PROJECT COMPLETION REPORT

FOR

(SHORT TERM) RESEARCH GRANT

PERFORMANCE ANALYSIS OF MECHANICAL PROPERTIES AND WELDMENT AREA OF ALUMINIUM ALLOYS

Principal Researcher : DR. AHMAD KAMELY BIN MOHAMAD

Co-Researchers : Johny Purnomo Joewono (FKP)

Project Code No. : PJP/2009/FKP(12A)S580

Report Submission Date : 4 July 2013

FACULTY OF MANUFACTURING ENGINEERING

1

ABSTRACT

PERFORMANCE ANALYSIS OF MECHANICAL PROPERTIES AND WELDMENT AREA OF ALUMINIUM ALLOYS

(Keywords : MIG robot welding, Aluminium, Mechanical properties, Response Surface Methodology)

The industrial revolutions of welding process cause welding applied in almost every operation that involves fabricating in manufacture. The increasing usage of aluminium for new technology has stimulated considerable interest in the development of improved aluminium alloys. The quality of welding can influence by many factors e.g. current, velocity, flow rate, etc. Aluminium welding still represents a critical operation due to his complexity and the high level of defect that can be produced in the joint. Aluminium has several chemical and physical properties that need to be understood when using the various joining processes. For designers and technologist are the greatest challenge to weld aluminium and its alloys, it caused aluminium alloys differ from conventional material like steel.

Therefore, it is necessary to find the optimum welding parameters to produce quality welding by analyzing the mechanical properties and microstructure of weldments area. Metal Inert Gas Robot welding is used in this study. From this study, it is found that good quality welding with the used of high current and high voltage. It was observed that the bending strength increased with the used of high current and high voltage (161086 Mpa). In the other hand the results also show very high ultimate tensile strength values of 1798.74 Mpa obtained with the used of high current (190 A) and high voltage (19 V).

Key Researchers:

DR. Ahmad Kamely bin Mohamad

En. Johny Purnomo Joewono

E-mail   :   kamely@utem.edu.my

Tel. No. :   06-3316488

Vote No. :   PJP/2003/FKP(12A) S580

ACKNOWLEDGEMENT

TABLE OF CONTENTS

5

LIST OF FIGURES

LIST OF TABLES

1.0   INTRODUCTION

1.1   Background

The industrial revolutions of welding process cause welding applied in almost every operation that involves manufacture with the fabrication process (Messler, 1996). Welding is the process of merging two or more materials using filler or not by heating them to temperatures of welding by using pressure or not (Jeffus, 1997). The quality of welding can be influenced by many factors such as current, velocity, flow rate, and etc. (Meran, 2006).

The increasing usage of aluminium for new technology has stimulated considerable interest in the development of improved aluminium alloys (Tanner & Robinson, 2003; Chen et al., 2003; Zander & Sandström, 2009). The significant aspect to weld aluminium is the chemical composition of weld bead and the combination between parent material and filler composition. Aluminium welding still represents a critical operation due to his complexity and the high level of defect that can be produced in the joint (Maggiolino & Schmid, 2008).

1.2   Problem Statement

Aluminium has several chemical and physical properties that need to be understood when using the various joining processes (Maggiolino & Schmid, 2008). Generally aluminium alloys have a low melting point (Park et al. 2008) and sensitive to solidification and liquation cracks (Gupta & Murty, 2006). Therefore, it is necessary stringent process control in order to achieve good quality results.

With the increasing of automation in arc welding, to satisfy a bead quality need to be specified the selection of welding procedure (Kim, 2003). Mathematical models need to be developed to make effective use of automated or robotic arc

© Universiti Teknikal Malaysia Melaka

welding (Kim, Son, Yang, et al. 2003). Automated welding and robotic welding can be effectively used by developing mathematical modeling (Correia et al., 2005). The survey reveals the high level of interest in the adaptation of Response Surface Methodology (RSM) to predict responses and to optimize the welding process. Therefore, it is necessary to find the optimum welding parameters to produce good quality welding

1.3   Objectives

The objectives of the research are as follows:

a) To study the effect of different welding parameter setting (current and voltage) on the mechanical properties (tensile strength, bending strength and hardness) of Aluminium Alloys 6064 weldments area.

b) To analyze the microstructure of Fusion Zone (FZ) and Heat Affected Zone (HAZ) on weldments area.

c) To study the correlation between welding parameter (current and voltage) and mechanical properties by using RSM.

1.4   Scope of Study

a) The materials used are aluminium Alloys 6064

b) MIG robot welding

c) The mechanical properties of the joints are evaluated using a combination of conventional tensile test, bending test and hardness test.

d) The micro structural characteristics of the welds are evaluated using optical microscopy and Scanning Electron Microscopy (SEM).

e) This study will analyze the effect of weldments using a RSM.

f) The welding parameters being study are current and voltage.

