

THE Effect Of Current On Characteristic For Welded Joint Between 316 And 316L  
Stainless Steel Including Microstructure And Mechanical Properties

NAVID MOSLEMI

A project report submitted in partial fulfilment of the  
requirements for the award of the degree of  
Master of Engineering (Materials Engineering)

Faculty of Mechanical Engineering  
Universiti Teknologi Malaysia

JANUARY 2014

*TO MY BELOVED PARENTS FOR  
THEIR ENDLESS LOVE AND SUPPORT*

## ACKNOWLEDGEMENT

Firstly, I am thankful to God for completing this master project report successfully. This project could not be written without the help of my supervisor, Dr. Norizah Bt Hj. Redzuan and my co supervisor Dr. Norhayati Ahmad who encouraged and challenged me through my academic program.

I would like to express my special gratitude to my parents, my brother, my brother-in-law and my sister. Without all of you, I will not be able to stand where I am today.

Thanks to my friends for their help and view at various occasions. In addition, I would like to express my appreciation to those who have given me either direct or indirect assistance in this project.

Eventually, I hope that this report will be advantageous in future.

## ABSTRACT

Arc welding is a method that is widely used for fixed joining process. TIG is most commonly used to weld thin sections of stainless steel and light metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing procedures. For this study, the influences of parameters of tungsten inert gas arc welding on the morphology, microstructure, hardness and tensile property, and fracture of welded joints of two kind of material including 316 stainless steel pipe and 316L stainless steel plate have been studied. Results show that the increase of welding current bring about the large amount of heat input in the welding pool, the enlargement of width and deepness of the welding pool, cumulative sigma phase in the matrix of both materials and reducing the chromium carbide percentage in 316 stainless steel welded joint. Arc current of 100A has also been identified as the most suitable arc current used to weld the two and half inches 316 stainless steel pipe. Since it gives the lowest defects and brings the highest value of hardness compared to others. For welding 316L stainless steel plate joint, the most suitable current was identified by 110A since it give the lowest defects and highest value of tensile strength compared to others. However, the value of Hardness is slightly lower than 130A.

## ABSTRAK

Kimpalan Arc adalah kaedah yang digunakan secara meluas untuk tetap proses penyambungan . TIG adalah yang paling biasa digunakan untuk mengimpal bahagian nipis daripada keluli tahan karat dan logam ringan seperti aluminium, magnesium, dan aloi tembaga. Proses ini memberi pengendali kawalan yang lebih besar ke atas kimpalan daripada prosedur yang bersaing. Untuk kajian ini, Pengaruh parameter tungsten lengai kimpalan arka gas morfologi , struktur mikro , harta tanah tegangan dan patah sendi dikimpal daripada dua jenis bahan termasuk 316 paip keluli tahan karat dan 316L plat keluli tahan karat telah dikaji. Keputusan menunjukkan peningkatan kimpalan membawa semasa kira-kira jumlah yang besar input haba dalam kolam kimpalan, pembesaran lebar dan deepness kolam kimpalan, sigma fasa terkumpul dalam matriks kedua-dua bahan dan mengurangkan peratusan karbida dalam 316 keluli tahan karat bersama dikimpal. Arc semasa 100A juga telah dikenal pasti sebagai semasa arka yang paling sesuai digunakan untuk mengimpal dua setengah inci 316 paip keluli tahan karat. Sejak ia memberikan kecacatan paling rendah dan membawa nilai tertinggi kekerasan berbanding dengan orang lain . Untuk kimpalan keluli tahan karat 316L plat bersama, semasa yang paling sesuai telah dikenal pasti oleh 110A kerana ia memberi kecacatan paling rendah dan nilai tertinggi kekuatan tegangan berbanding dengan orang lain . Walau bagaimanapun , nilai kekerasan adalah than130A rendah sedikit.

