

**EFFECT OF DIRECT METAL DEPOSITION OF STAINLESS
STEEL 308 LSi WIRE ON STAINLESS STEEL 304 BASE PLATE**

**MOHD SYAZWAN BIN MOHD NIZAM
B051410046**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA
2017**



EFFECT OF DIRECT METAL DEPOSITION OF STAINLESS STEEL 308 LSi WIRE ON STAINLESS STEEL 304 BASE PLATE

This report is submitted in accordance with requirement of the University Teknikal
Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering
(Manufacturing Process) (Hons.)

by

MOHD SYAZWAN BIN MOHD NIZAM

B051410046

930710-14-5943

FACULTY OF MANUFACTURING ENGINEERING

2017

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **EFFECT OF DIRECT METAL DEPOSITION OF STAINLESS STEEL 308 LSi WIRE ON STAINLESS STEEL 304 BASE PLATE**

Sesi Pengajian: **2016/2017 Semester 2**

Saya **MOHD SYAZWAN BIN MOHD NIZAM (930710-14-5943)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

SULI (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA

TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:

Cop Rasmi:

Tarikh:

Tarikh:

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Effect Of Direct Metal Deposition Of Stainless Steel
308 LSi Wire On Stainless Steel 304 Base Plate”
is the result of my own research except as cited in references.

Signature :
Author’s Name : MOHD SYAZWAN BIN MOHD NIZAM
Date : 19 June 2017

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Manufacturing Process) (Hons).

The member of the supervisory committee are as follow:

.....
(PROF MADYA DR. NUR IZAN SYAHRIAH BINTI HUSSEIN)

.....
(MOHAMAD NIZAM BIN AYOF)

ABSTRAK

Satu kajian eksperimen bertajuk "Kesan langsung pemendapan logam daripada keluli tahan karat 308 LSi wayar pada keluli tahan karat 304 plat asas" dikaji. Tujuan kajian ini adalah untuk menyiasat bagaimana parameter pemendapan menjejaskan mikrostruktur, dimensi kimpalan dan kekerasan mikro daripada keluli tahan karat bahan pemendapan. Proses pemendapan logam dijalankan dengan menggunakan kaedah kimpalan tungsten robot gas lengai (TIG). Pengetahuan latar belakang pemendapan logam termasuk kimpalan, sumber haba, bahan dan aplikasi komersial berhubung dengan proses logam pemendapan, parameter proses, sifat mikrostruktur, dimensi kimpalan dan variasi kekerasan juga dikaji. Kaedah eksperimen melibatkan memanipulasi dua faktor (parameter pemendapan logam iaitu kelajuan kimpalan dan arus elektrik kimpalan) untuk menentukan jika perubahan dalam pembolehubah ini punca berubah ke arah jawapan (nilai microhardness dan kimpal ketinggian manik). Kaedah ini bergantung kepada Reka bentuk Eksperimen (DOE) dengan menggunakan Metodologi Response Surface (RSM) dan proses ini berdasarkan Central Komposit Designs (CCD) untuk mencapai pengoptimuman parameter semasa menjalankan penyelidikan eksperimen ini. Kemudian, ia telah membuktikan bahawa apabila menggunakan input haba yang tinggi, ia menyebabkan ketinggian manik kimpal yang lebih tinggi apabila arus elektrik (120 Ampere) dan kelajuan (50 mm / min) dilaksanakan. Bagi microhardness, input haba yang rendah menyebabkan prestasi yang lebih baik apabila arus elektrik (135 Ampere) dan kelajuan (170,71 mm / min) digunakan. Selain itu, perubahan microhardness pada pemendapan bahan, HAZ dan asas logam yang dimendapkan telah dibincangkan. Purata nilai microhardness menunjukkan bahawa nilai kenaikan microhardness daripada bahan pemendapan ke logam asas. Ia juga telah membuat kesimpulan bahawa kelajuan kimpalan menyumbang faktor yang paling penting untuk ketinggian manik kimpal, manakala arus elektrik kimpalan menyumbang faktor yang paling penting bagi microhardness.

