porosity, crack, deformation and more. Occurrence of the defects will leads to inadequate in mechanical characteristics of material. A solid state welding, FSAM is proposed to solve the problem. The basic working principle of FSAM is the stirring of the tool will produce friction and it heats and plastizes the material and perform welding. The stirring between tool and material is expected to solve the porosity and crack in the material.

1.3 Objectives

The objectives of this study are:

I. To analyse the available literature of FSAM application in welding repair.

II. To predict welding performance of FSAM using literature results.

III. To perform pilot test of FSAM in laboratory setting.

1.4 Significant of Study

The two most common processes for on-site welding repair are shielded metal arc welding (SMAW) or welding rods, as well as flux-cored arc welding (FCAW) or flux-cored welding wire (Leisner, 2009). Fusion welding like TIG, MIG and SMAW are well known for defects that can occur after the welding, such as porosity, crack, deformation and more. By using solid-state welding, it is expected to solve the defect problems of the welded workpiece.

Besides avoiding the defects, solid-state welding will not produce flux during welding due to its low temperature characteristic. It is safe for on-site application. FSAM, as a new technology developed recently, it is not much prior study on using FSAM for repair welding. Therefore, it is the novelty of this research. After the FSAM process, the material experienced further stirring and mixing during the process, it will produce better mechanical characteristic material.

1.5 Scope

The scope of this project is to perform FSAM at grinded AA1100. Grinding process is done on the AA1100 to simulate the groove defects caused by fusion welding. The work piece length will be 121 mm x 200 mm x 6 mm.

After grinding the workpiece, the workpiece will undergoes FSAM with parameters variable of rotation speed (800 rpm), weld speed (60 mm/min), plunge depth of 9.2 mm and tool inclination of 2°. Both clockwise and counter clockwise rotation will be tested to investigate tool rotary direction on the impact of weld formation. The FSAM will be done by using CNC machine model HAAS VOP-C.

CHAPTER 2

LITERATURE REVIEW

This chapter will discussed about this final year project title from past researches and studies. It will then elaborate and analyse the findings and information regarding this project to gain more understanding and constructing the methodology.

2.1 Welding Repair

Repair welding is a commonly used technique where the broken material is removed by arc gouging, and the component is then welded to rejoin the material on either side of the crack. Repair welding is important in the industry to ensure the availability and safety of the parts. Repair is needed due to the wear and fatigue of the parts.

There are several reasons for repair welding. The possible cause of the failure is fatigue, which may be the result of weld defects or inadequate design. If welding defects is the only reason for the failure, it is then repaired to provide a higher quality weld and should be avoided in the future. The second failure was due to fatigue overload. In order to resolve this failure, it may be necessary to cut out the area including the crack and replace it with thicker steel to reduce the stress on the critical joint. This may involve three new welds, the second joining the thicker steel to the existing component and the third joining the two thicker parts by one-sided welding. The third possibility is brittle fracture. Although this may be caused by defects, the failure indicates that the original steel or weldment lacks toughness. (Bailey, 1994)

When a part is defective, the inspector will inspect it to determine the extent of damage that may be caused by repairing the weld and whether the part can perform its function if the defect is allowed to remain in place. If the function of the weldment is affected by the defect, the part must be discarded and replaced. If parts need to be reworked, a thorough welding procedure should be established to minimize the impact of repairs on the rest of the weld. The condition of the base metal and weld, the type of filler metal used in the repair, the welding sequence, any in-process inspections required during the repair, the tools required for repair, and the mechanical properties of the final weld must also be considered. Incomplete consideration of any of these factors can lead to further failure of weld repair and failures that may occur when the weld is put into service (Bowditch, Bowditch, & Bowditch, 2012).

The preferred method of repair is based on the type of component. For parts that are too small in size or shallow defects, grinding and blending contours may be more and less expensive than repair welding, especially if fatigue is a primary consideration. For brittle materials that are not welded, repair welds should be performed with extreme care, as repairs can cause more serious problems than the original failure. Underwater welding repairs are particularly difficult and expensive, and maintenance work is typically performed by transferring the load path to a reinforcing member that is bolted or grouted with plastic. (Bailey, 1994)

SMAW or GTAW is the most widely accepted welding process in the industry due to the availability of its welding equipment and skilled welders (Gupte, 2004). However, the gas shields in SMAW are not clean enough for active metals such as aluminum and titanium. The deposition rate is limited by the fact that when an excessively high welding current is used, the electrode cover layer tends to overheat and fall off. The limited length of the electrode (approximately 35 cm) requires electrode replacement, which further reduces overall productivity. Tthe deposition rate in GTAW is low too. Excessive welding current causes the tungsten electrode to melt and causes the tungsten inclusions in the weld metal to become brittle. (Lienert, Siewert, Babu, Acoff, & Specifications, 2011)

