Faculty of Manufacturing Engineering

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

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

SURAYA BINTI LAILY

A thesis submitted

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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.

Signature : .....

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Date : 23/10/2023

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 Izan 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 repaire 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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TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATION		
ABSTRACT		**i**
ABSTRAK		**ii**
ACKNOWLEDGEMENTS		**iii**
TABLE OF CONTENTS		**iv**
LIST OF TABLES		**vii**
LIST OF FIGURES		**ix**
LIST OF ABBREVIATIONS		**xiii**
LIST OF SYMBOLS		**xv**
LIST OF APPENDICES		**xvii**
LIST OF PUBLICATIONS		**xviii**
CHAPTER		
1.	**INTRODUCTION**	**1**
1.1	Research Motivation and Background	1
1.2	Problem Statement	2
1.3	Research Objectives	4
1.4	Scope of the Study	4
1.5	Outline of the Report Thesis	5
2.	**LITERATURE REVIEW**	**7**
2.1	Repair Welding of Dissimilar Material	7
2.2	Dissimilar Metal Pipe of Stainless Steel and Carbon Steel	20
	2.2.1 Carbon Steel BS 1387	24
	2.2.2 Stainless Steel AISI 304	24
	2.2.3 Filler Wire 308L	25
2.3	Step to Develop Repair Welding	26
2.4	Gas Metal Arc Welding (GMAW) Process on Repair Welding	28
2.5	Taguchi Method using Design of Experiment (DOE)	30
2.6	Parameter Used in GMAW	31
	2.6.1 Current (Amp)	31
	2.6.2 Travel Speed (RPM)	33
	2.6.3 Voltage (V)	34
2.7	Welding Position	35
2.8	Mechanical Properties	36
	2.8.1 Microhardness Testing	36
	2.8.2 Tensile Testing	39
	2.8.3 Fatigue Testing	41

2.8.4 Microstructure Analysis 42
2.9 Summary 43

3. METHODOLOGY 44
3.1 Gantt Chart 44
3.2 Characterization of AISI 304 and BS 1387 48
3.2.1 Tensile Testing 50
3.2.2 Microhardness Testing 51
3.2.3 X-Ray Diffraction (XRD) 52
3.3 Design of Experiment (DOE) 53
3.4 Welding of Dissimilar Material 54
3.4.1 Repair Welding 57
3.4.2 Fatigue Testing 58
3.5 Sample Preparation and Microstructure Analysis 59
3.6 Scanning Electron Microscope 64
3.7 X-Ray Diffraction Machine 66
3.8 Analysis of Variance (ANOVA) 67
3.9 Prediction of Preventive Maintenance 68
3.10 Summary 68

4. RESULT AND DISCUSSION 69
4.1 Introduction 69
4.2 Result on Characterization of AISI 304 and BS 1387 70
4.2.1 Tensile Testing and Microhardness Testing 71
4.2.2 X-Ray Diffraction (XRD) 72
4.2.3 Microstructure of BS 1387 and AISI 304L 75
4.3 Tensile Testing Result on Dissimilar Welding Material 76
4.3.1 Tensile Testing Result on First Repair 77
4.3.2 Tensile Testing Result on Second Repair 80
4.3.3 Tensile Testing Result on Third Repair 83
4.3.4 Tensile Testing Result on Fourth Repair 86
4.3.5 Effect of Repair Welding to Tensile Testing 89
4.4 Microhardness Testing Result on Dissimilar Welding Material 90
4.4.1 Microhardness Result for First Repair 91
4.4.2 Microhardness Result for Second Repair 94
4.4.3 Microhardness Result for Third Repair 97
4.3.4 Microhardness Result for Fourth Repair 100
4.4.5 Effect of Repair Welding to Microhardness Testing 103
4.5 Fatigue Testing Result on Repair of Dissimilar Welding Material 105
4.6 Microstructure Analysis on Dissimilar Welding Material 112
4.6.1 Microstructure analysis using SEM 115
4.7 Optimum Number of Repair Dissimilar Welding Material 117
4.8 Prediction of Service Life Cycle of Repair Welded Material 119
4.8.1 FMEA Chart 121