ABSTRACT

An experimental research titled “Effect of Direct Metal Deposition of Stainless Steel 308 LSi Wire on Stainless Steel 304 Base Plate” is studied. The aim of this study is to investigate how parameters of deposition affecting microstructure, weld dimension and microhardness of stainless steel deposited material. The metal deposition process had been conducted using robotic tungsten inert gas (TIG) welding method. Background knowledge of metal deposition including welding, heat source, materials and its commercial application in relation to metal deposition process, process parameters, microstructure properties, weld dimension and hardness variation were also reviewed. The experimental method involving manipulating two factors (metal deposition parameters which are welding current and welding speed) to determine if changes in these variables causes change towards the responses (microhardness value and weld bead height). This method relies on Design of Experiment (DOE) by using Response Surface Methodology (RSM) and the process is based on Central Composite Designs (CCD) in order to achieve optimization of parameters while conducting this experimental research. Then, it was proved that when using high heat input, it resulted to higher weld bead height when current (120 Ampere) and speed (50 mm/min) had been setup. As for microhardness, low heat input resulting a better performance of microhardness when current (135 Ampere) and speed (170.71 mm/min) were setup. Besides that, microhardness variation which was indented at the deposited material, HAZ and base metal were discussed. The average microhardness value showed that the microhardness value increases from deposited material to base metal. It is also concluded that the welding speed contributes the most significant factor for weld bead height, while welding current contributes the most significant factor for microhardness.

DEDICATION

To

my beloved father, Hj Mohd Nizam bin Abdul Rashid

my appreciated mother, Hjh Sa'adiyah binti Abu Hassan

my adored brother and sister, Mohd Syazni bin Mohd Nizam and Syazana binti Mohd Nizam

for giving me moral support, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully even though there are difficulties in completing this study.

My respected supervisor, Prof Madya Dr. Nur Izan Syahriah binti Hussein for the great mentoring that was given to me throughout this project. Besides that, I would like to express my gratitude to my respected co-supervisor, Mr. Mohamad Nizam bin Ayof for a kind supervision, advice and guidance as well as exposing me with meaningful experiences throughout the study.

I would also like to acknowledge with much appreciation to my family and friends for their understandings, supports and beneficial discussion in completing this FYP report.

Finally, I would like to thank everybody who was important to this FYP report, as well as expressing my apology that I could not mention personally each one of you.

TABLE OF CONTENT

Abstrak	i
Abstract	ii
Dedication	iii
Acknowledgement	iv
Table of Contents	v
List of Tables	viii
List of Figures	ix
List of Abbreviations	xi
List of Symbols	xii

CHAPTER 1: INTRODUCTION

1.1	Introduction	1
1.2	Background of Study	1
1.3	Problem Statement	2
1.4	Objectives	3
1.5	Scope of Study	3

CHAPTER 2: LITERATURE REVIEW

2.1	Welding	5
	2.1.1 Arc Welding	6
	2.1.2 Tungsten Inert Gas (TIG)	7
2.2	Metal Deposition	8
	2.2.1 Heat Source	10
	2.2.2 Commercial Application	11
2.3	Stainless Steel	12
	2.3.1 Substrate of Stainless Steel 304	12
	2.3.2 Filler material of Stainless Steel 308	13

2.3.3	Stainless Steel Composition	13
2.4	Process Parameters	15
2.5	Parameters relationship with material properties	17
2.5.1	Weld Dimension	18
2.5.2	Microstructure Properties	19
2.5.3	Microhardness	21
2.6	Design Of Experiment (DOE)	22

CHAPTER 3: METHODOLOGY

3.1	Flow Chart	25
3.2	Material preparation	26
3.2.1	Substrate	26
3.2.2	Filler material	27
3.3	Experimental setup	28
3.3.1	Robotic GTAW	28
3.4	Design Of Experiment (DOE)	29
3.4.1	Variable for Metal Deposition Parameter	29
3.4.2	Response Variable	30
3.5	Testing	31
3.5.1	Microstructure	31
3.5.2	Weld bead height	33
3.5.3	Microhardness	34

CHAPTER 4: RESULT AND DISCUSSION

4.1	Macrostructure of Deposited Stainless Steel	36
4.2	Design of Experiment	36
4.2.1	Design Factor	37
4.3	ANOVA for Response Surface Quadratic Model	38
4.3.1	Weld Bead Height	38
4.3.2	Microhardness	39

4.4	Result for Weld Bead Height	40
4.4.1	Effect of Parameters toward Weld Bead Height	40
4.4.2	Variables Criteria	41
4.4.3	Optimization of Variables	43
4.5	Discussion on Weld Bead Height	45
4.5.1	Validation	45
4.6	Result for Microhardness of Deposited Stainless Steel	46
4.6.1	Effect of Parameters toward Microhardness of Deposited Material	47
4.7	Heat Input	49
4.7.1	Effect of Heat Input towards Weld Bead Height	50
4.7.2	Effect of Heat Input towards Hardness Value of Deposited Material	51
4.8	Microhardness Variation	52
4.8.1	Discussion on Microhardness	54
4.9	Microstructural Development	55
4.9.1	Discussion on Microstructure Characterization	57
4.9.1.1	Fusion Zone	57
4.9.1.2	Heat Affected Zone	59