## TABLE OF CONTENTS

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	<b>DECLARATION</b>	<b>ii</b>
	<b>DEDICATION</b>	<b>ii</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
	<b>ABSTRACT</b>	<b>iv</b>
	<b>ABSTRAK</b>	<b>v</b>
	<b>TABLE OF CONTENTS</b>	<b>vi</b>
	<b>LIST OF TABLES</b>	<b>xi</b>
	<b>LIST OF FIGURES</b>	<b>xii</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xvii</b>
	<b>LIST OF APPENDICES</b>	<b>xix</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Introduction	1
	1.2 Problem statement	2
	1.3 Research objective	3
	1.4 Scope of the study	3
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>5</b>
	2.1 Stainless steel	5
	2.1.1 Introduction	5
	2.1.2 Classification of stainless steel	5

2.1.3	Austenitic stainless steel	6
2.1.4	Grade 316L	8
2.1.4.1	Composition	8
2.1.4.2	Properties	9
2.1.4.3	Application	10
2.2	Grade 316	11
2.2.1	Comparison of chemical composition and mechanical properties of 316 and 316L	11
2.2.2	Risk incurred during welding of 316 and 316L	12
2.2.2.1	Carbide precipitation	12
2.2.2.2	Hot cracking	12
2.2.2.3	Sigma phases	13
2.3	TIG Welding process	14
2.3.1	TIG Welding Equipment	14
2.3.2	Application	16
2.3.3	Advantages and Disadvantages of GTAW	17
2.3.4	TIG welding on 316 and 316L stainless steel	18
2.3.5	TIG welding parameter	19
2.3.6	Arc current and heat input	19
2.4	Mechanical analysis of TIG welding	27
2.4.1	Hardness test	27
2.4.2	Tensile Test	28
2.5	Microstructure analysis	28
<b>3</b>	<b>RESEARCH METHODOLOGY</b>	<b>29</b>

3.1	Introduction	29
3.2	Material selection	31
3.3	Material dimension	31
3.3.1	316 pipe size	31
3.3.2	316L stainless steel plate	32
3.4	Cutting tool	32
3.5	Join preparation	32
3.5.1	316 stainless steel pipe	32
3.5.2	316L stainless steel	33
3.6	TIG welding process	34
3.6.1	316 stainless steel pipe	34
3.6.2	316L stainless steel plate	34
3.6.3	Welding parameters	34
3.6.4	Welding process on 316L stainless steel plate	35
3.6.4.1	Filler rod	37
3.6.5	Sample preparation for testing	38
3.6.6	Tensile test	38
3.6.6.1	316 stainless steel pipe tensile sample	38
3.6.6.2	316 stainless steel plate tensile sample	40
3.6.7	Procedure of Tensile Test	41
3.6.8	Microstructure and Hardness	42
<b>4</b>	<b>RESULT AND DISCUSSION</b>	<b>48</b>
4.1	Introduction	48



4.2	Composition analysis	48
4.3	XRD result	49
4.3.1	XRD result for 316 stainless steel welded joint	49
4.3.2	XRD result for 316L stainless steel welded joint	50
4.4	Result of the Welding Experiments on 316L stainless steel plates	51
4.4.1	Result of the Welding Experiment One	51
4.4.2	Result of Welding Experiment Two	52
4.5	Welding Experiment Results	53
4.6	Morphology of Welded Joint	53
4.7	Microstructure analysis	54
4.8.1	FESEM_ EDX Analysis	57
4.8.2	Tensile Test of 316 Stainless Steel Pipe	62
4.8.3	Tensile Test of 316L Stainless Steel Plate	63
4.8.4	Fractography of Fracture Surface	67
4.8.4.1	316 stainless steels welded joint fractography	67
4.8.4.2	316L Stainless steel welded joint fractography	69
4.8.5	Vickers Hardness Test of 316 and 316L stainless steel welded sample	71
4.8.5.1	The result of Vickers Hardness Test of 316 stainless steels welded sample.	72

4.8.5.2	The result of Vickers Hardness Test of 316L stainless steel welded sample	75
<b>5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>78</b>
5.1	Introduction	78
5.1.1	316 stainless steels welded joint.	78
5.1.2	316L stainless steel welded joint	79
5.2	Recommendations	79
5.2.1	Future research	80
5.2.2	Limitations to consider	80
	<b>REFERENCES</b>	<b>81</b>
	<b>APPENDICES A-C</b>	<b>84</b>

## LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Composition ranges for 316L stainless steels	8
2.2	Mechanical Property Specification	12
2.3	Composition Specification (%)	12
2.4	How Material Properties are Affected by Increasing Heat Input for SMAW - SMAW with a heat input range of 15 to 110 kJ/in (Funderburk, 1999).	21
2.5	Tensile properties of the welded joints of GH99 superalloy under different welding parameter (Wang et al., 2011)	23
3.1	selected pipe size (Hor, 2012)	31
3.2	Welding parameters ( Welding Procedure Specification (WPS))	35
3.3	Welding parameters for 316L stainless steel	36
3.4	Chemical composition of filler rod (%)	37
4.1	GDS result	48
4.2	The result of tensile test for 316 stainless steel	62

