



Faculty of Manufacturing Engineering



**ANALYSIS OF REPETITIVE REPAIR WELDING ON PROPERTIES
OF STAINLESS STEEL TO CARBON STEEL DISSIMILAR METAL
JOINTS**

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Doctor of Philosophy

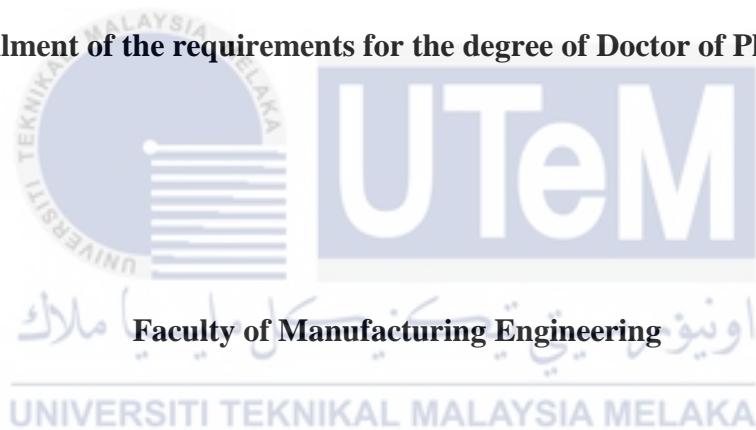
2023

**ANALYSIS OF REPETITIVE REPAIR WELDING ON PROPERTIES ON
STAINLESS STEEL TO CARBON STEEL DISSIMILAR METAL JOINTS**

SURAYA BINTI LAILY

A thesis submitted

in fulfilment of the requirements for the degree of Doctor of Philosophy



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this thesis entitled “Analysis Of Repetitive Repair Welding On Properties On Stainless Steel To Carbon Steel Dissimilar Metal Joints” 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.

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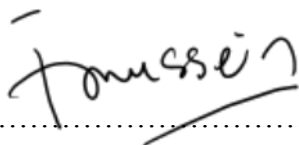
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : 

Supervisor Name : Associate Professor Dr. Nur Izzah Syahriah binti Hussein

Date : 23/10/2023



DEDICATION

To my beloved husband, son, daughter, late father, mother, my family in-laws, my supervisor and my supportive friends that accompany me along the difficult pathway in my university life especially during my PhD journey.



ABSTRACT

Repair welding of dissimilar material is frequently used in steel structures to replace the weldment defect and prolong the material service life. Generally, repair welding is a crucial topic that needs more discussion due to the lack of application in real industry. In order to reduce cost and dependence on the high skilled welders, repair welding on dissimilar pipe materials Stainless Steel 304 (AISI 304) and Carbon steel 1387 (BS 1387) were performed using Gas Metal Arc Welding (GMAW) with 100 mm each long. Furthermore, dissimilar is not just the material but also the diameter of the pipes. Fixed nozzle rotational jig was used as the main welding equipment with current (A), voltage (V) and rotational speed (rpm) as the main parameter. The study was focused on the effect of repair welding on mechanical properties, microstructure formation of AISI 304 and BS 1387 and prediction of service life of the dissimilar material repaired welded pipes. Tensile, microhardness, and fatigue tests were performed with nine runs of samples with three times of repetition as a planning matrix generated by Minitab Software. Design of Experiment (DOE) was used to plan the whole project using Taguchi Method as the main platform. Prediction of tensile testing and fatigue testing failure location was performed using ANSYS software. The outcome of the study shows that repair welding affected the performance of weldment, especially on mechanical properties. Tensile and microhardness testing showed the highest value on the second repair, while fatigue testing on the third repair. The heat generated during the welding process also affects the Heat Affected Zone (HAZ), and the microstructure formation of them was discussed. The regression equation of each repair was generated, and validation error was calculated. Prediction of the pipe service life schedule was performed using an FMEA chart in order to have a proper preventive maintenance schedule.

