



Faculty of Manufacturing Engineering

GMAW PARAMETERS EFFECTS ON MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF TOW SS304 AND BS1387

Mohd Zakaria Bin Mohd Noh

Master of Science in Manufacturing Engineering

2016

**GMAW PARAMETERS EFFECTS ON MICROSTRUCTURAL AND
MECHANICAL PROPERTIES OF TOW SS304 AND BS1387**

MOHD ZAKARIA BIN MOHD NOH

**A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
in Manufacturing Engineering**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitle “GMAW Parameters Effects on Microstructural and Mechanical Properties of TOW SS304 and BS1387” 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 :

Date :

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 Masters of Science in Manufacturing Engineering.

Signature :

Supervisor Name :

Date :

DEDICATION

To my beloved mother and father

ABSTRACT

Tailored orbital welding is a joining process of tubular product with dissimilar material and size depending on the application environment. One of the most common industries that apply this process is in power plant boiler water piping system. Dissimilar material is used to transmit water at various temperature, either in extremely high temperature water or room temperature water. In order to reduce cost and dependence on high-skill welder, tailored orbital welding of dissimilar material of Stainless Steel (SS) 304 and British Steel (BS) 1387 were performed by Gas Metal Arc Welding (GMAW) with automated fixed nozzle-rotational jig. The fixed nozzle-rotational jig was used to provide “steady hand” and constant travel speed for welding process. Thus, it will increase productivity and repeatability of the process, reducing the weld defects and produce good quality weldment. The study was focused on GMAW parameters variation effects on microstructure formation and mechanical properties of SS304 and BS1387 dissimilar material tailored orbital welding. The weldment quality was tested by performing non-destructive test and weld bead properties was studied to verify the influence of welding parameters variations. The study on microstructure formation, micro hardness and tensile strength were conducted to relate the solidification formation and mechanical properties. In addition, thermal effect was studied to understand the microstructure and micro hardness variations of tailored orbital welding. In this study, Design of Experiment (DOE) was employed to generate process parameter using Response Surface Methodology (RSM) method. Welding parameters include arc current, arc voltage and travel speed as input response, whilst, mechanical properties include micro hardness and tensile strength as output response. The effects of welding parameters on mechanical properties were also studied. Results from non-destructive test show no major defect was occurred. The weld bead dimension studies showed variation in welding parameters affect the weld bead formation. The heat generated during welding process also affect the microstructural and mechanical properties. The micro hardness value and tensile strength at weldment is higher than base material. The mathematical model for predicting hardness and tensile value was generated and validated. The validation fell within 90% prediction interval. The optimize parameters were generated in maximizing hardness and tensile value.

ABSTRAK

Kimpalan sambungan orbit merupakan satu proses penyambungan produk berbentuk tiub yang berlainan jenis bahan dan saiz yang bergantung kepada persekitaran penggunaan. Antara industri yang biasa menggunakan proses ini adalah sistem saliran dandang di pusat janakuasa. Berlainan bahan digunakan untuk mengalirkan air yang pelbagai suhu, samada air yang bersuhu tinggi atau air yang bersuhu bilik. Dalam mengurangkan kos dan kebergantungan terhadap pengkimpal berkemahiran tinggi, kimpalan sambungan orbit berlainan jenis bahan keluli tahan karat (SS) 304 dan keluli British (BS) 1387 dijalankan menggunakan Kimpalan Arka Logam Gas (GMAW) dengan berautomasi nozel tetap-jig berputar. Nozel tetap-jig berputar digunakan untuk menyediakan tangan yang tegap dan kelajuan yang malar untuk kerja kimpalan. Maka, ia akan meningkatkan pengeluaran dan pengulangan proses, mengurangkan kimpalan cacat dan menghasilkan kimpalan yang berkualiti. Penyelidikan bertumpu pada kesan parameter GMAW yang pelbagai pada pembentukan mikrostruktur dan sifat mekanikal kimpalan sambungan orbit berlainan jenis bahan SS304 dan BS1387. Kualiti kimpalan diuji dengan melaksanakan ujian tanpa-musnah dan sifat kimpalan di kaji untuk mengesahkan kesan parameter kimpalan yang pelbagai. Penyelidikan pada pembentukan mikrostruktur, kekerasan mikro dan kekuatan tegangan bertujuan untuk mengaitkan pembentukan pemejalan dan sifat mekanikal. Kesan haba dikaji untuk memahami mikrostruktur dan kekerasan mikro yang pelbagai pada kimpalan sambungan orbit. Dalam penyelidikan ini, Rekabentuk Ujikaji (DOE) telah digunakan untuk membentuk parameter proses menggunakan Kaedah Tindak Balas Permukaan (RSM). Parameter kimpalan; arus arka, voltan arka dan kelajuan pergerakan sebagai tindak balas masuk, manakala, sifat mekanikal; kekerasan-mikro dan kekuatan tegangan sebagai tindak balas keluar. Kesan parameter kimpalan keatas sifat mekanikal dikaji. Keputusan dari ujian tanpa musnah menunjukkan tiada kecacatan besar berlaku. Kajian terhadap dimensi bentuk kimpal menunjukkan variasi dalam parameter kimpalan memberi kesan kepada pembentukan bentuk kimpal. Haba yang dihasilkan semasa proses kimpalan juga memberi kesan kepada ciri-ciri mikrostruktur dan mekanikal. Nilai kekerasan mikro dan kekuatan tegangan pada kimpalan adalah lebih tinggi daripada bahan asas. Model matematik untuk meramal nilai kekerasan dan tegangan telah dihasilkan dan disahkan. Pengesahan jatuh dalam 90% selang ramalan. Parameter optimum telah dijana dalam memaksimumkan nilai kekerasan dan tegangan.