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Schaeffler-Delong stainless steels constitution diagram. Adapted (Blondeau, 2013)	6
2.2	Classification of stainless steel(Lo et al., 2009)	7
2.3	Pseudobinary sections of Fe-Cr-Ni ternary system at70%Fe (Lippold and Kotecki, 2005)	13
2.4	A diagram of a complete gas tungsten arc welding station (Lee et al., 2007)	15
2.5	TIG Welding Area(Tseng and Hsu, 2011)	15
2.6	Heat input influences cooling rate (Funderburk, 1999).	20
2.7	Effects of welding current on the macro morphology and microstructure of the butt-welding joint Welding current (a) 55A; (b) 80A; (c) 95A	21
2.8	Microstructure of the seam zone and the heat affected zone center (a) seam; (b) fusion zone; (c) overheating zone; (d) fine- grained zone; (e) incomplete recrystallization zone (Wang et al., 2011)	22

2.9	Penetration vs. Welding Current diagram for 20 cm/min welding speed (Ibrahim et al., 2012)	24
2.10	Hardness vs. Welding Current and arc voltage diagram (Ibrahim et al., 2012)	25
2.11	Microstructure of welded parts(Ibrahim et al., 2012)	25
2.12	developed model of past study on effect of current on welding joint	26
3.1	Flow chart of project procedure	30
3.2	selected plate size	32
3.3	Desired joint (Hor, 2012)	33
3.4	Desired joint	33
3.5	Filler rod	37
3.6	The providing of flat specimen (Hor, 2012)	38
3.7	Dimensions and tolerances for longitudinal strip tension test specimens for tubular products (follow ASTM A370) (Hor, 2012)	39
3.8	rounded specimen for tensile sample, (a) cut welded sample, (b) making rounded sample by using lath machine, (c) rounded sample	40
3.9	preparing tensile sample from rounded specimen, (a) CNC lath machine, (b) material dimention, (c) rounded tensile sample	41

3.10	Tensile Test of 316 L welded plate sample	42
3.11	Fractured samples after tensile test, (a) 316, (b) 316L	42
3.12	sample preparation by using: (a) grinding machine, (b) polishing machine, (c) electro polishing machine	43
3.13	Optical microscope	44
3.14	Vickers Hardness	44
3.15	SEM	43
3.16	FESEM – EDX	45
3.17	XRD machine	46
3.18	GDS Process (Yong, A, 2009)	47
4.1	XRD result for 316 SS and weld metal	49
4.2	XRD result for 316L SS and weld metal	50
4.3	Lack of fusion: (a) back face of welded joint; (b) cross section of welded joint	51
4.4	angular distortion	51
4.5	angular distortion of samples with arc current (a) 100A (b) 110A (c) 130 A	52
4.6	Back of fusion of welded joint	52
4.7	Effects of welding current on the macro morphology and microstructure of 316 SS butt-welding joint Welding current	53

	(a) 80A; (b) 90A; (c) 100A; (d) 110A.	
4.8	Effects of welding current on the macro morphology and microstructure of 316L SS butt-welding joint Welding current (a) 100A; (b) 110A; (c) 130A.	53
4.9	Microstructure of the seam zone and the heat affected zone center of 316L SS (a) seam; (b) fusion zone; (c) overheating zone; (d) fine-grained zone; (e) incomplete recrystallization zone	55
4.10	Microstructure of the seam zone and the heat affected zone center of 316 SS (a) seam; (b) fusion zone; (c) overheating zone; (d) fine-grained zone; (e) incomplete recrystallization zone	56
4.11	FESEM-EDX analysis of Diffusion zone of 316 SS welded joint-current 90A- mag 500X (a) Microstructure; (b) spectrum analysis	58
4.12	FESEM-EDX analysis of Diffusion zone of 316L SS welded joint-current 130A- mag 960X (a) Microstructure; (b) spectrum analysis	59
4.13	Pseudobinary sections of Fe-Cr-Ni ternary system at 70%Fe (Lippold and Kotecki, 2005)	60
4.14	Effects of welding current on the sigma and carbide phases distribution of 316 SS, achieved by FESEM – EDX – mag 500 – current 110A	61
4.15	Effects of welding current on the sigma and carbide phases distribution of 316 SS, achieved by FESEM – EDX – mag 1000 – current 130A	61

