# OPTIMIZATION OF NEW SEMI-AUTOMATIC TIG WELDING PROCESS FOR SURFACE QUALITY THROUGH TAGUCHI METHOD

MOHD KHAIRULAMZARI BIN HAMJAH

A project report submitted in partial

Fulfilment the requirement for the award of the

Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering

University Tun Hussein Onn Malaysia

JANUARY 2014

# ABSTRACT

Tungsten inert gas (TIG) welding which uses a non-consumable tungsten electrode and an inert gas for arc shielding, is an extremely important arc welding process. The aims of this research project are to find optimization parameters in weld bead using TIG. Semi-automatic TIG was developed to ensure the success of this research project. Samples are produce in single bead and padding bead on top of substrate (base metal) in horizontal position. Substrate material is from Mild Steel AISI 1018 while wire filler ER70S-6 has a diameter of 0.8 mm and Tungsten electrode EWth-2 (2% Thorium, Red) has a diameter 2.4mm. Argon is used as shielding gas for this research project. Parameters such as Ampere (A), Travel Speed (mm/s) and Wire Feed Rate (mm/min) has been determined and selected as factors that can influence the weld bead result. Taguchi orthogonal array L9 (Minitab 16) was used to determine the amount of runoff and the analysis of samples. The result for surface roughness was found to be better with an average value of Ra 2.96 μm for single bead and Ra 3.08 μm for padding bead when compared to the work of other researchers. Surface hardness has also shown improvement from this research project. Analysis result shows that the travel speed of the torch has the greatest effect on surface roughness followed by wire feed rate and ampere. Dye Penetrant Inspection (DPI) interpretations of the nearest Optimize level shows no cracks or porosity occurring on top of the bead surface. Defects only happen at the undercut weld due to improper start-up of the welding. For future study other parameters and optimization technics need to be considered. The parameter combination must reflect safety, environment issue and reasonable factors.

# ABSTRAK

*Tungsten inert gas* (TIG) adalah kaedah kimpalan yang tidak meleburkan elektrod tungsten dan menggunakan gas lengai sebagai perisai yang amat penting dalam proses kimpalan arka. Kajian ini menjurus ke arah pencarian optimum parameter dalam penghasilan kumai menggunakan mesin TIG separa-automatik yang telah dibangunkan. Kumai dihasilkan secara mendatar dalam dua keadaan iaitu kumai lurus dan kumai tindih di atas *substrat* yang telah melalui proses pencanaian permukaan. *Subtrat* adalah bahan logam AISI1018 (*Mild Steel*). Dawai suapan pula adalah dari jenis ER70S-6 diameter 0.8 mm. Elektrod *Tungsten* yang digunakan adalah dari jenis EWth-2 (2% Thorium, Red) diameter 2.4mm. Gas perisai yang digunakan adalah dari jenis Argon. Parameter arus (A), kelajuan pergerakan (mm/s) dan suapan wayar pengisi (mm/min) telah dipilih sebagai parameter yang mampu memberi kesan ke atas hasil kumai. Kaedah *Taguchi Orthogonal Array L9* (Minitab 16) digunakan bagi menentukan jumlah larian dan analisis terhadap sampel. Nilai purata Ra 2.96 µm kumai lurus and Ra 3.08 µm kumai tindih yang diperolehi adalah lebih baik berbanding pengkaji lain. Kekerasan permukaan juga menghasilkan peningkatan. Hasil analisis menunjukkan kelajuan pergerakan kimpalan adalah parameter utama yang memberi kesan terhadap hasil kumai diikuti dawai suapan dan arus. Interpertasi menggunakan *Dye Penetrant Inspection* (DPI) terhadap optimum sampel menunjukkan tiada kesan retakkan ataupun keliangan pada permukaan kumai. Kecacatan hanya berlaku pada kaki kimpalan di mana berlaku potong bawah disebabkan ketidaksempurnaan permulaan kimpal. Untuk kajian yang akan datang lain-lain parameter dan teknik optimum perlu diambil kira. Gabungan parameter mesti mencerminkan keselamatan, isu alam sekitar dan faktor yang munasabah

# CONTENTS


| | | | |
|---|---|---|---|
| | TITLE | | i |
| | DECLARATION | | ii |
| | DEDICATION | | iii |
| | ACKNOWLEDGEMENT | | iv |
| | ABSTRACT | | v |
| | CONTENT | | vii |
| | LIST OF TABLE | | x |
| | LIST OF FIGURES | | xii |
| | LIST OF SYMBOLS AND ABBREVIATIONS | | xv |
| | LIST OF APPENDICES | | xvii |
| CHAPTER 1 | INTRODUCTION | | 1 |
| | 1.1 | Background of Research Project. | 1 |
| | 1.2 | Problem Statement | 2 |
| | 1.3 | Objective | 3 |
| | 1.4 | Scope of Research Work | 3 |
| | 1.5 | Hypothesis | 4 |
| | 1.6 | Dissertation Content. | 4 |
| CHAPTER 2 | LITERATURE REVIEW | | 6 |
| | 2.1 | Tungsten Inert Gas (TIG) | 6 |
| | 2.2 | Weld bead geometry | 8 |
| | 2.3 | Parameter selection | 10 |
| | 2.4 | Conclusion | 17 |

| | | | |
|---|---|---|---|
| **CHAPTER 3** | **METHODOLOGY** | | **18** |
| | **3.1** | **Introduction** | **18** |
| | **3.2** | **Research project methodology.** | **18** |
| | **3.3** | **Robust Design of Taguchi Method in DOE** | **21** |
| | **3.4** | **Semi-Automatic TIG Machine** | **23** |
| | **3.5** | **Research project sample** | **24** |
| | **3.6** | **Validation of the sample** | **25** |
| | **3.7** | **Materials testing** | **27** |
| | **3.7.1** | **Dye Penetrant Inspection (DPI)** | **27** |
| | **3.7.2** | **Surface Roughness Test** | **28** |
| | **3.7.3** | **Surface Hardness Test** | **30** |
| | **3.8** | **Taguchi data analysis** | **31** |
| | **3.9** | **Data prediction** | **32** |
| **CHAPTER 4** | **EXPERIMENT SETUP** | | **33** |
| | **4.1** | **Experiment detail** | **33** |
| | **4.2** | **Inspection for validation** | **42** |
| **CHAPTER 5** | **RESULT AND DISCUSSION** | | **47** |
| | **5.1** | **Preliminary result** | **47** |
| | **5.2** | **Sample result** | **52** |
| | **5.3** | **Collection data result** | **53** |
| | **5.4** | **Analysis of Varian (ANOVA)** | **55** |
| | **5.4.1** | **Surface Roughness ANOVA** | **55** |
| | **5.4.2** | **Surface Hardness ANOVA** | **59** |
| | **5.5** | **Optimization analysis** | **62** |
| | **5.5.1** | **Surface roughness optimization** | **62** |
| | **5.5.2** | **Surface hardness optimization** | **64** |
| | **5.6** | **Prediction analysis** | **67** |
| | **5.7** | **Discussion on optimization sample** | **73** |

| | | | |
|---|---|---|---|
| **CHAPTER 6** | **CONCLUSION AND FUTURE DEVELOPMENT** | | **76** |
| | **6.1** | **Novelty of the research** | **76** |
| | **6.2** | **Conclusion** | **78** |
| | **6.3** | **Future development** | **80** |
| | **REFERENCES** | | **81** |
| | **APPENDIX** | | **84** |

# LIST OF TABLE


| | | |
|---|---|---|
| 2.1 | Pulse Parameter Test | 14 |
| 2.2 | Materials Influence on Inner bead Surface roughness | 14 |
| 2.3 | Results of ANOVA for the weld pool geometry (S.C. Juang, Y.S. Tang, 2002) | 15 |
| 2.4 | Surface roughness of the different specimens of AA6082.52 and AA6082.50, both in T6 temper condition. (Utne, 2013) | 16 |
| 2.5 | Results obtained from hardness measuring for tested samples. | 16 |
| 3.1 | DOE factor and level | 21 |
| 3.2 | Constant parameter (factor) | 22 |
| 3.3 | Robust Taguchi Design Matrix | 22 |
| 4.1 | Composition for Substrate (base metal) | 34 |
| 4.2 | Composition for Filler Metal ER70S-**6** | 38 |
| 5.1 | Result Surface Roughness and Surface Hardness | 54 |
| 5.2 | Surface roughness ANOVA for SN ratios (Single Bead) | 56 |
| 5.3 | ANOVA for SN ratios (Padding Bead) | 58 |
| 5.4 | Surface hardness ANOVA for SN Ratio (Single Bead) | 59 |
| 5.5 | Surface hardness ANOVA for SN ratio (Padding Bead) | 61 |
| 5.6 | Response Table for Signal to Noise Ratios Single Bead. (Smaller is better) | 62 |
| 5.7 | Response Table for Signal to Noise Ratios Padding Bead (smaller is better) | 64 |
| 5.8 | Response Table for Signal to Noise Ratios Single Bead (larger is better) | 65 |
| 5.9 | Response Table for Signal to Noise Ratios Padding | 66 |

