UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TRIBOLOGICAL AND SALT WATER CORROSION BEHAVIOR OF DISSIMILAR ALLOY WELDING USING FRICTION STIR WELDING

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MASTER OF MANUFACTURING ENGINEERING (MANUFACTURING SYSTEM ENGINEERING)

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SITI HARISHAH BINTI AZMAN

A master project submitted
in partial fulfillment of the requirements for the degree of
Master of Manufacturing Engineering (Manufacturing System Engineering)

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2024

DECLARATION

I declare that this master project entitled "Tribological And Salt Water Corrosion Behavior Of Dissimilar Alloy Welding Using Friction Stir Welding" is the result of my own research except as cited in the references. The master project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name : SITI HARISHAH BINTI AZMAN

Date : 21st July 2024

APPROVAL

I hereby declare that I have read this master project and in my opinion this master project is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Manufacturing System Engineering)

Signature :..

Supervisor Name : DR.Muhammad Zaimi Bin Zainal Abidin

Date :..

DEDICATION

To my beloved mother, Zabedah binti Bahar, whose unwavering love, support, and encouragement have been the guiding light throughout my life and academic journey. Your strength, wisdom, and selfless sacrifices have inspired me to pursue my dreams and reach for excellence.

To my dear husband, Shahrizwal bin Yakkop, my rock and partner in life. Your constant love, understanding, and belief in me have been my source of motivation and strength. Thank you for standing by my side through the challenges and triumphs of this master's program.

To my precious children, Harraz Shahmie bin Shahrizwal, Hifwat Shafi bin Shahrizwal, and Haura Raisha Safwa binti Shahrizwal, you are the joy and pride of my life. Your smiles, hugs, and innocent love have been my greatest comfort and inspiration. I hope this achievement will inspire you to always pursue knowledge and follow your passions.

I dedicate this master's project report to all of you, my beloved family. Your love, sacrifices, and unwavering support have been the foundation upon which I have been the bedrock upon which i have built my academic career as a master's student in manufacturing engineering (manufacturing system engineering). From an early age, you imparted in me the value of education and engendered a curiosity about technology and systems. I would not have attained my current knowledge and skills without everything you have done for me. Please accept my deepest gratitude for assisting me in arriving at this milestone and for always being my unshakable foundation. This is for you with abiding admiration and affection.

ABSTRACT

Friction stir welding (FSW) is a solid-state joining process that offers significant advantages in efficiency, cost-effectiveness, and environmental impact compared to traditional fusion welding techniques. This study focuses on the tribological and saltwater corrosion behavior of dissimilar aluminum alloy AA5052 and AA6061 welded joints produced using FSW, which are commonly used in marine applications due to their mechanical properties and corrosion resistance. The primary objective of this project was to comprehensively characterize the microstructure, mechanical properties, wear resistance, and corrosion behavior of dissimilar AA5052-AA6061 FSW joints. Various characterization techniques, including field-emission scanning electron microscopy (FESEM) and energy-dispersive X-ray spectroscopy (EDX), tensile testing, microhardness mapping, reciprocating pin-on-disk wear tests, and linear sweep voltammetry (LSV), were employed to evaluate these properties. The results revealed that the dissimilar FSW joints exhibited unique microstructural developments along the bond line, leading to higher tensile strength and ductility compared to similar alloy joints. The tensile strength of the dissimilar joints was slightly higher, but they demonstrated lower wear resistance due to the formation of intermetallic compounds, such as Al3Mg2, at the weld interface. Corrosion testing indicated that the dissimilar joints had a lower overall corrosion rate but were susceptible to localized galvanic corrosion at the interface. This susceptibility was attributed to changes in composition and the formation of a passive oxide film, which dissolved at approximately -0.6V. The microstructural analysis showed significant differences between the similar and dissimilar joints. The similar AA6061 joints exhibited a uniform and defect-free surface with fine grains, whereas the dissimilar AA6061-AA5052 joints displayed distinct regions corresponding to each alloy with a well-bonded interface. The EDX analysis provided insights into the elemental distribution, revealing a gradual transition in composition across the weld interface for the dissimilar joints, indicating effective material mixing during the FSW process. The mechanical testing results highlighted the superior performance of the dissimilar joints in terms of tensile strength and ductility. However, the wear testing results indicated that the dissimilar joints had lower wear resistance compared to the similar joints, which could be attributed to the formation of intermetallic compounds at the weld interface. The corrosion testing using LSV showed that while the dissimilar joints had a lower overall corrosion rate, they were more susceptible to localized galvanic corrosion due to the differences in composition and the formation of a passive oxide film. This project provides critical insights into optimizing FSW parameters to mitigate corrosion challenges and enhance the mechanical performance of dissimilar aluminum alloy joints. The findings have significant implications for the development of lightweight, corrosion-resistant marine structures, contributing to improved reliability and durability in harsh marine environments. The insights gained from this research are expected to inform future advancements in the field, addressing both performance and durability in practical applications.