4.16	Graph of arc current (A) versus mean of tensile strength (MPa) (Hor, 2012)	62
4.17	Stress - strain behavior of 316L SS welded joint tensile sample current 100A	64
4.18	Stress - strain behavior of virgin 316L SS tensile sample	65
4.19	comparison of tensile properties between default and welded joints of 316L SS	66
4.20	Typical morphology on the fracture surface of 316 SS welded joint achieved by FESEM – EDX – mag 1000 – current 100A	67
4.21	Fractography on fracture surface of 316 SS welded joint achieved by FESEM – EDX – mag 2500 – current 100A (a) microstructure; (b) spectrum analysis	68
4.22	Typical morphology on the fracture surface of 316L SS welded joint achieved by FESEM – EDX – mag 2500 – current 100A	69
4.23	Fractography on fracture surface of 316L SS welded joint achieved by FESEM – EDX – mag 7000 – current 100A (a) microstructure; (b) spectrum analysis	70
4.24	The indentation point of welded joint sample taken from left to right (a) 316SS welded joint (b) 316L SS welded joint	71
4.25	Comparison of number of points versus hardness value (HV) 316 stainless steel welded joint	73
4.26	Position when the microstructure photo is taken for 316 SS specimen welded using arc current 110 taken from left to right,	74



	316 SS welded joint	
4.27	The Micrograph of the indentation point of Figure 4.26	74
4.28	Comparison of number of points versus hardness value (HV) 316L stainless steel welded joint	76
4.29	Position when the microstructure photo is taken for 316 SS specimen welded using arc current 110 taken from left to right, 316L SS welded joint	77
4.30	The Micrograph of the indentation point of Figure 4.29	77

**LIST OF ABBREVIATIONS**

GMAW	GAS metal arc welding
GTAW	Gas tungsten arc welding
MIG	Metal inert gas
UTS	Ultimate tensile strength
TIG	Tungsten inert gas
SMAW	Shielded metal arc welding
SS	Stainless steel
WPS	Welding Procedure Specifications

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Gantt chart of MP1 & MP2	84
B	EDX result of 316 and 316L stainless steel weldedjoint	86
C	Tensile result	95

## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

Welded components and structures are widely used in almost all industries. Current engineering industry relies heavily on welded components and structures. Therefore, weld integrity becomes important for adequate and reliable performance of components, structures, and plants. Weld integrity is dependent on the base material, specifications, and welding processes. With the ever-increasing sophistication of processes, materials, and specifications, one must have a broad, comprehensive knowledge of the metallurgy and welding processes. Tungsten Arc Welding (GTAW) also known as Tungsten Inert Gas (TIG) involves striking an arc between a non-consumable tungsten electrode and the work piece. The weld pool and the electrode are protected by an inert gas, usually argon, supplied through a gas cup at the end of the welding gun, in which the electrode is centrally positioned. TIG welding can also be used for welding with filler material, which is applied in rod form by hand similar to gas welding. Tools for mechanized TIG welding are used for applications such as joining pipes and welding tubes into the end plates of heat exchangers. Such automatic welding tools can incorporate many advanced features, including mechanized supply of filler wire. The advantages of the process are stable arc and excellent control of the welding result. The main application for TIG welding is welding of stainless steel, welding of light metals, such as aluminum and magnesium alloys, and the welding of copper. It is also suitable for welding all

weldable materials, apart from lead and zinc, with all types of joints and in all welding positions.

However, TIG welding is best suited to thin materials, from about 0.5 mm up to about 3 mm thick. (For more thickness must use multi passes welding) (Blondeau, 2013; Storjohann *et al.*, 2005).