Bead (larger is better)
5.10 Surface Roughness Factor levels for predictions 68
5.11 Surface Hardness Factor levels for predictions 68
5.12 SN ratio Mean value of the experiment 69
5.13 Surface Roughness Comparison 72
5.14 Surface Hardness Comparison 73

# LIST OF FIGURES

| | | |
|---|---|---|
| 2.1 | Basic diagram of the conventional TIG circuit | 7 |
| 2.2 | Sketch of overlapping model by Yong Cao et al. | 8 |
| 2.3 | Parabolic cross-sectional profile of the bead | 9 |
| 2.4 | Multi-bead profile in the initial model | 9 |
| 2.5 | Overlap volume equal to volume of valley. | 9 |
| 2.6 | Automatic rapid prototyping VP-GTAW | 13 |
| 2.7 | Graph for variations of hardness versus distance for welded samples | 17 |
| 3.1 | Research project flow chart | 20 |
| 3.2 | Semi-automatic TIG machine schematic drawing by AutoCAD | 23 |
| 3.3 | Sample 1A (a) Single and (b) padding weld bead sample | 24 |
| 3.4 | Weld bead height | 26 |
| 3.5 | WG-4 Weld Gauge or Bridge Cam Gauge | 26 |
| 3.6 | DPI spray can, (1&3) Cleaner (2) Penetrant and (4) Developer. | 28 |
| 3.7 | Mitutoyo SJ-400 machine | 29 |
| 3.8 | Wilson Rockwell (HRA) hardness tester machine | 30 |
| 4.1 | Substrate (base sample) of the experiment | 35 |
| 4.2 | Single and padding weld bead diagram | 36 |
| 4.3 | TIG Miller Syncrowave 250 DX OC. AC/DC Squarewave Panel | 37 |
| 4.4 | UNI-ARC MIG 200C panel | 38 |
| 4.5 | Semi-Automatic TIG welding setup. | 39 |
| 4.6 | Angle of TIG and wire feeder torch | 40 |

| | | |
|---|---|---|
| 4.7 | Substrate (base metal) placement | 41 |
| 4.8 | Arm support with bracket | 42 |
| 4.9 | Weld gauge inspection | 43 |
| 4.10 | DPI inspection on the sample | 44 |
| 4.11 | Mitutoyo SJ-400 sample mounting. | 45 |
| 4.12 | Wilson Rockwell (HRA) Sample mounting | 46 |
| 5.1 | Manual preliminary sample single bead (a) 140A (b) 180A | 48 |
| 5.2 | Pre-run Sample (a) 140A (b) 150 A (c) 170A (d) 180A Semi-automatic Preliminary sample (single bead). | 49 |
| 5.3 | Pre run Sample (A) padding bead and (B) overlap bead sample | 50 |
| 5.4 | Area of the cutting pre-run sample | 51 |
| 5.5 | Cross section profile of weld bead | 51 |
| 5.6 | Sample 1A | 52 |
| 5.7 | Surface roughness Residual plot for SN ratios (Single Bead) | 57 |
| 5.8 | Residual plot for SN Ratios (Padding Bead) | 58 |
| 5.9 | Residual plot for SN Ratios (Single Bead) | 60 |
| 5.10 | Residual plot for SN Ratios (Padding Bead) | 61 |
| 5.11 | Parameter effect for SN Ratios (Single Bead) | 63 |
| 5.12 | Parameter effect for SN Ratios (Padding Bead) | 64 |
| 5.13 | Response Table for SN Ratio Single Bead (larger is better) | 65 |
| 5.14 | Response Table for SN Ratio Padding Bead (larger is better) | 67 |
| 5.15 | Graph SNRA1 and Mean1 of Surface Roughness (Ra) | 70 |
| 5.16 | Graph SNRA2 and Mean2 of Surface Hardness (HRA) | 71 |
| 5.17 | Graph Surface Roughness Comparison | 72 |
| 5.18 | Graph Surface Hardness Comparison | 73 |
| 5.19 | Optimized Sample 6A | 74 |
| 5.20 | DPI test on sample 6A | 75 |
| 6.1 | Customize Semi-automatic TIG machine setup. | 77 |

6.2 Semi-automatic TIG machine patent by (Imaizumi, Kato, & Nakashim, 1998) 78

# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| TIG | - | Tungsten Inert Gas |
| RP | - | Rapid Prototyping |
| FRGS | | Fundamental Research Grant Scheme |
| NDT | - | Non-destructive test |
| DOE | - | Design of Experiment |
| AISI | - | American Iron and Steel Institute |
| DPI | - | Dye Penetrant Inspection |
| HAZ | - | Heat Affected Zone |
| ANOVA | - | Analysis of variance |
| DC | - | Direct Current |
| ACHF | | Alternating Current of High Frequency |
| GTAW | - | Gas Tungsten Arc Welding |
| RSM | - | Response Surface Methodology |
| Ra | | Mean surface roughness |
| *l* | - | Bead length |
| w/2 | - | Half of the bead width |
| h | - | Height of the bead |
| (p) | - | Step over increment |
| CFH | - | Cubic foot per hour |
| LPM | - | Litter per minute |
| DT | - | Destructive test |
| MIG | - | Metal Inert Gas |
| DCSP | | Direct Current Straight Positive |
| V | | Volt |
| A | | Ampere |
| AutoCAD | | Auto Computer Aided Drawing |

| | | |
|---|---|---|
| ASTM | - | American Society for Testing and Materials |
| Ry | | maximum height |
| Rz | | ten-point mean roughness |
| Sm | | mean spacing of profile irregularities |
| S | | mean spacing of local peaks of the profile |
| tp | | profile bearing length ratio |
| EWTh | - | E-Electrode W-Tungsten Th-Thorium |
| EWP | - | P-pure |
| ER70-S6 | - | ER-Electrode S-Solid |
| JIS | | Japan International Standards |
| AC | - | Alternating Current |
| ANNs | | Artificial Neural Networks |
| DCHF | - | Direct Current High Frequency |
| ANSI | - | American National Standards Institute |
| BS | - | British standard |
| F | - | F-test |
| HRA | | Hardness Rockwell (A) |
| SS | | Sum of squares |
| DF | | Degree of freedom |
| MS | | Mean Square |
| C | | Contribution |
| SN | - | Signal to noise |
| means | - | Means |
| Fe | - | Ferum |
| C | - | Carbon |
| Mn | - | Manganese |
| P | - | Phosphorus |
| S | - | Sulphur |
| Ar | - | Argon |
| GA | - | Genetic algorithm |

# LIST OF APPENDICES


| APPENDIX | TITLE | PAGE |
|---|---|---|
| A | Samples | 84 |
| B | Die Penetrant Inspection (DPI) on Samples | 87 |

# CHAPTER 1

# INTRODUCTION

Tungsten inert gas (TIG) is a process used for joining pieces of metal, and probably, the most successful and widely used welding method in industry today. The weld bead can also perform as a deposited layer on top of the substrate (base metal). The surface quality of a weld bead is a crucial issue in welding, and in many cases a weld must fulfil some specific quality requirements. However, it is very difficult to find the best parameter setup to control the TIG process and it might not be possible to achieve the desired weld quality. Therefore this chapter will express the direction of the research project.

## 1.1 Background of Research Project

Currently the application of arc welding takes a leading position among other methods of welding. However, arc welding introduces stress concentration, residual stresses and distortion (A. Tradia, F.Roger, E. Guyot, 2010). Besides arc welding, TIG welding process is superior to arc welding in terms of higher productivity and better quality. This can be proven in Rapid Prototyping (RP) technology where the demand to produce prototypes by using TIG had already been developed. TIG welding which uses a non-consumable tungsten electrode and an inert gas for arc shielding is an extremely important arc welding process. It is commonly used for welding hard-to-weld metals such as stainless steel (Cary, 1989).

The greatest advantage of the TIG process is that it can weld more types of metal and alloy than any other arc welding process. TIG can also weld dissimilar metals to one another such as copper to brass and stainless to mild steel (TIG Handbook for GTAW). Basically, TIG weld quality is strongly characterized by the weld pool geometry. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld. Therefore, it is very important to select the welding process parameters for obtaining optimal weld pool geometry (X.M. Zeng, J. Lucas, M.T.C. Fang, 1993) (C.E. Bull, K.A. Stacey, R. Calcraft, 1993) (Y.M. Zhang, R. Kovacevic, L. Li, 1996) (S.C. Juang, Y.S. Tarng, H.R. Lii, 1998) (Y.S. Tarng, H.L. Tsai, S.S. Yeh, 1989). Traditional TIG welding process yield good weld quality and is one of the frequently used welding processes for aluminium and stainless steel.