The uses of fusion welding is wide in welding repair but it forms some types of defects during the process including porosity and crack, which have significant influence on mechanical properties of the parts. Defective joints and product repair welding processes have attracted widespread attention. FSW is a solid-state connection technology that has been proven in many metals and can be used as a repair technology for welded joints and cast products to alter the microstructure or eliminate defects. (Besharati-Givi & Asadi, 2014)

In 1999, a patent of using friction stir welding process to repair voids in aluminum alloys was filed. The invention provides a method in the process of repairing voids in an aluminum alloy, particularly friction stir welding in an aluminum alloy. In order to repair the circular void in the weld or the exit hole in the process, the method includes the steps of forming a filler material having the same composition or compatible with the parent material into a plug form to fit into the void, positioning the plug in the void, And friction stir welding on the plug and through the plug (Rosen, Litwinski, & Valdez, 1999).

In 2007, a patent of crack repair using friction stir welding on materials including metal matrix composites, ferrous alloys, non-ferrous alloys, and superalloys was filed. It is a system and method for crack repair or preventive maintenance of various materials and structures using friction stir welding and friction stir processing, where the structure includes pipes, ships and nuclear reactor containment. Friction stir welding and machining can be performed over long distances and harsh environments (such as underwater or in the presence of radiation) (Packer, Steel, Babb, Reed, & Taylor, 2007).

Another study of welding repair process for FSW groove defect is conducted in 2009. The groove defects formed in the friction stir welding greatly reduce the welding appearance and mechanical properties of the joint due to its larger size and penetration. Therefore, friction stir repair welding is used to remove such groove defects. Experimental results show that groove defects can be removed by friction stir welding (Liu & Zhang, 2009). Figure 2.1 (a) and (b) shows the cross sectional morphologies of initial joint with groove defect and its repair joints respectively.

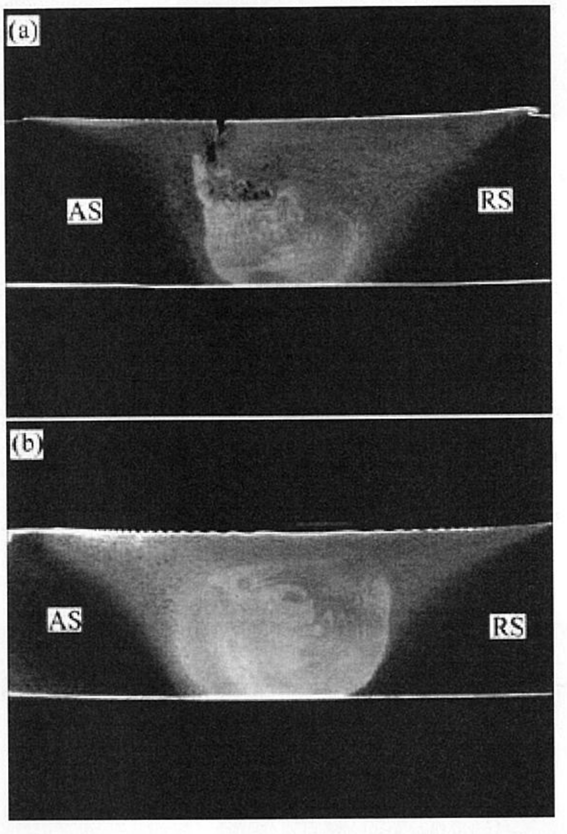

Figure 2.1: (a) Cross sectional morphologies of initial joint with groove defect (b) Repaired joint with no groove defect (Liu & Zhang, 2009)

The FY07 Aging Aircraft Study conducted by the South Dakota School of Mines and Technology identified friction stir welding and processing (FSW & P) technology, which is ready to enter the qualification process and used as standard maintenance technology for aging weapon systems. The FSP refurbished the actual parts successfully. Radiographic inspections showed that volume defects and fatigue cracks were treated from candidate components. The study carried out a cost-benefit analysis and estimated that the US Air Force could save $ 9.4 million annually on components that can be repaired using only FSW & P (Tweedy, Arbegast, Hrabe, & Hutto, 2009). Figure 2.2 shows the pre and post repair of the Ruddervator staking damage.