Austenitic stainless steel type 316 is an austenitic chromium nickel stainless steel containing molybdenum. This addition of Mo increases general corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperatures. Type 316L is an extra-low carbon version of type 316 that minimizes harmful carbide precipitation due to welding. Typical uses include exhaust manifolds, furnace parts, heat exchangers, jet engine parts, pharmaceutical and photographic equipment, digesters, tanks and parts exposed to marine atmospheres. This type is used extensively for weldments where its immunity to carbide precipitation due to welding assures optimum corrosion resistance. The weld microstructure of this alloy is mainly composed of delta ferrite and austenite as a dominant phase (Silva *et al.*, 2009). It is well known that the cycle of rapid heating and cooling occurring during welding affects the microstructure, mechanical properties and surface composition of welds (Yong, A, 2009).

The influences of parameters of tungsten inert gas (TIG) arc welding, such as welding current, welding speed, impulse frequency, weld remelting number and grooves are so important on the morphology, microstructure, tensile property and fracture of welded joints of 316 and 316L stainless steel. Arc current as a one of welding parameters plays an important role on morphology and mechanical properties of welded joint (Blondeau, 2013).

## **1.2 Problem statement**

Welding current of tungsten inert gas (TIG) arc welding effects on the morphology, microstructure, tensile property and fracture of welded joints of austenite stainless steel due to heat input, optimized processing Arc current are

significant , which provide experimental guidance for the application of stainless steel (Juncai, 2007; Wang *et al.*, 2011).

At present, there exist some processing problems, which affect the quality and property of welded joint, in the welding of grade 316 and 316L structural components. The problems like hot cracking, carbide precipitation phase and sigma phase can reduce significantly the mechanical property of this welded joint. Therefore, selection suitable welding parameters (arc current) and proper material is so important to control the mentioned problems (Lothongkum *et al.*, 2001; Minghui, 2006; Zhang *et al.*, 2005).

Therefore, that needs to find the optimization current as a one of welding parameters for TIG welding on 316L stainless steel to reduce welding effect and to achieve best mechanical properties.

### **1.3 Research objective**

To investigate the effect of current on characteristic for welded joint between 316 and 316L stainless steel: microstructure and mechanical properties.

### **1.4 Scope of the study**

The scopes of this research consist of:

- Literature review on the 316L and 316 stainless steel.
- Literature review on TIG welding principle and the welding parameters of the method chosen.
- Perform TIG welding on 316L stainless steel plate 316 stainless steel pipe with different Arc current as a variable value.
- Specimen preparation.
- Microstructure and metallurgical fractography analysis of welded 316L stainless steel plate 316 stainless steel pipe stainless steel by using Optical, XRD, FESEM-EDX and SEM microscopes.

- The mechanical properties test conducted are tensile and Vickers hardness tests.
- Evaluate the effect of Arc current shift and type of material on welded 316L stainless steel plate and welded 316 stainless steel pipe in terms of microstructure and mechanical properties of the welded joints.

## REFERENCES

- Association, B. S. S. (2004). A profile of the UK stainless steel markets: United Kingdom, British Stainless Steel Association report: October.
- Blondeau, R. (2013). *Metallurgy and mechanics of welding*: Wiley. com.
- Brickstad, B. and Josefson, B. (1998). A parametric study of residual stresses in multi-pass butt-welded stainless steel pipes. *International Journal of Pressure Vessels and Piping*, 75(1), 11-25.
- Chandler, H. (1999). Introduction to hardness testing. *Hardness testing. USA: ASM International*, 1-13.
- Czichos, H., Saiato, T. and Smith, L. L. R. (2006). *Springer handbook of materials measurement methods*: Springer.
- Davis, J. R. (2002). *Surface hardening of steels: understanding the basics*: ASM international.
- Funderburk, S. (1999). Key concepts in welding engineering. *Welding Innovation*, 16(1).
- Handbook, W. (1981). volume I. Proceedings of the 1981 American Society for,
- Handbook, W. (1991). Welding processes. *American Welding Society*, 2, 8.
- Huang, H. and Spaepen, F. (2000). Tensile testing of free-standing Cu, Ag and Al thin films and Ag/Cu multilayers. *Acta Materialia*, 48(12), 3261-3269.
- Ibrahim, I. A., Mohamat, S. A., Amir, A. and Ghalib, A. (2012). The Effect of Gas Metal Arc Welding (GMAW) Processes on Different Welding Parameters. *Procedia Engineering*, 41, 1502-1506.
- Juncai, Z. (2007). Effect of welding temperature on weld of welded tube. *WELDING AND JOINING-HARBIN-*, 1, 60.
- Klug, H. P. and Alexander, L. E. (1974). X-ray diffraction procedures: for polycrystalline and amorphous materials. *X-Ray Diffraction Procedures: For Polycrystalline and Amorphous Materials, 2nd Edition*, by Harold P. Klug, Leroy E. Alexander, pp. 992. ISBN 0-471-49369-4. Wiley-VCH, May 1974., 1.
- Lee, H.-Y., Lee, S.-H., Kim, J.-B. and Lee, J.-H. (2007). Creep-fatigue damage for a structure with dissimilar metal welds of modified 9Cr-1Mo steel and 316L stainless steel. *International Journal of Fatigue*, 29(9), 1868-1879.
- Lippold, J. C. and Kotecki, D. J. (2005). Welding metallurgy and weldability of stainless steels. *Welding Metallurgy and Weldability of Stainless Steels*, by