Usually, the desired welding process parameters are determined based on experience or from a handbook. However, this does not ensure that the selected welding process parameters can produce the optimal or near optimal weld pool geometry for that particular welding machine and environment. Many researchers have studied on the TIG parameter selection by using automatic machine. Most of them did not explain in detail the result of surface quality in terms of the surface roughness and surface hardness of the weld bead. The semi-automatic machine selected for this research project is due to ease and flexibility of the equipment compared to the automatic TIG machine. The machine is portable and easy to maintain, since its part are from the conventional equipment. Compared to the automatic TIG machine, most of the equipment is especially made for the particular machine Based on this reason; this research project will focus on parameter selection to achieve its goal by using semi-automatic TIG machine setup. This research project work is funded under FRGS grant Vot1057.

## 1.2 Problem Statement

Many researchers are still working on the parameter selection to produce the best weld pool surface by using automatic TIG system. But getting the optimal surface quality of weld bead is something which is still not fully discovered yet. Researchers (Xinhong Xiong, Haiou Zhangb, Guilan Wang, 2009) has mentioned that the accuracy and surface quality of the metallic parts and tools using direct metal prototyping techniques are still low compared to conventionally machined parts. Most of the rapid prototyping (RP) methods still need post processing such as milling and polishing as surface finishing. Based on this reason, this research project will focus on the parameter selection to achieve the goal of increasing the accuracy as well as the surface quality and strengthening the body of the weld bead by using semi-automatic TIG setup. Semi-automatic TIG is very easy to setup and can be customized by using conventional TIG welding equipment.

## 1.3 Objective

i. To identify the welding process parameter of surface quality through Taguchi method
ii. To analyse surface quality of the weld bead geometry through mechanical and Non-destructive Testing (NDT) method.

## 1.4 Scope of Research Work

i. Design of Experiment (DOE) using Taguchi Method for optimizing problem will be implemented.
ii. Semi-automatic TIG technology is used to deposit ER70-S6 filler metal into single bead and padding bead on top of substrate (base metal) mild steel AISI1018 plate (75 mm X 50 mm X 5 mm).

iii. Parameter study will focus on Voltage, Gas flow rate, filler wire diameter, Arc gap (mm), Flow rate (l/min) and wire feed angle as constant parameter. While Welding current (Ampere), Welding speed (travel speed), Wire feed rate will be set as variable parameter.
iv. Samples are test using NDT (Dye Penetrant Inspection).
v. Analysis, surface roughness and hardness test are inspecting onto weld bed (deposited layer)
vi. Software tool Minitab 16 will be used to analyse the optimization and analyses of the variance (ANOVA).
vii. Heat Affected Zone (HAZ) area will not be considered for this research project because the main focus is to analyse the surface quality of the weld bead.

## 1.5 Hypothesis

It is hypothesized that, travel speed; wire feed rate and ampere as a selection parameter setup will provide optimization value on the surface quality of the weld bead.

## 1.6 Dissertation Content.

Chapter 1 has described introduction of the research, background of the project, problem statement, scope of study and objectives. A literature review about effect of welding parameter on the weld bead quality and optimization procedure also discussed in Chapter 2. Chapter 3 has presented the process flow of the research project work about Analysis of Variance (ANOVA) and Signal to Ratio (S/N) on the sample by using Taguchi Method. Experiment setup through Semi-Automatic TIG machine welding has been conducted in Chapter 4. Then Chapter 5 result and discussion about optimization in weld bead surface quality. Chapter 6 present the conclusion, suggestion, future work and novelty of the research work has been clearly highlighted.

# CHAPTER 2

# LITERATURE REVIEW

This chapter will explore the literature relevant to the concept of TIG and semi-automatic TIG technology. In literature review, the related ideas and findings from previous researchers will be discussed and special attention on surface quality that converges to the research project will be focussed upon.

## 2.1 Tungsten Inert Gas (TIG)

In TIG welding, electric arc occurs when electricity is passed to the tungsten electrode. The distance between the tip of the tungsten electrode and the work piece surface will cause the flow of electrons. The flow of electrons in turn produces arc and high heat to melt the metal. TIG welding is done in a controlled atmosphere using a tungsten electrode which serves to produce an arc to melt the metal. Direct current (DC) or Alternating Current of High Frequency (ACHF) is used to enable the resulting continuous and stable arc without touching the metal electrodes. The arc is ignited by pressing the starter switch which is located on the blowpipe flame. Filler rod to feed and deposit into the cauldron of molten metal is used as an additive. During extended inert gas welding, gas cylinder through the blowpipe functions as a shield to protect the molten crater of atmospheric air trapped in it. Theory of TIG process can be read from books or manufacturer's guide in details. (TIG Handbook for GTAW) (Miller Electric Manufacturing Co., 2013). Figure 2.1 shows the basic diagram of the conventional TIG circuit.

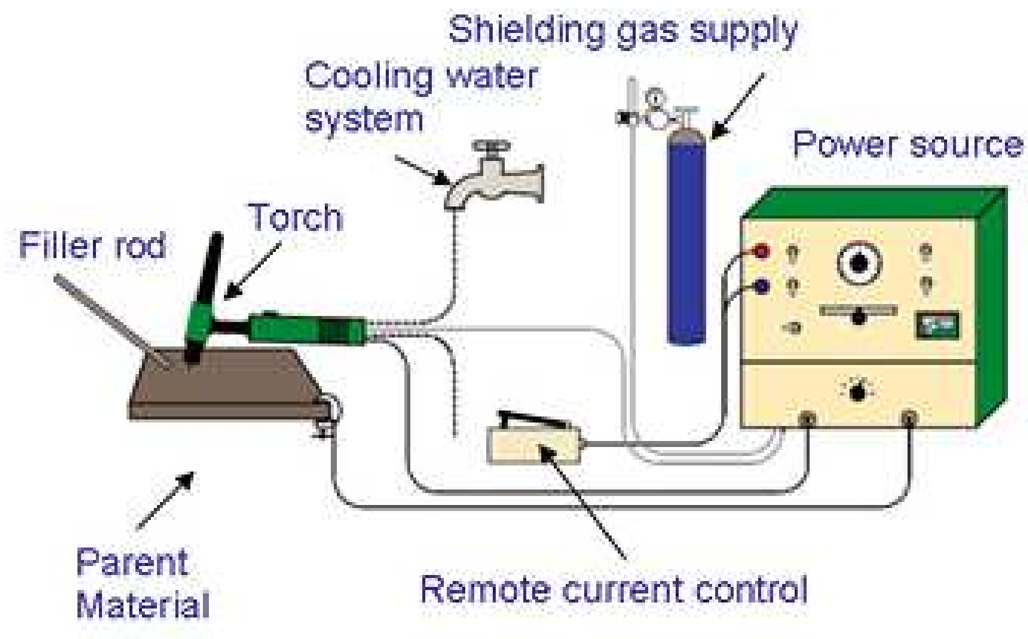


Figure 2.1: Basic diagram of the conventional TIG circuit.

Many researchers are using TIG technology to study the optimized parameter on their research (S. Suryakumar, K.P. Karunakaran, Alain Bernard, U. Chandrasekhar, N Raghavender, Deepak Sharma, 2011) (S.C. Juang, Y.S. Tang, 2002) (Palani.P.K, Saju.M, 2013) (Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu, Sueda Ozgun, 2009) (Y.S. Tarng, H.L. Tsai, S.S. Yeh, 1989). The reason TIG is becoming the most preferred technology is because it has the cleanest weld bead. Other researchers also studied TIG parameter by using Fuzzy Logic controller and the result found that fuzzy clustering technique to be adequate for establishing the relationship between the input process parameters and the outputs (H. K. Narang, U. P. Singh, M. M. Mahapatra and P. K. Jha, 2011) (A. Tradia, F.Roger, E. Guyot, 2010), has come out with the numerical model by using TIG spot pulsed current welding on their study. But the study did not focus on the weld bead roughness. The research focussed on the profile of the weld bead by using automated TIG setup. TIG also has been developed into Rapid Prototyping (RP) technology by

(H Wang, R Kovacevic, 2001). But none these researchers came out with the result to improve the surface roughness of weld bead.

## 2.2 Weld bead geometry

In order to find the parameter optimization, study on the weld bead profile is needed. (Yong Cao, Sheng Zhu, Xiubing Liang, Wanglong Wang, 2011) stated that the sectional geometry of single-pass bead and the overlap of the adjacent beads have critical effects on the dimensional accuracy and quality of metal parts and the conclusion is that the edge detection of bead section with Canny operator is continuous and distinct, and as compared with Gaussian function, logistic function and parabola function, sine function has higher accuracy to fit the measured data, and ‘‘surfacing of equivalent area’’ method shows to be rational and feasible by the experiments. Figure 2.2 shows sketch of overlapping model by Yong Cao et al.