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1	Introduction	61
5.2	Summary of Research	61
5.3	Research Findings	62
5.4	Recommendation for Future Research	63
5.5	Conclusion	64

REFERENCES	65
-------------------	----

APPENDICES

LIST OF TABLES

2.1	Nominal composition of 304 and 308 LSi stainless steel in wt% (Mirshekari et al., 2013)	13
2.2	Welding Current, A	15
2.3	Gas flow rate, litre/min	16
2.4	Welding Time, second	16
2.5	Welding voltage, V	16
2.6	Welding speed, mm.min ⁻¹	17
3.1	Welding parameters for robotic GTAW	29
3.2	Parameters and limits of metal deposition process	30
3.3	Design of Experiment matrix	30
4.1	Design Factor	37
4.2	ANOVA result for weld bead height	38
4.3	ANOVA result for microhardness	39
4.4	Constraints and Solution based on DOE	42
4.5	Heat input for each samples	50
4.6	Average hardness values at weldment area	54
4.7	Average hardness values at HAZ area	54
4.8	Average hardness values at base area	54
4.9	Solidification type, reactions and resultant microstructure (Lippold and Kotecki, 2005)	58

LIST OF FIGURES

2.1	Welding process (Singh <i>et al.</i> , 2014)	6
2.2	TIG welding process (Hadji <i>et al.</i> , 2016)	8
2.3	Schematic illustration of direct metal deposition (Hussein <i>et al.</i> , 2008)	9
2.4	Schematic diagram of weld dimension (Chai <i>et al.</i> , 2016)	18
2.5	Austenite microstructure of stainless steel 304 (Kurt and Samur, 2013)	19
2.6	Fusion zone of welded stainless steel 304 (Kurt and Samur, 2013)	20
2.7	Microstructure of HAZ (Mirshekari <i>et al.</i> , 2013)	21
2.8	Microhardness of material at fusion zone, HAZ and base metal (Mirshekari <i>et al.</i> , 2013)	22
3.1	Flow Chart of Experimental Research	25
3.2	Filler wire stainless steel 308 LSi (FKP Laboratory, 2016)	27
3.3	OTC FD-V6 GTAW Robot Welding (FKP Laboratory, 2016)	28
3.4	Optical Microscope (FKP Laboratory, 2016)	31
3.5	Grinding machine (FKP Laboratory, 2016)	32
3.6	Vertical Optical Comparator (FKP Laboratory, 2016)	33
3.7	Measurement of weld bead height	33
3.8	Vickers Microhardness machine (FKP Laboratory, 2016)	34
4.1	Cross-section of deposited material	36
4.2	Relationship between welding current and weld bead height	40
4.3	Relationship between welding speed and weld bead height	41
4.4	Variable criteria for welding current	42
4.5	Variable criteria for welding speed	42
4.6	Variable criteria for weld bead height	43
4.7	Relationship between different set of parameters and microhardness variation	46
4.8	Relationship between constant welding current 120 A and different welding speed	47
4.9	Relationship between constant welding current 135 A and	47

	different welding speed	
4.10	Relationship between constant welding current 150 A and different welding speed	48
4.11	Perturbation graph of welding current (A), welding speed (B) and hardness value	49
4.12	Relationship between heat input and weld bead height	51
4.13	Relationship between heat input and hardness values	52
4.14	Location of hardness test at weldment, HAZ and base area	53
4.15	Microstructure of weldment area	56
4.16	Microstructure of HAZ area	56
4.17	Microstructure of weldment area consist of vernicular and lathy ferrite	58
4.18	Relationship of solidification type to the pseudobinary phase diagram (Lippold and Kotecki, 2005)	59
4.19	Ferrite along austenitic grain boundaries in HAZ	60

LIST OF ABBREVIATIONS

3D	-	Three Dimensional
ANOVA	-	Analysis Of Variance
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
CCD	-	Central Composite Design
DCEN	-	Direct Current Electrode Negative
DOE	-	Design of Experiment
EDM	-	Electrical Discharge Machining
FA	-	Ferrite Austenite
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
HV	-	Vickers Hardness
MIG	-	Metal Inert Gas
RSM	-	Response Surface Methodology
SEM	-	Scanning Electron Microscopy
SMAW	-	Shielded Metal Arc Welding
TIG	-	Tungsten Inert Gas