TRIBOLOGI DAN SIFAT KARAT BERUNSURKAN AIR GARAM TERHADAP ALOI BERLAINAN JENIS DENGAN MENGGUNAKAN KIMPALAN KACAU GESERAN (FSW)

ABSTRAK

Kimpalan kacau geseran (FSW) ialah proses penyambungan keadaan pepejal yang menawarkan kelebihan ketara dalam kecekapan, penjimatan kos dan tidak memberi kesan alam sekitar berbanding teknik kimpalan gabungan tradisional. Kajian ini memberi tumpuan kepada sifat tribologi dan karat berunsurkan air garam bagi sambungan kimpalan aloi aluminium AA5052 dan AA6061 yang tidak serupa yang dihasilkan menggunakan FSW, yang biasanya digunakan dalam aplikasi marin kerana sifat mekanikal dan rintangan kakisannya. Objektif utama projek ini adalah untuk mencirikan secara menyeluruh struktur mikro, sifat mekanikal, rintangan haus, dan kelakuan kakisan bagi sambungan AA5052-AA6061 FSW yang berbeza. Pelbagai teknik pencirian, termasuk mikroskop elektron pengimbasan pelepasan medan (FESEM) dan spektroskopi sinar-X (EDX) penyebaran tenaga, ujian tegangan, pemetaan kekerasan mikro, ujian kehausan pin-pada-cakera salingan, dan voltammetri sapuan linear (LSV), telah digunakan untuk menilai. Keputusan menunjukkan bahawa sambungan FSW yang berbeza mempamerkan perkembangan mikrostruktur yang unik di sepanjang garis ikatan, membawa kepada kekuatan tegangan dan kemuluran yang lebih tinggi berbanding dengan sambungan aloi yang serupa. Kekuatan tegangan bagi sambungan yang berbeza adalah lebih tinggi sedikit, tetapi ia menunjukkan rintangan haus yang lebih rendah disebabkan oleh pembentukan sebatian antara logam, seperti Al3Mg2, pada antara muka kimpalan. Ujian kekaratan menunjukkan bahawa sambungan yang tidak serupa mempunyai kadar kakisan keseluruhan yang lebih rendah tetapi terdedah kepada kakisan galvanik setempat pada antara muka. Kecenderungan ini disebabkan oleh perubahan dalam komposisi dan pembentukan filem oksida pasif, yang terlarut pada kira-kira -0.6V. Analisis mikrostruktur menunjukkan perbezaan yang ketara antara sendi yang serupa dan tidak serupa. Sambungan AA6061 yang serupa mempamerkan permukaan yang seragam dan bebas kecacatan dengan butiran halus, manakala sambungan AA6061-AA5052 yang berbeza memaparkan kawasan yang berbeza sepadan dengan setiap aloi dengan antara muka yang diikat dengan baik. Analisis EDX memberikan pandangan tentang pengedaran unsur, mendedahkan peralihan beransur-ansur dalam komposisi merentas antara muka kimpalan untuk sambungan yang berbeza, menunjukkan pencampuran bahan yang berkesan semasa proses FSW. Keputusan ujian mekanikal menyerlahkan prestasi unggul sendi yang berbeza dari segi kekuatan tegangan dan kemuluran. Walau bagaimanapun, keputusan ujian haus menunjukkan bahawa sambungan yang tidak serupa mempunyai rintangan haus yang lebih rendah berbanding dengan sambungan yang serupa, yang boleh dikaitkan dengan pembentukan sebatian antara logam pada antara muka kimpalan. Ujian kakisan menggunakan LSV menunjukkan bahawa walaupun sambungan yang tidak serupa mempunyai kadar kakisan keseluruhan yang lebih rendah, mereka lebih mudah terdedah kepada kakisan galvanik setempat disebabkan oleh perbezaan dalam komposisi dan pembentukan filem oksida pasif.Projek ini memberikan pandangan kritikal untuk mengoptimumkan parameter FSW untuk mengurangkan cabaran kekaratan..