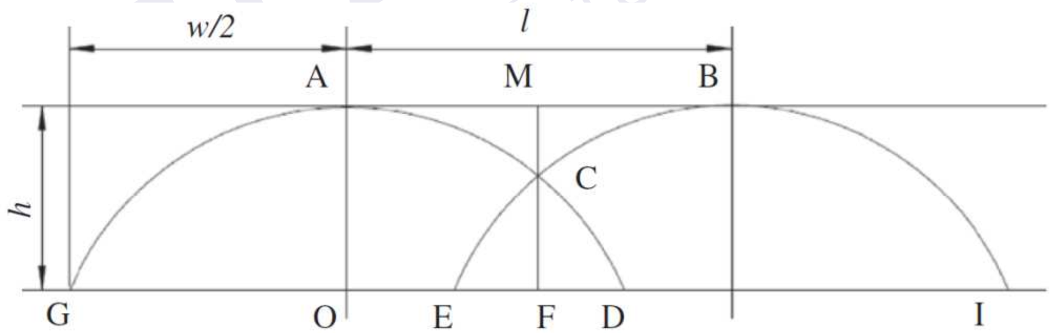


Figure2.2: Sketch of overlapping model by Yong Cao et al.

(S. Suryakumar, K.P. Karunakaran, Alain Bernard, U. Chandrasekhar, N Raghavender, Deepak Sharma, 2011) Identified the bead profile above the substrate is assumed to be a symmetric parabola of the form y = a + $cx^2$ (Figure 2.3) and a simple overlapping parabolic pattern shown in Figure 2.4 was assumed for the multiple bead deposition. The distance between the consecutive beads is referred as step over increment (p). In this model, it was assumed that: a) every bead has same cross-sectional profile. b) The parabolic bead profile is unchanged during the overlapping process. S. Suryakumar *et al* has come out with the improved model, as the step over increment decreases, the overlapping volume increases with a commensurate decrease in the volume of the valley. Therefore, the radius of the fillet increases with the decrease in the step over increment. At some point when these volumes become equal, the fillet will degenerate into a straight line Figure 2.5.

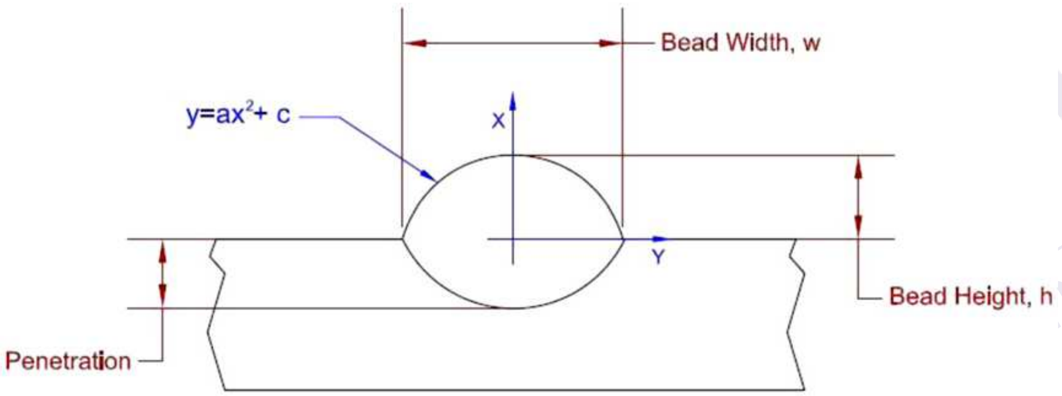


Figure 2.3: Parabolic cross-sectional profile of the bead

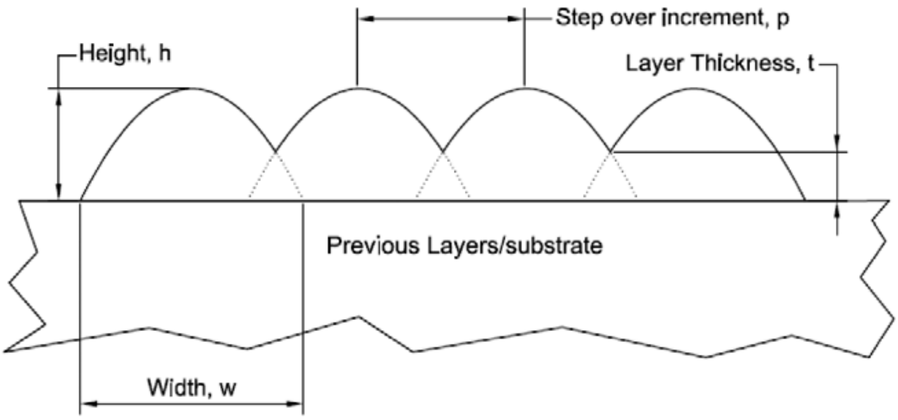


Figure 2.4: Multi-bead profile in the initial model

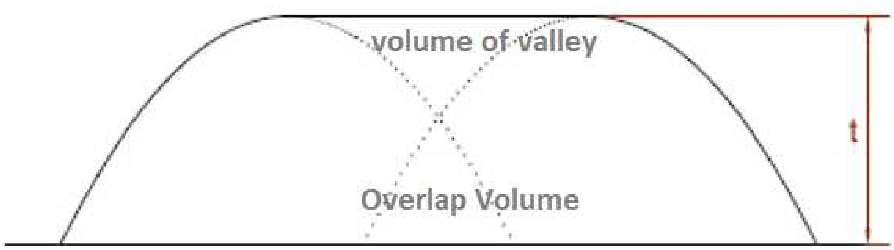


Figure 2.5: Overlap volume equal to volume of valley.

## 2.3 Parameter selection

The shape and dimensions of the weld bead are very important in the use of the rapid prototyping system based on a welding technique, because these factors determine the limits of the wall thickness that can be built and influence the quality of the surface finish. Numerous experiments were undertaken to build single beads for a range of welding conditions. The parameters that were varied include the welding current, the welding arc voltage, the welding speed, and the wire-feed speed. The welding current and arc voltage are monitored. Subsequently, the sizes (height and width) are measured of the built weld bead. The four main welding parameters are the welding current, arc voltage, welding speed, and wire-feed speed. When one of the parameters increases, the others are kept constant. (Huijun Wang, Radovan Kovacevic). They also conclude that there are three important keys to the success of the process, namely the preheating of the substrate (base metal), the arc-length monitoring and controlling, and the heat-input controlling. This process allows the components to be made directly and successfully with aluminium alloy. Several parts are made with perfectly acceptable quality for the surface finishing, mechanical characteristics, and dimensions. The influence of welding parameter such as current ratio and pulse frequency on the weld pool shape shows that for a stainless steel the choice of the peak current, background current and pulsed frequency affects considerably the weld pool shape. (A. Tradia, F.Roger, E. Guyot, 2010)

The optimal weld pool geometry has four smaller-the-better quality characteristics, i.e. the front height, front width, back height and back width of the weld pool. The modified Taguchi method is adopted to solve the optimal weld pool geometry with four smaller-the better quality (S.C. Juang, Y.S. Tang, 2002) (Dongjie Li, Shanping Lu, Wenchao Dong, Dianzhiong Li, Yiyi Li, 2012), done their research based on three parameter selection which is speed travel, arc length and current under two TIG shielding method. Study on parameter on welding speed, welding current, shielding gas flow rate and gap distance (arc gap) give a significant result to the bead geometry, they found that Taguchi Method is a very effective tool for optimization. (Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu, Sueda Ozgun, 2009). Optimization is a method in which the improvement of the quality can be done without additional cost. There are a variety of techniques implementing this method. (Y.S. Tarng, H.L. Tsai, S.S. Yeh, 1989), are using neural network to construct the relationships between welding process parameters and weld pool geometry in tungsten inert gas (TIG) welding. An optimization algorithm called simulated annealing (SA) is then applied to the network for searching the process parameters with optimal weld pool geometry and the quality of aluminium welds based on the weld pool geometry is classified and verified by a fuzzy clustering technique. (Palani.P.K, Saju.M, 2013), has done their study by using Response Surface Methodology (RSM). RSM is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. With this technique, the effect of two or more factors on quality criteria can be investigated and optimum values are obtained. In RSM design there should be at least three levels for each factor. RSM also quantifies relationships among one or more measured responses and the vital input factors. The version 14 of the MINITAB software was used to develop the experimental plan for RSM.