5. CONCLUSION AND RECOMMENDATIONS **123**
5.1 Conclusions 123
5.2 Recommendation for Future Research 125

REFERENCES **126**
APPENDICES **142**

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Chemical composition of carbon steel BS 1387 (Callister and Wiley, 2007)	24
2.2	Chemical composition AISI 304L (Callister and Wiley, 2007)	25
2.3	Chemical composition of filler wire of 308L SS (Lincoln, 2006)	26
2.4	Brinell hardness value at weld and HAZ zone (AghaAli et al., 2014)	36
2.5	GMAW Process (Road, 2012)	38
2.6	GTAW Process (Road, 2012)	38
2.7	Results of the tensile test (AghaAli et al., 2014)	39
2.8	Results of the tensile test (Vega et al., 2008)	41
3.1	Nominal Composition of carbon steel BS 1387, wt% (Callister and Wiley, 2007)	48
3.2	Nominal composition AISI 304L, wt % (Callister and Wiley, 2007)	49
3.3	Planning Matrix using Taguchi Method	53
3.4	Nominal composition of filler wire of ER 308L SS (Lincoln, 2006)	55
3.5	Illustration of the repair welding process	57
4.1	Tensile Testing result on AISI 304L and BS 1387	71
4.2	Microhardness result on AISI 304L and BS 1387	72
4.3	GMAW parameter	76
4.4	Planning Matrix by Minitab Software	77
4.5	Result of Tensile Testing on First Repair	78
4.6	Response table for SN ratio for Tensile Testing on First Repair	79

4.7	Result of Tensile Testing on Second Repair	81
4.8	Response table for SN ratio for Tensile Testing on Second Repair	82
4.9	Result of Tensile Testing on Third Repair	84
4.10	Response table for SN ratio for Tensile Testing on Third Repair	85
4.11	Result of Tensile Testing on Fourth Repair	87
4.12	Response table for SN ratio for Tensile Testing on Fourth Repair	88
4.13	Result for UTS for the optimum parameter for each repair	90
4.14	Result on Microhardness of First Repair	92
4.15	Response table for SN ratio for Microhardness Testing on First Repair	93
4.16	Result of Microhardness of Second Repair	95
4.17	Response table for SN ratio for Microhardness Testing on Second	96
4.18	Result on Microhardness of Third Repair	98
4.19	Response table for SN ratio for Microhardness Testing on First Repair	99
4.20	Result on Microhardness of Fourth Repair	101
4.21	Result for microhardness for the optimum parameter for each repair	103
4.22	Fatigue testing result for first repair welding	106
4.23	Fatigue testing result on second repair welding	108
4.24	Fatigue testing result for third repair welding	109
4.25	Fatigue testing result for fourth repair welding	110
4.26	Basic FMEA chart on PM schedule on Tensile Testing	122
4.27	Basic FMEA chart on PM schedule on Microhardness Testing	122

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	The amount of ferrite against the number of repairs (AghaAli et al., 2014)	12
2.2	Effect of the number of repairs on hardness in HAZ stainless steel (Jiang et al., 2013)	12
2.3	Vickers hardness in the HAZ as a function of the number of repairs for a) upper area, b) central area, and c) bottom area (Vega et al., 2008)	13
2.4	Half Bead Welding (Lant et al., 2001)	17
2.5	Temper Bead technique (Lant et al., 2001)	18
2.6	British Steel DDR process (a) milled cavity of railway, where the defect is removed, and weld cavity is prepared using CNC milling, (b) square wave pattern welding process with three layers and (c) grinding procedure where the original railhead geometry is restored (Michele, 2017)	20
2.7	Gas Metal Arc Welding (Kalpakjian and Schmid., 2009)	30
2.8	Impact energy against heat input (Ghazvinloo et al., 2010)	32
2.9	Deepest penetration on 110.39 mm/min (Tewari et al., 2010)	33
2.10	Pipe welding position ASME Section IX (Progression et al., 2010)	35
2.11	Hardness value against repair number (Jiang et al., 2013)	37
2.12	Results of the tensile stress (MPa) against elongation (%) (AghaAli et al., 2014)	40