ACKNOWLEDGEMENT

First and foremost, I would like to thank Allah the Almighty for blessing me to complete my master by research project. I want to take this opportunity to record my utmost and sincere gratitude to my supervisor, Mr. Mohamad Nizam Ayof. Without him, I can never start work on my project and to proceed until this point. He has shown me guidance, important advice, and inspiration throughout my research. I am very thankful to my co-supervisor, Associate Professor Dr. Nur Izan Syahriah Hussein. She has given me essential knowledge and valuable discussion in doing this research.

I would like to express my gratitude to Mr. Nizamul Iqbal Bin Khaeruddin, Mr. Mohamad Zin Bin Mahmud, and all other assistant engineers as well as technicians from Faculty of Manufacturing Engineering for their assistance and support in laboratory works.

To my beloved family, I would like to forward my obliged to them for their continuous support during my study period, their patience and benevolence. Last but not least, I would like to thank everyone who has contributed during my research studied, your kindness and cooperation of my paperwork is much appreciated.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	iv
LIST OF APPENDICES	xiii
LIST OF ABBREVIATIONS	xiv
LIST OF PUBLICATIONS	xviii
CHAPTER	
1. INTRODUCTION	1
1.0 Background of Study	1
1.1 Problem Statement	3
1.2 Objectives	5
1.3 Scope	6
1.4 Significance of Study	7
2. LITERATURE REVIEW	8
2.0 Introduction	8
2.1 Tailor Welded Blanks (TWB)	9
2.2 Tailored Orbital Welding (TOW)	10
2.3 Dissimilar Materials Joining (DMJ)	11
2.3.1 DMJ of Stainless Steel and Carbon Steel	12
2.4 Stainless Steel	13
2.4.1 Austenitic Stainless Steel	13
2.4.2 Stainless Steel 304	14
2.5 Carbon Steel	15
2.5.1 Carbon Steel BS 1387	16
2.6 Welding Process	16
2.6.1 Gas Tungsten Arc Welding (GTAW)	16
2.6.2 Gas Metal Arc Welding (GMAW)	17
2.6.3 GMAW as Heat Source	19
2.7 Consideration in Manual Welding Dissimilar Metals	20
2.7.1 Weld Joints	22
2.7.2 Butt Joints of Dissimilar Metals	24
2.7.3 Tube Alignment and Manual Tacking	24
2.7.4 Heat Input	25
2.7.5 Welding Position	26
2.7.6 Fixed-Nozzle Rotational Jig	27
2.8 Tailored Orbital Welding Equipment	27
2.8.1 Pipe Wall Thickness	27
2.8.2 Filler Material	28
2.8.2.1 ER308L Filler Material	29