(S.C. Juang, Y.S. Tang, 2002), also complete their study by using modified Taguchi Method. Basically, classical process parameter design is complex and not easy to use (Montgomery, 1991.). Especially, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. To consider several quality characteristics together in the selection of process parameters, the Taguchi method needs to be modified to evaluate several loss functions corresponding to different quality characteristics Usage of the Taguchi method to determine the welding process parameters with the optimal weld pool geometry is reported. This is because the Taguchi method (Y.M. Zhang, R. Kovacevic, L. Li, 1996) (S.C. Juang, Y.S. Tarng, H.R. Lii, 1998) (Peace, 1993) is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development (A. Bendell, j. Disney, W.A.

Pridmore, 1989) so that high quality products can be produced quickly and at a lower cost. However, the original Taguchi method has been designed to optimize a single quality characteristic. To consider several quality characteristics together in the selection of process parameters, the Taguchi method must be modified to integrate several loss functions corresponding to different quality characteristics. Therefore, the modified Taguchi method is adopted in this paper to analyse the effect of each welding process parameter, and then to determine the process parameters with the optimal weld pool geometry.

The aim of this research is to get as minimum as possible result on surface roughness. In order to find optimization parameter setup in TIG welding many researchers have done their research by using automatic machine setup. Pervious researcher (Huijun Wang, Wenhui Jiang, Jiahu Quyang, Radovan Kovacevic, 2004) has stated the surface roughness of a deposited wall of a 4043 Al-alloy is found to relate to the direction along which the measurements are taken with respect to the welding. Four directions of surface roughness are examined for each sample: both parallel and perpendicular to the welding direction on the top surface, and the horizontal and vertical directions on both the outside and inside of the walls. It is found that the roughness in the vertical direction on the sidewall is distinctly greater than the horizontal direction. At the top surface, the roughness perpendicular to the welding direction is much greater than the roughness parallel to the welding direction. If a heat input is not controlled, the surface undulations of a deposited wall are found to be directly related to the thickness of the wall. From their study, the average of the surface roughness Ra is 4.67–5.44m. As for verticality of the deposited wall, at present the accuracy is about 5%, and it is expected that it will be reduced eventually to 2% by monitoring welding variables so as to reduce the amplitude of surface ripples  Figure 2.6 shown automatic rapid prototyping VP-GTAW on their experiment setup.

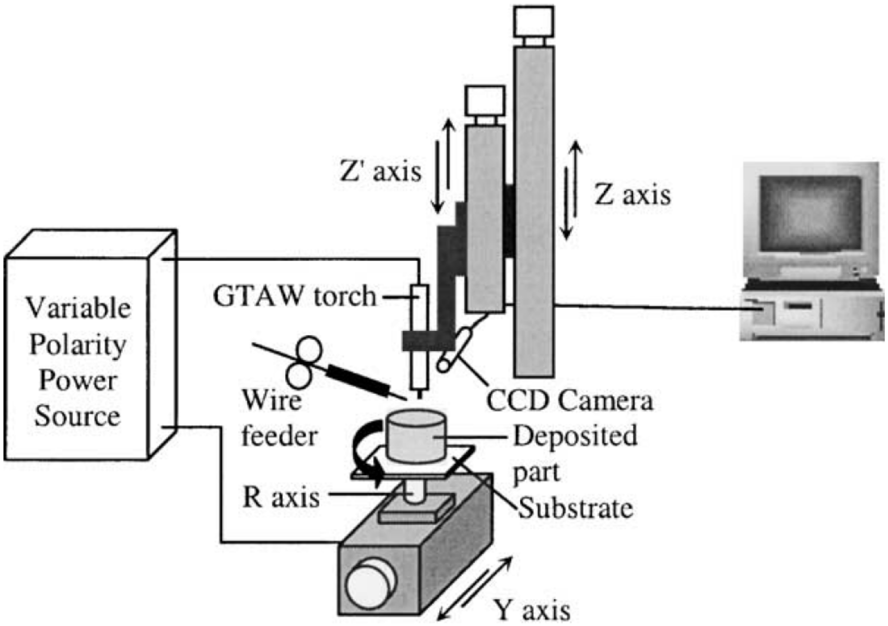


Figure 2.6: Automatic rapid prototyping VP-GTAW (Huijun Wang, Wenhui Jiang, Jiahu Quyang, Radovan Kovacevic, 2004)

(J. Tapp, I.M. Richhrdson and N.J. Woodward) has studied surface roughness in few factor which is gas comopistion, travel speed, pulsed welding, materials composition and multi-pass evaluation. They has discovered, a material composition is of significant importance in minimizing surface roughness. Higher welding speeds and low heat inputs to lead reduced surface roughness values. The average surface roughness measurement Ra may not be the most suitable index for surface characteristic when low values of surface roughness are considered. Current pulsing has been found to have some influence on the bead surface roughness, a pulsed weld with moderate peak amplitude and equal mark space ratio gave the lowest roughness values. Multi pass welding has only a small influence on the average surface roughness, but has been found to reduce the maximum variance R max of the surface profile, possibly due to a reduced heat input and modified thermal gradients Table 2.1 shows result obtained from (J. Tapp, I.M. Richhrdson and N.J. Woodward)

Table 2.1: Pulse Parameter Test (J. Tapp, I.M. Richhrdson and N.J. Woodward)

| Weld No | High Current | Low current | Movement | Roughness Ra (µm) Mean | |
|---|---|---|---|---|---|
| 1 | 74 | 25 | continuous | 1.90<br>1.84 | 1.87 |
| 2 | 150 | 25 | continuous | 2.18<br>2.41 | 2.29 |
| 3 | 120 | 10 | step | 3.95<br>3.92 | 3.94 |

Table 2.2 Materials Influence on Inner bead Surface roughness. (J. Tapp, I.M. Richhrdson and N.J. Woodward)

| | **Average Surface Roughness Ra (µm)** | | **Variation (%)** |
|---|---|---|---|
| | | **Mean** | |
| Cast 1, Low Sulphur | 1.16<br>1.08 | 1.12 | 7.1 |
| Cast 2, High Sulphur | 1.90<br>1.84 | 1.87 | 3.2 |

(S.C. Juang, Y.S. Tang, 2002) used servo servo mechanism to control traveling speed of the electrode in their automation TIG system.. The welding power source is provided by a thermalarc AC welding machine (HeroTIG 250P). In their research, the front height, front width, back height and back width of the weld pool are used to describe the weld pool geometry and measured by a 3D-Hommelewerk profilometer. Results of ANOVA indicate that arc gap, flow rate, welding current and welding speed are the significant welding process parameters affecting the multiple quality characteristics. The percentage contributions due to these process parameters are shown in Table 2.3 below.

Table 2.3: Results of ANOVA for the weld pool geometry (S.C. Juang, Y.S. Tang, 2002)

| Symbol | Process parameter | Degree of freedom | Sum of square | Mean square | *F* | Contribution percentage |
|---|---|---|---|---|---|---|
| A | Arc gap | 3 | 16.06 | 5.35 | 4.97 | 26.86 |
| B | Flow rate | 3 | 9.47 | 3.16 | 2.93 | 15.84 |
| C | Welding current | 3 | 14.36 | 4.79 | 4.45 | 24.01 |
| D | Welding speed | 3 | 16.68 | 5.56 | 5.17 | 27.89 |
| Error | | 3 | 3.23 | 1.08 | | 5.40 |
| Total | | 15 | 59.79 | | | 100 |

(J. Raveendra, R. S. Parmar, 1987) have built mathematical models using the fractional factorial technique to predict the weld bead geometry and shape relations (penetration, width to penetration ratio, percentage dilution and reinforcement height). The base metal was a 3 13-mm thick low carbon structural steel plate. The parameters of the FCAW process considered in this work were: arc voltage, welding current, welding speed, gun angle and nozzle-to-plate distance. They have developed models which can be used either to predict the bead geometry or to determine a combination or a range of parameters to obtain the desired bead geometry dimensions within the factors domain. Furthermore, these models can also be used in a production system for automatic control of welding conditions. Some work has been carried out on the influence pf welding conditions on surface notably by (W, 1996) (Schloz. W, Flint. S, 1995), who has investigated difference weldnig processes and evaluated the effects on tweld bead roughnes. The study showed that GTAW and plasma arc welding produce the smotest weld beads. Improvement to the parameter it is possible to significantly reduce weld bead roughness.

(Utne, 2013) has complete their study on surface roughness on the different specimens of AA6082.52 and AA6082.50 and the result shown in Table 2.4. from the result, the higest Ra value was 5.74 μm and the lowest is 0.422 μm for both specimens.