LIST OF SYMBOLS

μm	-	Micron Metre
%	-	Percentage
A	-	Ampere
Ar	-	Argon
C	-	Carbon
Cr	-	Chromium
Fe	-	Iron
H ₂	-	Hydrogen
He	-	Helium
Hz	-	Hertz
kgf	-	Kilogram.Force
kJ/mm	-	Kilo Joule per millimeter
mm	-	Millimeter
mm/min	-	Millimeter per minutes
Mn	-	Manganese
Mo	-	Molybdenum
Ni	-	Nickel
P	-	Phosphorus
S	-	Sulfur
S	-	Second
Si	-	Silica
V	-	Voltage
wt%	-	Weight Percentage

CHAPTER 1

INTRODUCTION

1.1 Introduction

Direct metal deposition is a process of depositing additive material onto substrate material in which the process is implemented based on different purpose that comprise of direct part production, surface modification and repair. It can also be known as cladding, hard facing and welding overlays. Direct metal deposition process may also alter the properties of substrate due to repeated of heating and cooling process. In addition, direct metal deposition is being implement in order to eliminate surface corrosion, fatigue, cracks, improve wear resistance and hardness of substrate material.

1.2 Background of Study

This project is related to the effect of deposition of stainless steel 308 LSi wire on stainless steel 304 base plate. Experimental procedures were selected as a methodology of this project. Throughout the experiment, stainless steel 304 base plate and built structure from

stainless steel 308 LSi wire undergone testing in order to achieved the effect of metal deposition parameters.

In presence, it is a common method of implementing metal deposition for parts restoration, direct parts production and improve surface of materials by adding material layer-by-layer to achieve the desired or a near-net shape. Metal deposition process is patented originally by Rolls Royce which it is a technology in manufacturing process. Computer Aided Design (CAD) is used in building directly a complex part without aid from tools. In contrast with traditional machining method, metal deposition process only require wire in producing the parts which contributes a lot in reducing lead time, waste of material and cost efficiency (Bonaccorso *et al.*, 2011).

A high deposition rate and improvement of material performance are potential advantages that is being expected by the wire feedstock. In this study, robot Gas Tungsten Arc Welding (GTAW) or also known as Tungsten Inert Gas (TIG) was selected as a heat source and filler wire is stainless steel. The use of welding process was reported in this paper.

The aim of the experimental investigation is to study the characteristics of stainless steel 304 after deposition by stainless steel 308 LSi. For this purpose, stainless steel 308 LSi was deposited on stainless steel 304 with different values of welding current and welding speed. Microstructure, weld bead height and microhardness of deposited material were studied as respond from different values of welding current and welding speed. Heat input is also being calculated for better understanding towards cooling rates.

1.3 Problem Statement

Stainless steel 304 is a material that is useful for structural engineering as it has its specific properties such as good corrosion resistance and good weldability (Mirshekari *et al.*, 2014). These advantages are related to the used of this material as components in transportation, aerospace and turbine industries. Despite all of these, this material experiences limitations of

performance in their applications due to fatigues and overload operating condition, causing it to have wear failures and deep cracks (Song *et al.*, 2016). Besides that, there is also a possibility that the component is subjected to impacts, stress and corrosion, resulting to crack and defect (Pinkerton *et al.*, 2008). Thus, surface restoration can be done in order to achieve the performance of stainless steel 304 materials instead of discarding it as useless components. Deposition of stainless steel 308 LSi filler wire on stainless steel 304 base plate by using TIG welding is proposed in order to investigate the effect of the method towards the material, in terms of hardness and height of weldment. Height of weldment can be a factor to determine the number of layers is needed in order to achieve the desired shape.

1.4 Objectives

The objectives of this study are:

- i) To study the effect of deposition parameters on weld bead height and microhardness of the deposited material.
- ii) To characterize the microstructure of deposited stainless steel 308 LSi wire on stainless steel 304 base plate.

1.5 Scope of Study

There are two material involves in this study which are stainless steel 304 and stainless steel 308 LSi wire. Stainless steel 304 is the substrate while stainless steel 308 LSi is the filler wire that function as a deposition material or build structure. Stainless steel 304 had been deposited by stainless steel 308 LSi wire through welding by using robot TIG as a heat source. In order to observe the effect on microstructure, weld bead height and microhardness of the

material, two parameters were selected which are welding current and welding speed. The experiment was carried out by using Design of Experiment (DOE) by Response Surface Methodology (RSM) method.