ANALISIS KIMPALAN PEMBAIKAN BERULANG PADA SIFAT SAMBUNGAN BAHAN TIDAK SERUPA KELULI TAHAN KARAT TERHADAP KELULI KARBON

ABSTRAK

Kimpalan pembaikan bahan yang berbeza sering digunakan dalam struktur keluli untuk menggantikan kecacatan kimpalan dan memanjangkan hayat perkhidmatan bahan. Secara amnya, pembaikan kimpalan adalah salah satu topik penting yang perlu dibincangkan lebih lanjut kerana kekurangan aplikasi dalam industri sebenar. Bagi mengurangkan kos dan pergantungan kepada pengimpal berkemahiran tinggi, pembaikan kimpalan pada bahan paip berbeza Keluli Tahan Karat 304 (AISI 304) dan keluli Karbon 1387 (BS 1387) telah dilakukan menggunakan Kimpalan Arka Logam Gas (GMAW) dengan panjang 100mm setiap satu. Tambahan pula, perbezaan bukan sahaja bahan tetapi juga diameter sampel. Jig putaran muncung tetap digunakan sebagai peralatan kimpalan utama dengan arus (A), voltan (V) dan kelajuan perjalanan (Amp) sebagai parameter utama. Kajian tertumpu kepada kesan kimpalan pembaikan ke atas sifat mekanikal, pembentukan struktur mikro AISI 304 dan BS 1387 dan ramalan hayat perkhidmatan bahan logam yang tidak serupa. Ujian tegangan, ujian microhardness dan ujian keletihan telah dilakukan dengan sembilan larian sampel dengan tiga kali ulangan sebagai matriks perancangan yang dihasilkan oleh Minitab Software. Reka Bentuk Eksperimen (JAS) telah digunakan untuk merancang keseluruhan projek menggunakan Kaedah Taguchi sebagai platform utama. Ramalan lokasi kegagalan ujian tegangan dan ujian keletihan telah digunakan perisian ANSYS. Hasil kajian menunjukkan bahawa kimpalan pembaikan telah mempengaruhi prestasi kimpalan, terutamanya pada sifat mekanikal. Ujian tegangan dan ujian microhardness menunjukkan nilai tertinggi pada pembaikan kedua manakala ujian keletihan menunjukkan pada pembaikan ketiga. Haba yang dijana semasa proses mengimpal juga mempengaruhi Zon Terjejas Haba (HAZ) dan pembentukannya telah dibincangkan. Persamaan regresi setiap pembaikan telah dijana dan ralat pengesahan dikira. Ramalan hayat perkhidmatan paip telah dilakukan menggunakan carta FMEA untuk mempunyai jadual penyelenggaraan pencegahan yang betul.

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LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
AISI	-	American Iron and Steel Institute
BS	-	British Standard
Psi	-	Pounds per square inch
GMAW	-	Gas metal arc welding
GTAW	-	Gas tungsten arc welding
MIG	-	Metal Inert gas welding
SS	-	Stainless steel
DE-GMA	-	Double electrode gas metal arc
HAZ	-	Heat affected zone
DOE	-	Design of experiment
RSM	-	Response surface methodology
C	-	Carbon
Si	-	Silicon
Mn	-	Manganese
P	-	Phosporus
S	-	Sulphur
Cr	-	Chromium
Ni	-	Nickel
N	-	Nitrogen
Mo	-	Molybdenum
Cu	-	Copper
EDMWM	-	Electrical Discharged Machine Wire Cut

CO ₂	-	Carbon Dioxide
Ar	-	Argon
AC	-	Alternating current
DC	-	Direct current



LIST OF SYMBOLS

Å	-	Angstrom
θ	-	Contact angle
D	-	Crystallite size
°	-	Degree
°C	-	Degree celsius
eV	-	Electronvolt
h	-	Hour
μ l	-	Microliter
μ m	-	Micrometer
mg	-	Milligram
ml	-	Milliliter
mm/s	-	Millimeters per second
nm	-	Nanometer
ppm	-	Parts per million
cm^{-1}	-	Per centimeter
min^{-1}	-	Per minute
%	-	Percentage
rpm	-	Rotation per minute



s - Second

W - Watt



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LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

1. Hussein, N.I.S., Laily, S., Salleh, M.S. and Ayof, M.N., 2019. Statistical Analysis of Second Repair Welding on Dissimilar Material Using Taguchi Method, *Journal of Mechanical Engineering and Science*, 13(2), pp.5021-5030.
2. Hussein, N.I.S, Ayof, M.N., Laily, S. and Salleh, M.S., 2019. Tensile Strength of Dissimilar Materials Pipes Welded by GMAW Repair Welding, *Journal of Design and Concurrent Engineering*. 26.
3. Hussein, N.I.S, Ayof, M.N., Akasak, N.S. and Laily, S., 2020. Effect of Repetitive Welding Using Orbital GMAW on Tensile Properties of AISI 304 Austenitic Stainless Steel Pipes. *Journal of Engineering and Management in Industrial System*, 8(1), pp.2477-6025.
4. Hussein, N.I.S, Nasri, A.N., Laily, S., Ayof, M.N. and Adenan, M.S., 2021. Paramater and Bead Geometry Relationship of Wire and Arc Additive Manufacturing for Aluminium Alloy ER5183. *Lecture Notes in Mechanical Engineering*, pp.2195-4356.

CHAPTER 1

INTRODUCTION

1.1 Research Motivation and Background

Repair welding is considered in the field of maintenance welding and is frequently used in steel structures to recover the fabrication defect or prolong the weldment's service life. Generally, repair welding can be defined as welded metal removed by grinding and inspected to verify the effective removal of the defect to work again on the same part. Kang et al. (2021) stated that defects in weldment, such as porosity, lack of penetration, slag inclusions, incomplete fusion, misalignment and undercut, may develop in pipeline fabrication, especially in the offshore industry. With non-destructive testing, the weldment should be repaired with all these defects. Repaired parts may be more serviceable than the original, even though they adversely affect structural integrity. It is more economical to weld repair since repairing the damaged part is much lower than the cost of replacing the new part. Appropriate selection needs to be done in terms of preparation and welding process depending on the same factors considered in the welding process for manufacturing. Because of the limitation in repair welding, such as the necessity to get quick equipment for immediate repair work, gas tungsten arc welding, shielded metal arc welding, gas metal arc welding and oxyacetylene welding are the most commonly used (Liang et al., 2019).

In offshore standards, a weld repair pipeline also supported it, stating that weld seams may only be repaired twice in the same area. However, this standard does not limit the number of repair welding, and there is a lack of studies on the effect of repeated weld repairs performed. It also defined that the usual maximum number of repair welding at the same area is two, but still there is no limitation to do over it depending on the material situation.