2.8.3	Shielding Gas	30
2.8.4	Penetration	30
2.9	Welding Parameters Consideration for Tailored Orbital Welding	31
2.10	Microstructure	33
2.11	Mechanical Properties	34
2.11.1	Tensile Test	35
2.11.2	Micro Hardness Vickers	38
2.12	Design of Experiment (DOE)	40
2.13	Summary	42
3.	METHODOLOGY	43
3.0	Introduction	43
3.1	Research Flow	43
3.2	Design of Experiment (DOE)	45
3.2.1	RSM; Box Behnken	45
3.3	Stainless Steel 304 and Carbon Steel BS1387	46
3.4	Material Preparation	48
3.4.1	Tacking Process	48
3.5	Tailored Orbital Welding Setup	50
3.5.1	Filler Material	51
3.5.2	Shielding Gas	51
3.5.3	Jig Setup	51
3.6	Non-Destructive Testing	52
3.7	Mechanical Test	54
3.7.1	Tensile Test	54
3.7.2	Micro Hardness Test	56
3.8	Microstructural Analysis	57
3.8.1	Grinding and Polishing	57
3.8.2	Etching	58
3.9	Thermal Analysis	58
3.10	Data Analysis	59
4.	RESULTS AND DISCUSSION	60
4.0	Introduction	60
4.1	Non-Destructive Test	60
4.1.1	Dye Penetrant	60
4.2	Measurement of Weld Bead Dimension	62
4.2.1	Effect of the Welding Parameters on Weld Bead Dimensions	65
4.3	Mechanical Properties	65
4.3.1	Micro Hardness Vickers	66
4.3.2	Tensile Properties	67
4.4	Process Parameters-Properties Relationship	68
4.4.1	Appropriate Polynomial Equation for RSM Hardness Model	70
4.4.2	ANOVA Analysis of the Response Surface Quadratic Model for Hardness	71
4.4.3	Significant Factors Influencing Hardness	73
4.4.3.1	Effect of Arc Current (A) on Hardness	73
4.4.3.2	Effect of Arc Voltage (B) on Hardness	74
4.4.3.3	Effect of Travel Speed (C) on Hardness	75
4.4.3.4	Effect of Interaction between Arc Current and	

Arc Voltage (AB) on Hardness	76
4.4.3.5 Effect of Interaction between Arc Current and Travel Speed (AC) on Hardness	77
4.4.4 Quadratic Polynomial Equation for Hardness Value	78
4.4.5 Hardness Value Model Validation	81
4.4.6 Appropriate Polynomial Equation for RSM Tensile Model	83
4.4.7 ANOVA Analysis of the Response Surface Quadratic Model for Tensile	84
4.4.8 Significant Factors Influencing Tensile Value	85
4.4.8.1 Effect of Travel Speed (C) on Tensile	86
4.4.8.2 Effect of Interaction between Arc Current and Arc Voltage (AB) on Tensile	87
4.4.9 Quadratic Polynomial Equation for Tensile Value	88
4.4.10 Tensile Value Model Validation	91
4.4.11 Modelling Summary	93
4.4.12 Effect of Welding Parameters on Weld Bead Hardness	94
4.4.13 Effect of Welding Parameters on Tensile Strength	95
4.5 GMAW Parameter Optimization for TOW	96
4.6 Microstructure of Tailored Orbital Welding	99
4.6.1 Fusion Zone (FZ)	100
4.6.2 Heat Affected Zone (HAZ) between ER 308L and BS1387	102
4.6.3 Heat Affected Zone (HAZ) between ER 308L and SS304	103
4.7 Thermal Analysis	105
4.8 Summary	107
5. CONCLUSION AND RECOMMENDATIONS	109
5.0 Conclusion	109
5.1 Recommendations for Future Research	111
REFERENCES	112
APPENDICES	125

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Chemical composition of SS304 and BS1387 pipe, in wt. %	13
2.2	Typical mechanical properties of SS304	14
2.3	Mechanical properties of BS1387 at room temperature	16
3.1	Levels of parameters factors for GMAW processes	45
3.2	GMAW parameters for TOW generated by Design Expert Software	46
3.3	Nominal composition of ER 308L SS wire, wt. %	51
3.4	Adler Etchant composition	58
4.1	Non-destructive test (dye penetrant) result on tailored orbital welding samples	61
4.2	Weld bead dimensions	64
4.3	Pearson Correlation Test by SPSS software	64
4.4	SS304 and BS1387 base material mechanical properties	66
4.5	Micro hardness Vickers result with parameters of experiment	67
4.6	Tensile test results with parameters of experiment	68
4.7	Experimental run and results of TOW	69
4.8	SMSS analysis for hardness model	70
4.9	Lack of fit test for hardness model	70
4.10	ANOVA analysis of the quadratic model for response hardness	72

4.11	Validation calculation for hardness response surface model	82
4.12	SMSS analysis for tensile model	83
4.13	Lack of fit test for tensile model	83
4.14	ANOVA analysis of the quadratic model for tensile	85
4.15	Validation calculation for tensile response surface model	92
4.16	Models developed represented as polynomial equations	93
4.17	The welding parameters and interaction significantly influence the respective developed polynomial models	93
4.18	Optimization constraints in Design Expert 7 software	96
4.19	Optimization solution generated by Design Expert 7 software	97
4.20	Optimum parameters hardness results and prediction value validation	98
4.21	Optimum parameters tensile results and prediction value validation	98
4.22	Heat input and temperature generate by welding process	107