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LIST OF ABBREVIATIONS

AA5052	-	Aluminum alloy 5052
AA6061	-	Aluminum alloy 6061
FSW	-	Friction stir welding
GMAW	-	Gas metal arc welding
NDT	-	Non-destructive testing
UTeM	-	Universiti Teknikal Malaysia Melaka
LSV	-	Linear scanning voltammetry
UTS	-	Ultimate tensile strength
HV	-	Vickers hardness
rpm	-	Revolutions per minute
MMC	-	Metal matrix composite
HRS	-	High resistance steel
EDX	-	Energy dispersive X-ray spectroscopy
XRD	-	X-ray diffraction
EDS	-	Energy dispersive spectroscopy
SEM	-	Scanning electron microscope
OM	-	Optical microscope
W	-	Weld
HAZ	-	Heat affected zone
TMAZ	-	Thermomechanically affected zone

LIST OF SYMBOLS

ω	-	Welding speed
ω	-	Welding rotation speed
T	-	Welding Tool
φ	-	Tool pin diameter
r	-	Tool shoulder diameter
t	-	Plate thickness
η	-	Tool travel angle
θ	-	Welding pitch
HAZ	-	Heat affected zone
TMAZ	-	Thermomechanically affected zone
UTS	-	Ultimate tensile strength
YS	-	Yield strength
E	-	Young's modulus
HV	-	Vickers hardness number
ρ	-	Density
ΔH	-	Heat of fusion
I	-	Current
V	-	Voltage
R	-	Resistance
N	-	Load
K	-	Corrosion rate
Ecorr	-	Corrosion potential
icorr	-	Corrosion current density

CHAPTER 1

INTRODUCTION

1.1 Background

Friction stir welding (FSW) has gained considerable attention in recent years due to its many advantages over traditional fusion welding methods. FSW offers multiple benefits such as improved mechanical properties, lowered environmental impact, and enhanced corrosion resistance. The welding process produces joints with minimal defects and a narrow heat-affected zone, making it suitable for welding dissimilar materials as show in figure 1.1.

This study focuses on examining the tribological and saltwater corrosion behavior of dissimilar alloy welding using FSW for brass and aluminum alloys. The goal is to investigate the welding process, tribology, microstructure, mechanical properties, and corrosion resistance of brass plate and aluminum alloy plate joints created using FSW.

Aluminum and its alloys are widely used across many industries because of properties such as high strength-to-weight ratio and corrosion resistance. However, welding aluminum alloys can be challenging due to their high thermal conductivity, low melting point, and susceptibility to defects like porosity and cracking. Therefore, it is important to develop reliable welding techniques that can produce high-quality joints with minimal defects.

Welding dissimilar materials such as brass and aluminum alloys presents issues in achieving strong and corrosion-resistant joints, particularly when exposed to salty environments. FSW offers a unique solution to this problem by providing a welding process that minimizes the heat-affected zone and produces joints with improved mechanical properties.

This chapter aims to briefly introduce the importance of welding techniques for aluminum alloys and the significance of understanding welding processes for dissimilar alloys. The chapter emphasizes the need for reliable and durable joints in aluminum structures, especially in marine applications, and challenges related to welding dissimilar aluminum alloys.