2.13	Fatigue test graph of dissimilar weld material (Raja et al., 2018)	42
2.14	Image of stress corrosion crack (SCC) (IAEA, 2018)	43
3.1	Flowchart on (a) Characterization of material, (b) Design of Experiment set up, (c) Welding process and testing involved, and (d) Preventive Maintenance	45
3.2	Specimen of BS 1387	49
3.3	Specimen of AISI 304L	49
3.4	Dimension of dogbone shape	50
3.5	Tensile Testing Machine	51
3.6	Microhardness testing machine	51
3.7	Microhardness measurements	52
3.8	X-ray Diffraction machine	52
3.9	Welding setup on 1G position on the jig	54
3.10	GMAW machine	55
3.11	308L wire electrode	56
3.12	Tacking position along the pipe	56
3.13	Turning process on the lathe machine	58
3.14	Air Servo hydraulic machine Instron 8802	59
3.15	Step-by-step grinding process	60
3.16	Solution and pad used in the polishing process	61
3.17	Etching solution for BS 1387	62
3.18	Schematic diagram of the electrolytic etching process	62
3.19	Scanning Electron Microscope	64
3.20	X-Ray Diffraction Machine	66

3.21	Dogbone shape analysis using ANSYS Workbench software	68
4.1	Elements in BS 1387	73
4.2	Elements in BS 1387 (Korosy et al., 2013)	73
4.3	Elements in AISI 304L	74
4.4	Elements in AISI 304L (Korosy et al., 2013)	74
4.5	Optical Microscope micrograph on 20µm	75
4.6	SEM micrograph on 500µm magnification	75
4.7	Main Effect Plot for SN Ratio for Tensile Testing on First Repair	79
4.8	Main Effect Plot for SN Ratio for Tensile Testing on the Second Repair	82
4.9	Main Effect Plot for SN Ratio for Tensile Testing on the Third Repair	85
4.10	Main Effect Plot for SN Ratio for Tensile Testing on Fourth Repair	88
4.11	Graph on UTS value of repair welding	90
4.12	Indentation area on microhardness samples	91
4.13	Main Effect Plot for SN Ratio for Microhardness Testing on First Repair	93
4.14	Main Effect Plot for SN Ratio for Microhardness Testing on Second Repair	96
4.15	Main Effect Plot for SN Ratio for Microhardness Testing on Third Repair	99
4.16	Main Effect Plot for SN Ratio for Microhardness Testing on Fourth Repair	102
4.17	Graph on microhardness value of repair welding	104

4.18	Scatter plot with a best-fitted line of microhardness vs heat input on the second repair	104
4.19	Fatigue testing specimen before and after experimental	106
4.20	Graph on strain life curve versus the number of repair welding	111
4.21	Microstructure of 1(a) HAZ of BS 1387 for the first repair, 1(b) HAZ of AISI 304 for the first repair, 2(a) HAZ of BS 1387 for the second repair, 2(b) HAZ of AISI 304 for the second repair, 3(a) HAZ of BS 1387 for the third repair, 3(b) HAZ of AISI 304 for third repair, 4(a) HAZ of BS 1387 for the fourth repair, 4(b) HAZ of AISI 304 for the fourth repair.	114
4.22	Scanning Electron Microscope image of (a)(b) first repair of BS 1387 and AISI 304, (c)(d) second repair of BS 1387 and AISI 304, (e)(f) third repair of BS 1387 and AISI 304 and, (g)(h) fourth repair of BS 1387 and AISI 304	116
4.23	Graph on the highest value of microhardness testing and UTS on the second repair of dissimilar welding material	118

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
µl	-	Microliter
µm	-	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

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt Chart of Sample Preparation and Repair Welding	142
B	Tensile Test Data	144

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 AluminiumAlloy 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.