LIST OF FIGURES

TABLE	FIGURE	PAGE
1.1	Example of TOW application in power plant	4
1.2	High skilled welder performed TOW in power plant	5
2.1	Chromium vs Nickel graph, relationship between families of stainless steel	14
2.2	Macrograph of the duplex stainless steel and low alloy steel dissimilar metal weld after immersion for 30 days in artificial deep water	19
2.3	Incorrect joint fit-up may affect the mechanical properties	21
2.4	Five basic types of joints used in welding	22
2.5	Butt weld joint of piping with dissimilar wall thickness	23
2.6	Equalize the heat flow by tapering the heavier material to the thickness of the thinner material	23
2.7	The butt joints with square root edges	24
2.8	Alignment gauge	24
2.9	Pipe welding position ASME Section IX	26
2.10	Stainless steel filler material is used in many stainless steel weld combination	28
2.11	Mechanical properties of steels at room temperature	34

2.12	Tensile test specimen	35
2.13	Typical stress-strain curve obtained from tensile test	36
2.14	General characteristics of hardness-testing methods and formulas of calculating hardness	39
3.1	Experimental Process Flow Chart	44
3.2	Details dimension for SS304	47
3.3	Details dimension for BS1387	47
3.4	Example of pipe position on the V-shape steel bar	48
3.5	Manual GMAW machine setting for tacking process	49
3.6	Pipe SS304 and BS1387	49
3.7	Position of welding nozzle, grounding cable and pipe on the fixed-nozzle rotational jig	50
3.8	GMAW machine Fronius TransSynergic 4000 integrate with VR 4000 wire feed system	52
3.9	Dye penetrant test three kits	53
3.10	Tension test specimens for large-diameter tubular products	54
3.11	AG-I Shimadzu Universal Testing Machine	55
3.12	Mitutoyo HR-523 machine, Vicker Micro Hardness Tester	56
3.13	Illustration of indentation line through BS1387, ER308L SS FZ and SS304	56
3.14	Buehler Omniment Optical Microscope	57
3.15	OPTEX Thermo-Hunter VF-3000 thermal camera	58
4.1	Sample no. 6 of TOW without any visual defect with 160 A, 19.25 V and 4 RPM as parameter	62

4.2	Sample no. 1 of TOW with visual defect with 160 A, 19.25 V and 3 RPM as parameter	62
4.3	The optical microscopy measurement image	63
4.4	Behaviour of weldment hardness in response to variation of welding current	73
4.5	Behaviour of weldment hardness in response to variation of welding voltage.	74
4.6	Behaviour of weldment hardness in response to variation of welding travel speed	75
4.7	Interaction between arc current and arc voltage with respect to welding hardness	76
4.8	Interaction between arc current and travel speed with respect to welding hardness	77
4.9	Interaction between arc current and arc voltage	79
4.10	Interaction between arc current and travel speed	80
4.11	Interaction between arc voltage and travel speed	81
4.12	Behaviour of weldment tensile in response to variation of welding travel speed	86
4.13	Interaction between arc current and arc voltage with respect to welding tensile strength	87
4.14	Interaction between arc current and arc voltage	89
4.15	Interaction between arc current and travel speed	90
4.16	Interaction between arc voltage and travel speed	91
4.17	The cross-sectioned of TOW of SS304 and BS1387; sample 7	99
4.18	Microstructure of 308L SS weld FZ	101

4.19	The microstructure result between ER 308L wire and BS1387	102
4.20	The microstructure result between SS304 and ER 308L	104
4.21	Plotted graph temperature over time for Sample 12, Sample 14 and Optimized	106

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Dye Penetrant Test Results	125
B	Weld Bead Detail Dimensions	131
C	Microhardness Vickers Results	140
D	Tensile Test Results	151
E	Optical Microscope Results	173

LIST OF ABBREVIATIONS

°C	-	Degree Celsius
3D	-	3 Dimension
A	-	Welding current
AISI	-	American Iron and Steel Institute
Amps	-	Ampere
ANN	-	Artificial Neural Network
ANOVA	-	Analysis of Variance
Ar	-	Argon
ASME	-	American Society of Mechanical Engineering
AWS	-	American Welding Standard
BM	-	Base Material
BS	-	British Standard
C	-	Carbon
CO ₂	-	Carbon dioxide
Cr	-	Chromium
CRS	-	Controlled Random Search
Cu	-	Cuprum
DMJ	-	Dissimilar Metal Joint
DOE	-	Design of Experiment
DOP	-	Depth of Penetration