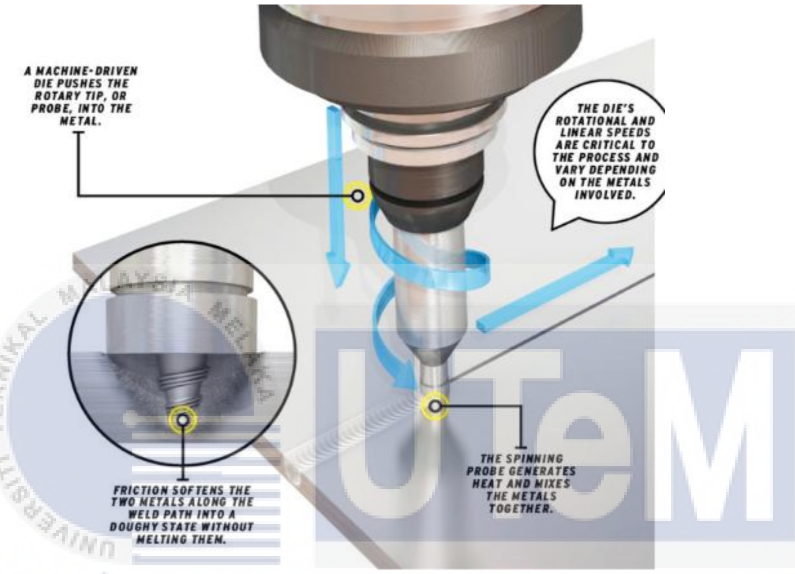

Figure 1.1: Friction stir welding (FSW) joining material process

At dissimilar alloy interface, the differences in mechanical properties lead to complex abrasive, adhesive and surface fatigue wear mechanisms. The resultant wear rate and friction depends on the effectiveness of material mixing and defect formation in the weld nugget zone (S. et al., 2023). Galvanic corrosion is another major concern for dissimilar aluminum welds in marine environments. The micro-galvanic couples formed between the alloys, intermetallic particles, and variable weld zones result in localized galvanic corrosion (Salavaravu and Dumpala, 2021).

While FSW is beneficial for aluminum welding, comprehensive understanding of the HAZ microstructural evolution, weld surface characteristics, material mixing, defect formation, wear behavior, and corrosion resistance in dissimilar aluminum FSW joints is currently lacking (Preethi and Daniel Das, 2021). This Project will address these gaps through an in-depth investigation. The outcomes will facilitate optimizing FSW parameters and advancing dissimilar aluminum welding for demanding marine structural applications.

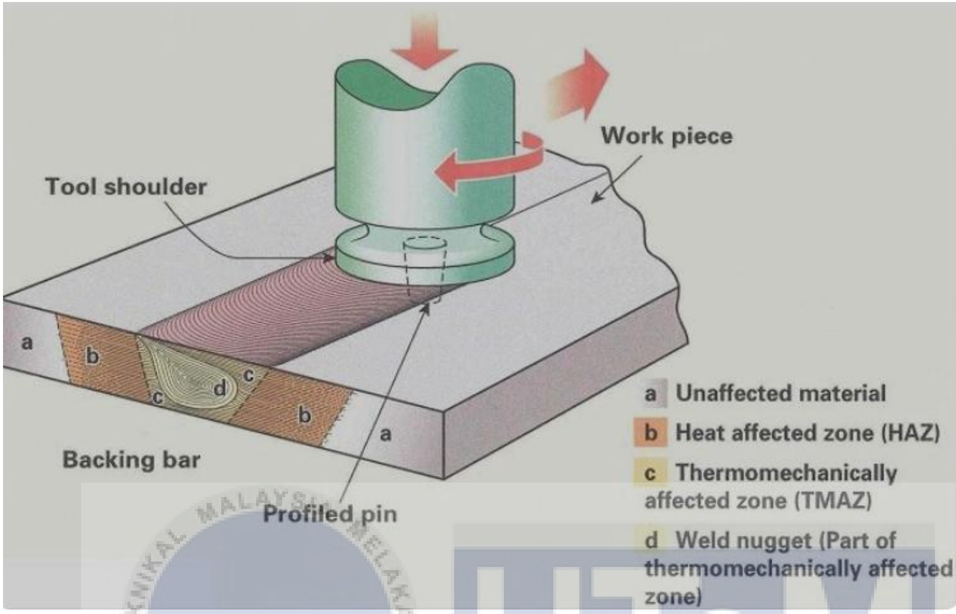

Figure 1.2: The FSW process is illustration

1.2 Background Study

Friction stir welding (FSW) is a solid-state joining process that has gained significant attention in recent years due to its numerous advantages over traditional fusion welding methods as show in figure 1.2. FSW offers several benefits, such as improved mechanical properties, reduced environmental impact, and enhanced corrosion resistance. The welding process produces joints with minimal defects and a narrow heat-affected zone, making it suitable for welding dissimilar materials. The focus of this study is on the tribological and saltwater corrosion behavior of dissimilar alloy welding using FSW for brass and aluminum alloys. The study aims to investigate the welding process, microstructure, mechanical properties, and corrosion resistance of brass plate and aluminum alloy plate joints produced using FSW.