Microhardness properties of deposition had been examined by using Vickers microhardness in accordance with ASTM E92-82. For microstructure observation, model ZEISS of Optical Microscope had been used. A sample preparation for microstructural had been done according to ASTM 112. Other aspect which is weld dimension and heat input were also included in this study.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review based on literatures related to welding, deposition process, stainless steel materials and also metal deposition parameters. Besides that, literature related to TIG as a heat source, weld dimension, microstructure, microhardness and design of experiment also being included in this chapter.

2.1 Welding

Joining is a process that joints two material or parts. For instance, bolt and nut is use to joint parts for a chair. This is a joining process by means of mechanical. Another joining process is welding. Welding is a process of joining a similar or dissimilar materials by using heat or pressure. Figure 2.1 shows a welding process. In presents, welding is a favorable method by industries as it provides a high strength of joints (Mirshekari *et al.*, 2014). Filler material is used in welding process in order to form weld pool during melting of base metal. When the weld pool reaches solidification, it builds a strong joint with the base material, allowing high strength properties to be achieved.

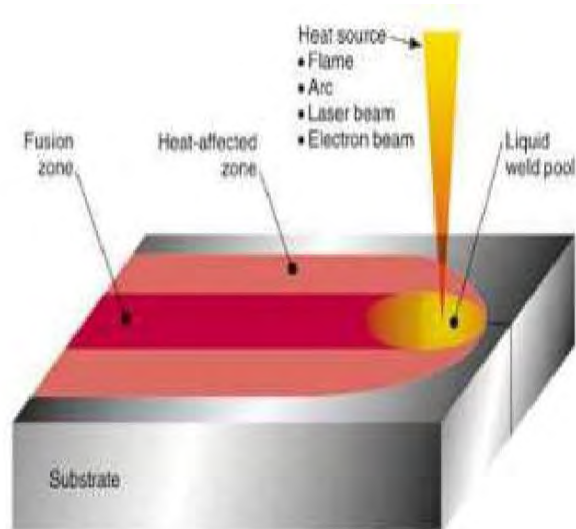


Figure 2.1: Welding process (Singh *et al.*, 2014)

2.1.1 Arc Welding

Arc welding is a process that use electric arc which produces extreme heat to melt the material and electrode wire, that contribute the joining process to occur. Electrode is used in arc welding process to conduct electrical energy from electric arc and it also provides filler metal when it melts. The types of arc welding includes shielded metal arc welding (SMAW), gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW).

Shielded metal arc welding which is also known as stick welding uses an electric arc and consumable coated electrodes that act as filler metal for welding a stainless steel. Equipment for SMAW is relatively low but it also has a low deposition rates causing it to have a slow welding process due to a repeated replacement of electrodes (The Lincoln Electric Company, 2003).

Gas metal arc welding is also known as a metal inert gas (MIG) uses a continuous fed electrode wire to melt and joints material through heat source from electric arc. Inert gas works as a protection towards the electrode wire to avoid any contamination from the welding process. MIG is highly recommended for the process of thick material with long joints as it has high deposition rates (The Lincoln Electric Company, 2003)

Gas tungsten arc welding or it is also called as tungsten inert gas (TIG) uses tungsten as the electrode. The electrode is non-consumable while the inert gas works as shield to avoid any defect towards the weldment.

2.1.2 Tungsten Inert Gas (TIG)

TIG welding is a method that the heat produced through metal substrate and a non-consumable electrode made of tungsten. Figure 2.2 shows welding process by using TIG. The electrode is a part of the weld as that melt from the base metal due to the sufficient heat produced from electric arc and it leads to the production of the weld pool and it leaves no slag. The inert gas perform in covering the arc area in order to protect weld pool free from defects and porosity (Prajapati and Shah, 2016). In addition, TIG welding is a process that produced a high quality and good appearance of weldment (Prajapati and Shah, 2016).

As for the shielding gas, there are mixtures of argon (Ar), helium (He) and hydrogen (H₂). Argon is basically used for stainless steel, mild steel, aluminum and titanium as it able to perform at a high arc voltage. Helium can be used for stainless steel and it offers a small heat affected zone causing a deeper penetrations. Helium can also be mix with argon. Helium promotes a high input of heat for increasing the speed of welding. As for hydrogen, it should not be applied to a martensitic, ferritic and duplex stainless steel as it may demolish electrode. As for the selection of shielding gas, it is depends on the base material. According to Kumar *et al.* (2015a); Mirshekari *et al.* (2014); Bonaccorso *et al.* (2011); SHIRI *et al.* (2012), the suggested shielding gas for stainless steel 304 base plate is Argon.