E	-	Arc Voltage
<i>E</i>	-	Modulus Young
EDX	-	Energy Disperse X-ray
Er	-	Erbium
FA	-	Ferrite-Austenite
Fe-C	-	Iron-Carbon
FZ	-	Fusion Zone
G	-	Groove Weld
GA	-	Generic Algorithm
GFW	-	Welding wire electrode
GMAW	-	Gas Metal Arc Welding
GMAW-P	-	Gas Metal Arc Welding-Pulsed
GPa	-	Giga Pascal
GTAW	-	Gas Tungsten Arc Welding
H	-	Heat input
HAZ	-	Heat Affected Zone
HV	-	Hardness Vickers
I	-	Current
ID	-	Inside diameter
in	-	Inch
ISO	-	International Standard Organization
Kg	-	Kilo gram
kJ	-	KiloJoule
min	-	Minutes
mm	-	milimeter

MMA	-	Manual Metal Arc
Mn	-	Manganese
Mo	-	Molybdenum
Mpa	-	Mega Pascal
MRA	-	Multiple Regression Analysis
Nb	-	Niobium
NDT	-	Non-destructive Testing
Ni	-	Nickel
O ₂	-	Oxygen
OD	-	Outside diameter
OM	-	Optical Microscope
P	-	Phosphorus
Pb	-	Lead
PI	-	Prediction Interval
RPM	-	Rotation Per Minutes
RSM	-	Response Surface Methodology
S	-	Sulfur
S	-	Travel speed
S/N	-	Signal to noise
Sec	-	Second
SEM	-	Scanning Electron Microscopy
Si	-	Silicon
SiC	-	Silica Carbide
SMAW	-	Shielded Metal Arc Welding
SMSS	-	Sequential Model Sum of Squares

SS	-	Stainless Steel
STEM	-	Scanning Transmission Electron Microscopy
STS	-	Stainless Steel Grades
TEM	-	Transmission Electron Microscopy
TIG	-	Tungsten Inert Gas
TNB	-	Tenaga Nasional Berhad
TO	-	Tailored Orbital
TOW	-	Tailored Orbital Welding
TWB	-	Tailor Welded Blanks
US	-	United States
UTM	-	Universal Testing Machine
UTS	-	Ultimate Tensile Strength
V	-	Welding voltage
volts	-	Voltage
Y	-	Yield Stress

LIST OF PUBLICATIONS

Ayof, M.N., Hussein, N.I.S., Noh, Z.M., and Mohd Pauzi, M.F., 2013. Tailored Orbital Welding of Dissimilar Stainless Steels Material. *Proceeding of Malaysian Technical Universities Conference on Engineering and Technology (MUCET 2013)*, 3-4 December. Pahang: Universiti Malaysia Pahang (UMP).

Ayof, M.N., Noh, Z.M., and Hussein, N.I.S., 2014. Mechanical Properties Comparison of Stainless Steel 304L and Carbon Steel BS1387 Prior to Orbital Welding. *Proceedings of International Conference on Design and Concurrent Engineering (iDECON 2014)*, 22-23 September. Melaka: Universiti Teknikal Malaysia Melaka (UTeM).

CHAPTER 1

INTRODUCTION

1.0 Background Study

Welding is a versatile joining process which is applicable to almost all types of materials. It is one of the permanent joining processes that produce coalescence of the material by heating workpiece to the melting temperature with or without the existence of pressure or by the application of pressure itself and with or without the use of filler material for metal or non-metallic materials. Welding technique has been widely used in various industries such as automotive, oil and gas, aerospace, and many others. There are various types of welding and it differs according to the heat source, process and type of welded material such as, shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) and laser welding.

In many industries, welding plays an important role in reducing the production cycle time, thus reducing the delivery time (Vandewynckéle et al., 2013). Orbital welding is a joining process of tubes of similar thickness. It was one of the major improvements in pipe welding technology since 1980s. The orbital arc welding produces high quality of welded seams and has good repeatability. It is an alternative to manual welding process as it increases speed and ensure repeatability (Vandewynckéle et al., 2013).

Tailored orbital (TO) is welded tubular product made of tube from different materials of different thickness or coatings to component or other tubes, depending on the application in taking advantages in cost, weight and function (Goppelt, 2006). If the material joint is different to each other, it is also known as dissimilar metal joint (DMJ).