Table 2.4: Surface roughness of the different specimens of AA6082.52 and AA6082.50, both in T6 temper condition. (Utne, 2013)

| Alloy | Specimen | $L_t$ [mm] | $R_a$ [$\mu m$] | $R_z$ [$\mu m$] | $R_t$ [$\mu m$] |
|---|---|---|---|---|---|
| AA6082.52 | Base material | 5.60 | 0.422 | 2.82 | 5.43 |
| | As welded | 5.60 | 0.824 | 5.00 | 10.4 |
| AA6082.50 | Base material | 17.5 | 2.14 | 13.8 | 19.7 |
| | As welded | 17.5 | 3.24 | 16.8 | 37.5 |
| | Welded + PWHT | 17.5 | 1.894 | 5.47 | 30.1 |
| | Welded before SP | 17.5 | 3.672 | 15.4 | 22.8 |
| | Welded + SP | 17.5 | 5.742 | 37.3 | 56.0 |

(Gholamreza Razavi, Gholamreza Zirepour, Mohsen Saboktakin, Hossein Monajati, 2011) has used Laser Beam Welding, Electron Beam Welding, and Plasma Arc Welding to improve surface properties and perform surface hardening.Although welding is recognized as a process for connecting parts, but it is regarded as one of the most important and widely used coating processes through mass-coating on the surface of industrial parts. They found that with a 50A continuous current, the hardness variations are reduced from the sample surface towards center with a mild gradient; but considerable increase in surface hardness has not been obtained compared to base metal. This trend has a steep gradient with a 60A current and the sample has a mean hardness. With a 75A continuous current, the trend of hardness variation has a steep gradient and the maximum surface hardness has been obtained in this state. With a 75A pulsed current, the hardness variations have a mild and slow gradient and the sample has a relatively high hardness. Table 2.5 and Figure 2.7 shows hardness result obtain from (Gholamreza Razavi, Gholamreza Zirepour, Mohsen Saboktakin, Hossein Monajati, 2011).

Table 2.5: Results obtained from hardness measuring for tested samples.

| **Distance from the surface (mm)** | **Current(A)** | | | |
|---|---|---|---|---|
| | 50 | 60 | 75 | 75 pulse |
| 0 | 380 | 503 | 600 | 520 |
| 1 | 355 | 401 | 505 | 450 |
| 2 | 337 | 339 | 406 | 376 |
| 3 | 336 | 335 | 339.4 | 335.9 |
| 4 | 335 | 334 | 334.1 | 334.5 |

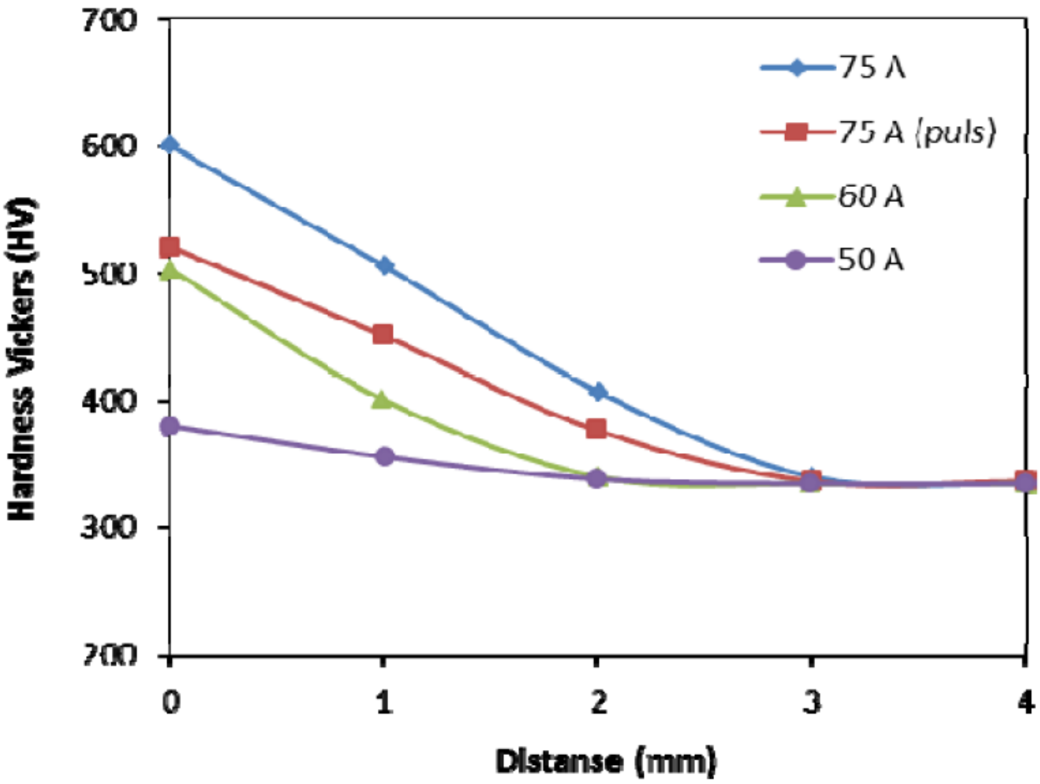


Figure 2.7: Graph for variations of hardness versus distance for welded samples (Gholamreza Razavi, Gholamreza Zirepour, Mohsen Saboktakin, Hossein Monajati, 2011)

## 2.5 Conclusion

Based on what has been discussed in this study, it can be concluded that the selection of the parameters is a key factor in producing the optimal surface roughness of weld bead. Surface roughness plays a very important factor in mould industries. By improving the surface roughness, extra work or finishing can be avoided and it can reduce time and manpower constraint in producing mould. Nevertheless, the accurate selection of parameters is also very important in the success. Variable parameters such as ampere, travel speed and filler rod feed rate are major factors in producing the best welding surface, Parameters such as current, CFH, arc gap and other parameters must be taken as a constant parameter when setup is done based on the type and dimensions of the work piece. The next chapter will explain in detail how the project research work was conducted.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction.

This chapter has described the method and procedure to obtain the data and how the data was analysed in this project work. This section is to justify the means in which the research project was obtained and to help in giving it purpose and strength as it will then be truthful and analytical correct. All of these will help in the processing of the data and the formulation of conclusions.

## 3.2 Research project methodology.

Research project starts with the implementation concept of Design of Experiment (DOE) by using Taguchi Method and Figure 3.1 show the research project flow chart. Selected parameter levels are chosen based on preliminary result. Before the experiments are conducted, substrates (base metal) of the sample was undergo with the surface grinding to remove the surface from any oxidizing (rust) and uneven surface. Then the experiments are conducted based on parameter and level setup. Each sample was inspected for validation. Validations of the sample are based on (American Welding Society, 1998) standards. If the samples are rejected, the sample were redo and improved until fulfil the requirement. The observation process for produced the sample was recorded. Non-Destructive Test (NDT) such as Dye Penetrant Inspection (DPI) was conducted for obtained defect on the samples surface. Surface roughness and hardness as destructive test was conducted for surface analysed.