*John C. Lippold, Damian J. Kotecki, pp. 376. ISBN 0-471-47379-0. Wiley-VCH, March 2005., 1.*

- Lo, K., Shek, C. and Lai, J. (2009). Recent developments in stainless steels. *Materials Science and Engineering: R: Reports*, 65(4), 39-104.
- Lothongkum, G., Viyanit, E. and Bhandhubanyong, P. (2001). Study on the effects of pulsed TIG welding parameters on delta-ferrite content, shape factor and bead quality in orbital welding of AISI 316L stainless steel plate. *Journal of Materials Processing Technology*, 110(2), 233-238.
- Min, D., Shen, J., Lai, S. and Chen, J. (2009). Effect of heat input on the microstructure and mechanical properties of tungsten inert gas arc butt-welded AZ61 magnesium alloy plates. *Materials Characterization*, 60(12), 1583-1590.
- Minghui, S. (2006). Welding of HP45NbTi superalloy pipe. *WELDING AND JOINING-HARBIN-*, 8, 22.
- Norma, A. (2001). A240/A240M-01: Standard Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate. *Sheet, and Strip for Pressure Vessels*.
- Peckner, D. and Bernstein, I. M. (1977). *Handbook of stainless steels*: McGraw-Hill New York, NY.
- Richard, E. (2009). Hardness, Bearings, and the Rockwells. *ADVANCED MATERIALS & PROCESSES*, 167(NETL TPR-2896).
- Silva, C. C., de Miranda, H. C., de Sant'Ana, H. B. and Farias, J. P. (2009). Microstructure, hardness and petroleum corrosion evaluation of 316L/AWS E309MoL-16 weld metal. *Materials Characterization*, 60(4), 346-352.
- Smith, R. (2003). *Industrial machinery repair: best maintenance practices pocket guide*: Butterworth-Heinemann.
- Society, A. W., Weisman, C. and Kearns, W. (1984). *Welding handbook* (Vol. 1): American Welding Society.
- Storjohann, D., Barabash, O., David, S., Sklad, P., Bloom, E. and Babu, S. (2005). Fusion and friction stir welding of aluminum-metal-matrix composites. *Metallurgical and Materials Transactions A*, 36(11), 3237-3247.
- Tseng, K.-H. and Hsu, C.-Y. (2011). Performance of activated TIG process in austenitic stainless steel welds. *Journal of Materials Processing Technology*, 211(3), 503-512.
- Wang, Q., Sun, D., Na, Y., Zhou, Y., Han, X. and Wang, J. (2011). Effects of TIG Welding Parameters on Morphology and Mechanical Properties of Welded Joint of Ni-base Superalloy. *Procedia Engineering*, 10, 37-41.
- Wu, C., Ushio, M. and Tanaka, M. (1997). Analysis of the TIG welding arc behavior. *Computational Materials Science*, 7(3), 308-314.
- Zhang, H.-Q., Zhao, H.-Y., Zhang, Y.-H., Li, L.-H. and Zhang, X.-A. (2005). Analysis on the microfissuring behavior in the heat-affected zone of electron-beam welded nickel-based superalloy. *Cailiao Gongcheng(J. Mater. Eng.)*, (3), 22-25.

- Hor, T. (2012). Identify effects of arc current on TIG welding performance. *Universiti teknologi malaysia. ( Bachelor. Eng)*
- Yong, A. (2009). The effects of welding parameter ( Arc current) of TIG on Microstructure and mechanical properties of Duplex stainless steel. *Universiti Teknologi Malaysia. ( Master. Eng)*