Aluminum and its alloys are widely used in various industries due to their favorable properties, such as high strength-to-weight ratio and corrosion resistance. However, welding of aluminum alloys can be challenging due to their high thermal conductivity, low melting point, and susceptibility to defects such as porosity and cracking. Therefore, it is essential to develop reliable welding techniques that can produce high-quality joints with minimal defects.

The welding of dissimilar materials, such as brass and aluminum alloys, presents challenges in terms of achieving strong and corrosion-resistant joints, particularly when exposed to saltwater environments. FSW offers a unique solution to this problem by providing a welding process that minimizes the heat-affected zone and produces joints with improved mechanical properties. This chapter provides a brief overview of the importance of welding techniques for aluminum alloys and the significance of understanding the welding processes for dissimilar alloys and its tribiology behaviour in saltwater.

1.3 Problem Statement

The provided problem statement is comprehensive and well-articulated. It addresses the challenges and significance of friction stir welding (FSW) of dissimilar aluminum alloys, particularly the AA5052 and AA6061 alloys, and highlights the need to understand the tribological behavior, corrosion resistance, and joint integrity of the welded joints, especially under saline operating conditions. The statement also emphasizes the importance of investigating the microstructure, mechanical properties, sliding wear behavior, electrochemical corrosion kinetics, and resultant surface damage morphology of the dissimilar weld as show in figure 1.3.

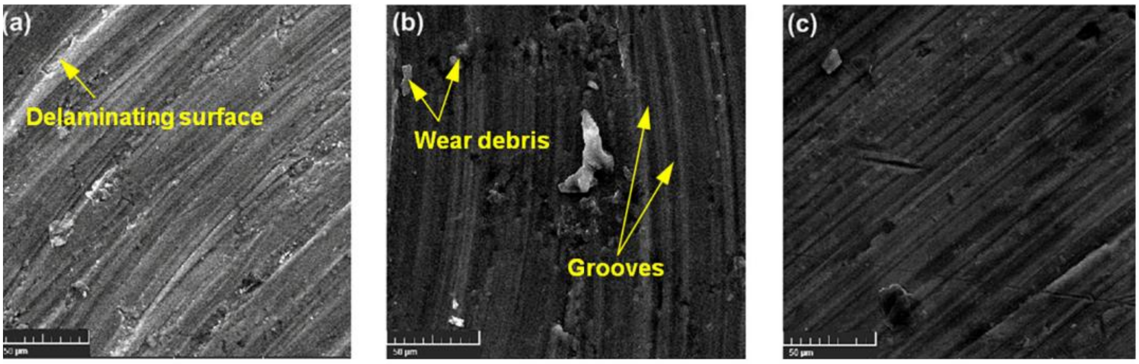

Figure 1.3: Scanning electron microscope images of worn-out surfaces(M et al.,2021).

Furthermore, it outlines the specific experimental techniques and tests to be conducted, such as pin-on-disk sliding wear tests, scanning electron microscopy, electrochemical corrosion experiments, salt spray exposure, and immersion testing. The statement also underlines the Project's objective to reveal optimal process parameters through structure-property-performance relations, aiming to facilitate the greater adoption of AA5052-AA6061 dissimilar aluminum FSW joints in lightweight engineering applications requiring excellent wear and corrosion resistance.

The problem statement is well-supported by relevant Project, such as the optimization of friction stir welding of dissimilar grades of aluminum alloy.(Rajesh et al., 2022), the corrosion and tribological behavior of friction stir processed aluminum alloys (Hari et al., 2022), and the effects of friction stir processing on the tribological, corrosion, and erosion properties of steel (Ralls et al., 2021). These sources provide valuable insights into the tribological, and corrosion properties of materials processed using friction stir welding, supporting the need for a comprehensive investigation into the dissimilar alloy welding process (Namboodiri et al., 2018).

Overall, the tribological properties of the dissimilar friction stir welding of AA5052-AA6061 is less know. Thus, in this study of the tribiological properties of friction stir welding are analyze using FESEM-EDX, tensile test, hardness and dry friction pin-on-disk test.