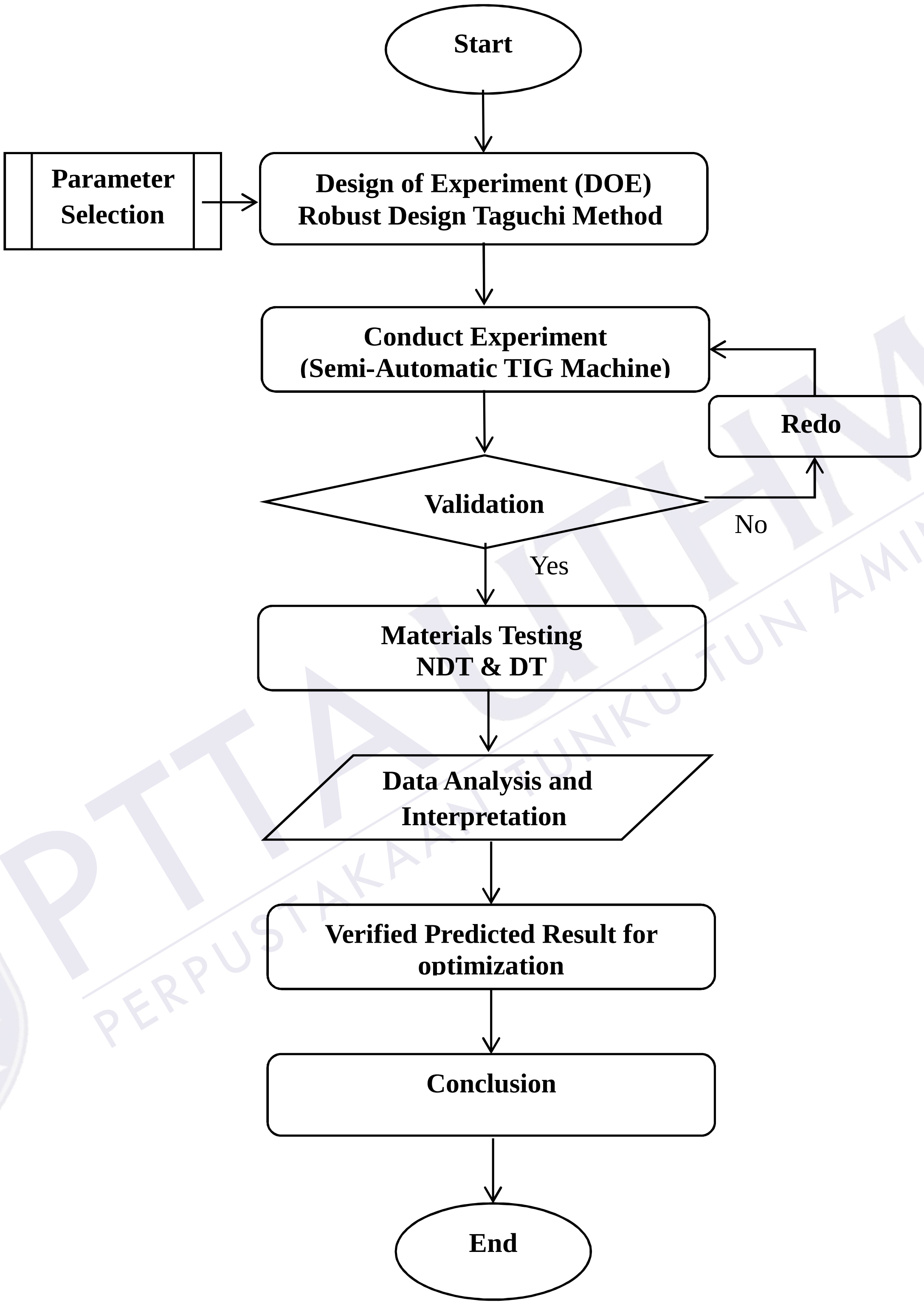


Figure 3.1: Research project flow chart

### 3.3 Robust Design of Taguchi Method in DOE

A Taguchi Design or an orthogonal array is a method of Design of Experiments (DOE) that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor. In robust parameter design, first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise the inner array. At the same time, determine a set of noise factors, along with an experimental design for this set of factors. The noise factors comprise the outer array. The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array.

In this research project, three (3) parameters that will affect the results were chosen namely Ampere (a) Travel Speed (mm/s) and Feed Rate (mm/min). These parameters we set as a factor with level of three (3). Table 3.1 below shows the DOE factor and level of the research project. The other parameters are set to be a constant factor in Table 3.2. Once the factor and level has been decided, Taguchi Robust Design Matrixes for 3**4 L9 orthogonal arrays are then generated. Table 3.3 shows Robust Design Matrix with three (3) factor, three (3) level and nine (9) runs. The advantage of the Taguchi Method includes helping to study the effect of many factors (variables) on the desired quality most economically. By studying the effect of individual factors on the results, the best factor combination can be determined.

Table 3.1: DOE factor and level

| Level / Parameter (factor) | Low | Medium | High |
|---|---|---|---|
| **Ampere (a)** | 150 | 160 | 170 |
| **Travel Speed (mm/s)** | 150 | 186.11 | 222.22 |
| **Feed Rate (mm/min)** | 1.50 | 3.06 | 4.61 |

Table 3.2: Constant parameter (factor)

| Parameter (factor) | Low |
|---|---|
| **voltage** | 415 V |
| **Arc gap** | 3 mm |
| **Torch angle** | 80 $^{o}$ |
| **Wire feed angle** | 30 $^{o}$ |
| **Wire feed size** | 0.8 mm |
| **Electrode size** | 2.4 mm |
| **Cup size** | 6 |
| **Colet size** | 2.4 |
| **Argon flow** | 17 CFH (8 l/min) 20 Psi |
| **Polarity** | Electrode negative (DCSP) |
| **Post flow time** | 9 sec |

Table 3.3: Robust Taguchi Design Matrix

| No | Ampere (a) | Travel Speed (mm/s) | Feed Rate (mm/min) |
|---|---|---|---|
| 1 | 150 | 150.00 [1.0] | 1.50 [1] |
| 2 | 150 | 186.11 [1.5] | 3.06 [2] |
| 3 | 150 | 222.22 [2.0] | 4.61 [3] |
| 4 | 160 | 150.00 [1.0] | 3.06 [2] |
| 5 | 160 | 186.11 [1.5] | 4.61 [3] |
| 6 | 160 | 222.22 [2.0] | 1.50 [1] |
| 7 | 170 | 150.00 [1.0] | 4.61 [3] |
| 8 | 170 | 186.11 [1.5] | 1.50 [1] |
| 9 | 170 | 222.22 [2.0] | 3.06 [2] |

*[ ] Minitab 16 notation

## 3.4 Semi-Automatic TIG Machine

To perform the experiment, Semi-automatic TIG machine were customized. All the equipment was fitted by using conventional TIG equipment. TIG torch was attached to the travel car to make sure the torch is fixed at a setup angle. Wire feed was supplied from the torch of the MIG machine and feeder unit. The wire feeder also fits into an arm support on the travel car. The Travel car will travel on the track and only can perform in straight direction. Control of the Ampere (A), Travel speed and wire feed are done manually for each sample run. Angle of the TIG torch and wire feeder nozzle was set to be a constant variable. In this research project, the Semi-automatic TIG was customized to make sure all the parameters are working in the firm position without any errors. The accuracy of the setup plays a very important point because all data recorded must be valid for analysis. Figure 3.2 shows the drawing of Semi-automatic TIG machine using AutoCAD drawing software.

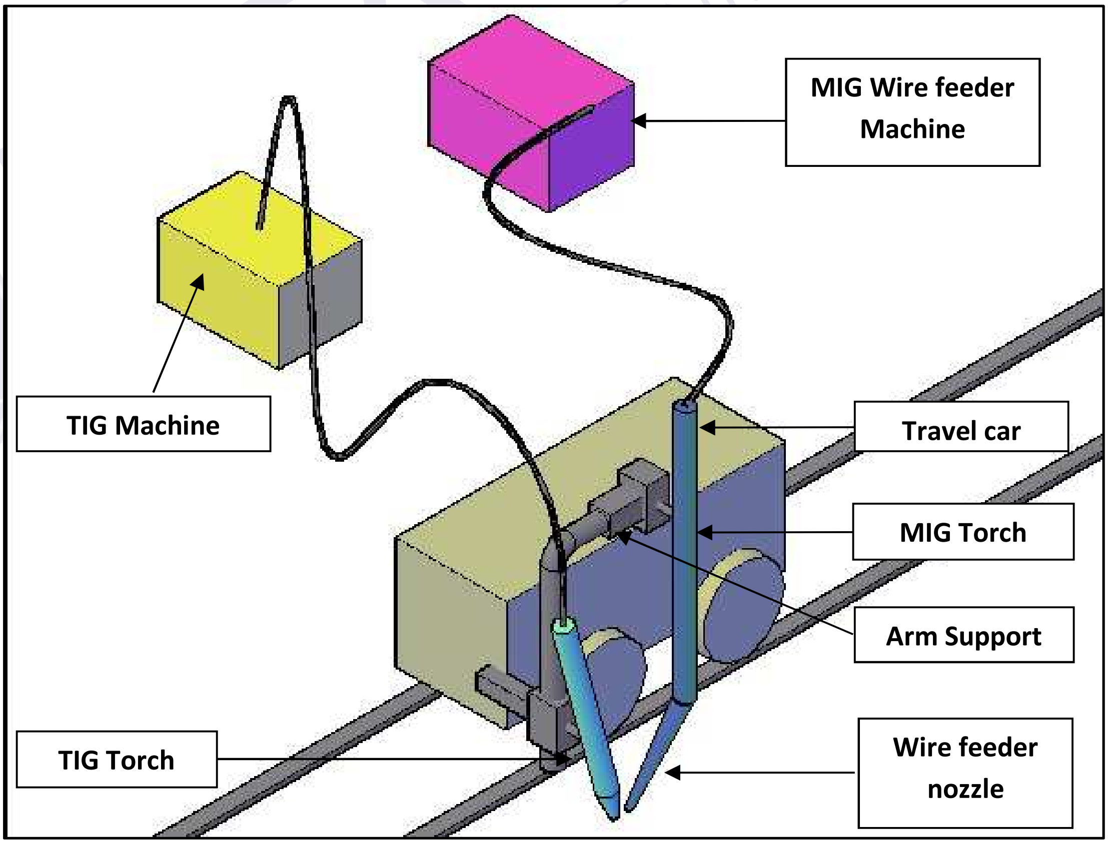


Figure 3.2: Semi-automatic TIG machine schematic drawing by AutoCAD

## 3.5 Research project sample

Samples will be produced in single bead and padding bead. Figure 3.3 (a) single bead (b) padding weld bead show a photo of the Sample 1A**.** Each run was replicated for three (3) samples and represented as A, B and C. Before the samples were produced, substrates (base metals) were done with the process of surface grinding. This process is to flatten the substrate (base metal) and remove any dirt and oxides on top of the surface before weld. After the surfaces are cleaned, single bead are produced on top of the surface. To perform padding bead (b), single bead must be done first. After the first weld bead, the sample will be cooled. After which the second run of the weld bead are done on top of the first weld bead. The weld bead starts at the same starting point of the first weld bead. For each replication, the observatory data has been recorded for three (3) times. Illustrations diagram of the samples are shown in the Figure 4.3 in the next chapter.

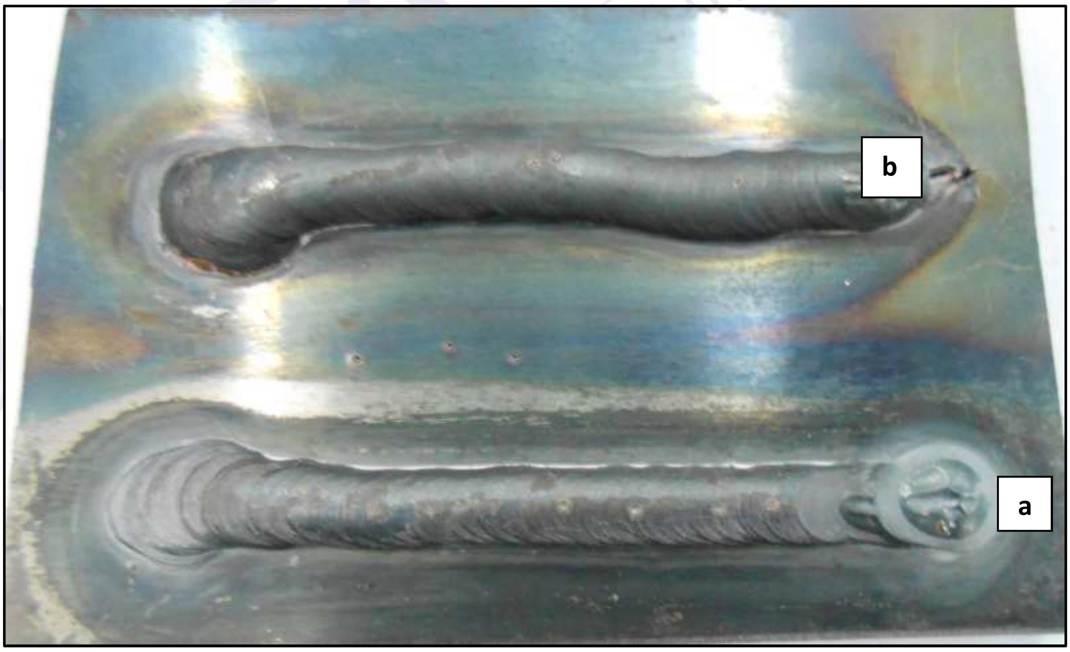


Figure 3.3: Sample 1A (a) Single and (b) padding weld bead sample

# REFERENCES

A. Bendell, j. Disney, W.A. Pridmore. (1989). *Taguchi Methods : Application in World Industry.* UK: IFS Publication.

A. Tradia, F.Roger, E. Guyot. (2010). Optimal parameter for pulsed gas tungsten arc welding in partially and fully penetrated weld pools. *International Journal of Thermal Sciences, 49,* 1197-1208.

American Welding Society, A. W. (1998). *ANSI/AWS D1. 1-98, Reference Manual.* American Welding Society. Retrieved from http://www.aws.org.

C.E. Bull, K.A. Stacey, R. Calcraft. (1993). On line weld monitoring using ultrasonic. Nondestructive Testing. *35 (2) 57–64.*

Cary, H. (1989). *Modern Welding Technology.* Englewood NJ: Prentice-Hall.

Dongjie Li, Shanping Lu, Wenchao Dong, Dianzhiong Li, Yiyi Li. (2012). 6 Study of the law between the weld pool shape variations with the welding parameters under two TIG processes. *Materials Procssing Technology*, 128-136.

*Examination Book of Specifications.* (2008). American Welding Society.

Gholamreza Razavi, Gholamreza Zirepour, Mohsen Saboktakin, Hossein Monajati. (2011). Investigation of Enhancing Surface Hardness in Ti-6Al-4V Alloy by. *International Conference on Advanced Materials Engineering.* Singapore: IACSIT Press.

H Wang, R Kovacevic. (2001). Rapid Prototyping Based On Variable Polarity Gas Tungsten Arc Welding For a 5356 Aluminium Alloy. *Proc Instn Mech Engrs Vol 215 Part B,* 1519-1527.

H. K. Narang, U. P. Singh, M. M. Mahapatra and P. K. Jha. (2011). Prediction of the Weld Pool Geometry of TIG Arc Welding by Using Fuzzy Logic Controller. *International Journal of Engineering, Science and Technology, 3*(9), 77-85.

Huijun Wang, Radovan Kovacevic. (n.d.). Variable Polarity GTAW in Rapd Prototyping of Aluminum Parts., (pp. 369-376). Texas.

Huijun Wang, Wenhui Jiang, Jiahu Quyang, Radovan Kovacevic. (2004). Rapid prototyping of 4043 Al-Alloy by VP-GTAW. *Materials Processing Technology, 148*, 93-102.

Imaizumi, H., Kato, T., & Nakashim, H. (1998). *Patent No. 5789717.* Japan/Tokyo.

J. Tapp, I.M. Richhrdson and N.J. Woodward. (n.d.). Factors Influencing Inner Bead Surface Roughness in GTA Welded Stainless Steel Pipelines.

Jeffus, L. F. (2004). *Welding, 5e: Principles and Applications.*

*Miller Electric Manufacturing Co.* (2013). Retrieved May 30, 2013, from Miller Electric Manufacturing Co. Web Site: http://www.millerwelds.com/resources/TIGhandbook/

*Minitab Inc.* (2014). Retrieved January 21, 2014, from Minitab Inc. Web Site: http://www.minitab.com/en-US/products/minitab/free-trial.aspx

*Misumi Corporation.* (2014). Retrieved January 20, 2014, from Misumi Corporation Web Site: http://us.misumi-ec.com/pdf/press/us_12e_pr1257.pdf

Montgomery, C. (1991.). *Design and Analysis of Experiments.* Singapore: Wiley.

Palani.P.K, Saju.M. (2013). Modelling and Optimization of process Parameter for TIG Welding of Aluminium-65032 Using Response Surface Methodology. *International Journal of engineering research and Applications*, 230-236.

Peace, G. (1993). *Taguchi Methods: A Hand-on Approach.* MA: Addison Wesley.

S. Suryakumar, K.P. Karunakaran, Alain Bernard, U. Chandrasekhar, N Raghavender, Deepak Sharma. (2011). Wled bead modeling and process optimization in Hybrid layerd Manufacturing. *Computer Aided Design, 43*, 331-334.

S. Suryakumar, K.P. Karunakaran, Alain Bernard, U. Chandrasekhar, N Raghavender, Deepak Sharma. (2011). Wled bead modeling and process optimization in Hybrid layerd Manufacturing. *Computer Aided Design, 43*, 331-334.

S.C. Juang, Y.S. Tang. (2002). Process parameter selection for optimizing the weld pool geometry in the Tungsten Inert Gas welding of stainless steel. *Journal of Materials Processing Technology*(122), 33-37.

S.C. Juang, Y.S. Tarng, H.R. Lii. (1998). A comparison between the backpropagation and counter-propagation networks in the modeling of the TIG welding process. *75 54–62.*

TIG Handbook for GTAW. (n.d.).

Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu, Sueda Ozgun. (2009). Optimization of Weld Bead Geometry in Tig Welding Process Using Grey Relation Analysis and Taguchi Method. *Materials and technology*, 143-149.

Utne, S. C. (2013). *Fatigue of Welded AA6082 Alloys - Effects of PWHT and Shot Peening.* Trondheim, Norway: Norwegian University of Science and Technology.

X.M. Zeng, J. Lucas, M.T.C. Fang. (1993). Use of neural networks for parameter prediction and quality inspection in tungsten inert gas welding. *15 (2) 87–95*.

Xinhong Xiong, Haiou Zhangb, Guilan Wang. (2009). Metal direct prototyping by using hybrid plasma deposition and milling. *Materials Processing Technology*, *209*, 124-130.

Y.M. Zhang, R. Kovacevic, L. Li. (1996). *36 (7) 799–816*.

Y.S. Tarng, H.L. Tsai, S.S. Yeh. (1989). Modeling, optimization and classification of weld quality in TIG welding. *International Journal of Machine Tools & Manufacture, 39 (9)1427–1438*, 1427-1438.

Yong Cao, Sheng Zhu, Xiubing Liang, Wanglong Wang. (2011). Overlapping model of beads and curve fitting of bead section for rapid manufacturing by robotic MAG welding process. *Robotics and Computer-Integrated manufacturing*, 641-645.