9

2.0   LITERATURE REVIEW

Aluminium is a very strong ferrite stabilizer (Norton, 2006). Alumunium alloys have lower melting point than steel (Luijendijk, 2000) and sensitive solidifications and liquations cracks (Gupta & Murty, 2006). Aluminium alloy 6064 has good machinability and high mechanical properties and has a good resistance to corrosion and suitability to hard, protective and decorative anodizing.

In the recent years, uses of aluminium in several industries will increase and it increases opportunities in aluminium welding (Figure 2.1) and have replaced conventional materials in the automotive world because it is lightweight (Praveen & Yarlagadda, 2005).
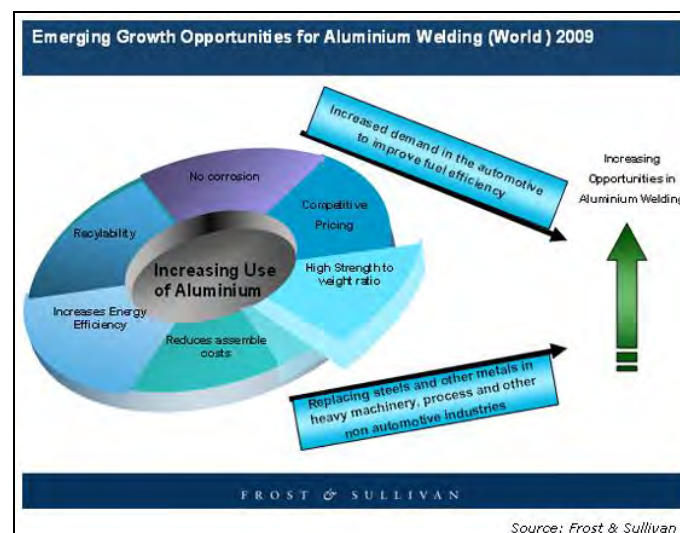
Figure 2.1 Emerging Growth Opportunities for Aluminium Welding

Aluminium alloys series' primary are choice to reduce weight and extensively used in many applications such as pipeline, marines frames, storage tanks, automotive industries, high performance building and aircraft applications (Sayer et al., 2008; Elangovan et al., 2009; Elangovan & Balasubramanian, 2008; Praveen et al., 2006). The specific mechanical strength and corrosion resistance make important advantage between aluminium alloys and the other structural alloys (Lean, 2003). Aluminium alloys series primary are choice to reduce weight and extensively used in many

10

applications such as pipeline, marines frames, storage tanks, automotive industries, high performance building and aircraft applications. The specific mechanical strength and corrosion resistance make important advantage between aluminium alloys and the other structural alloys (Lean, 2003).

Heat treatable wrought aluminium–magnesium–silicon alloys conforming to AA6061 are of moderate strength and possess excellent welding characteristics over the high strength aluminium alloys (Thomas et al., 1995). The microstructure of the welded joint is formally divided into three zones: heat affected (HAZ), thermomechanically affected (TMAZ) and stirred zone (Lomolino et al., 2005). Bussu & Irving, (2003) in their study of friction stir welded 2024-T351 aluminium joints found that crack propagation behaviour was sensitive to both weld orientation and the distance of the crack from the weld line. In addition the Growth rates both faster and slower than in the parent material were observed, depending on the crack orientation and distance from the weld (Bussu & Irving, 2003) .

Weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during welding metal solidification. This often results in inferior weld mechanical properties and poor resistance to hot cracking. It is thus highly desirable to control solidification structure in welds and such control is often very difficult because of higher temperatures and higher thermal gradients in welds in relation to castings and the epitaxial nature of the growth process. Nevertheless, several methods for refining weld fusion zones have been tried with some success in the past: inoculation with heterogeneous nucleants, microcooler additions, and surface nucleation induced by gas impingement and introduction of physical disturbance through techniques such as torch vibration (Balasubramanian et al., 2007).

The fatigue life of friction welded joints was poorer than in as-received base material. In alloy 6061/alloy 6061 joints, fatigue failure initiated in the softened heat-affected-zone region. In metal matrix composite joints, fatigue failure initiated at the bond line region (Zhou et al., 1997) The relationship between joining parameter settings, the tensile and torsional strength properties of inertia friction welded alloy 6061 tubing containing 10 vol% Al_2O_3 particles have been examined (Cola, 1992; Cola & Baeslack n.d.,1992). Welded joints have been investigated and compared in terms of their microstructures, mechanical properties and hardness and FSW have

11

yielded the best mechanical properties (Yeni et al., 2009). The loss of both alloying elements reduces the effect of hardening and results in the reduction of tensile strength and ductility.
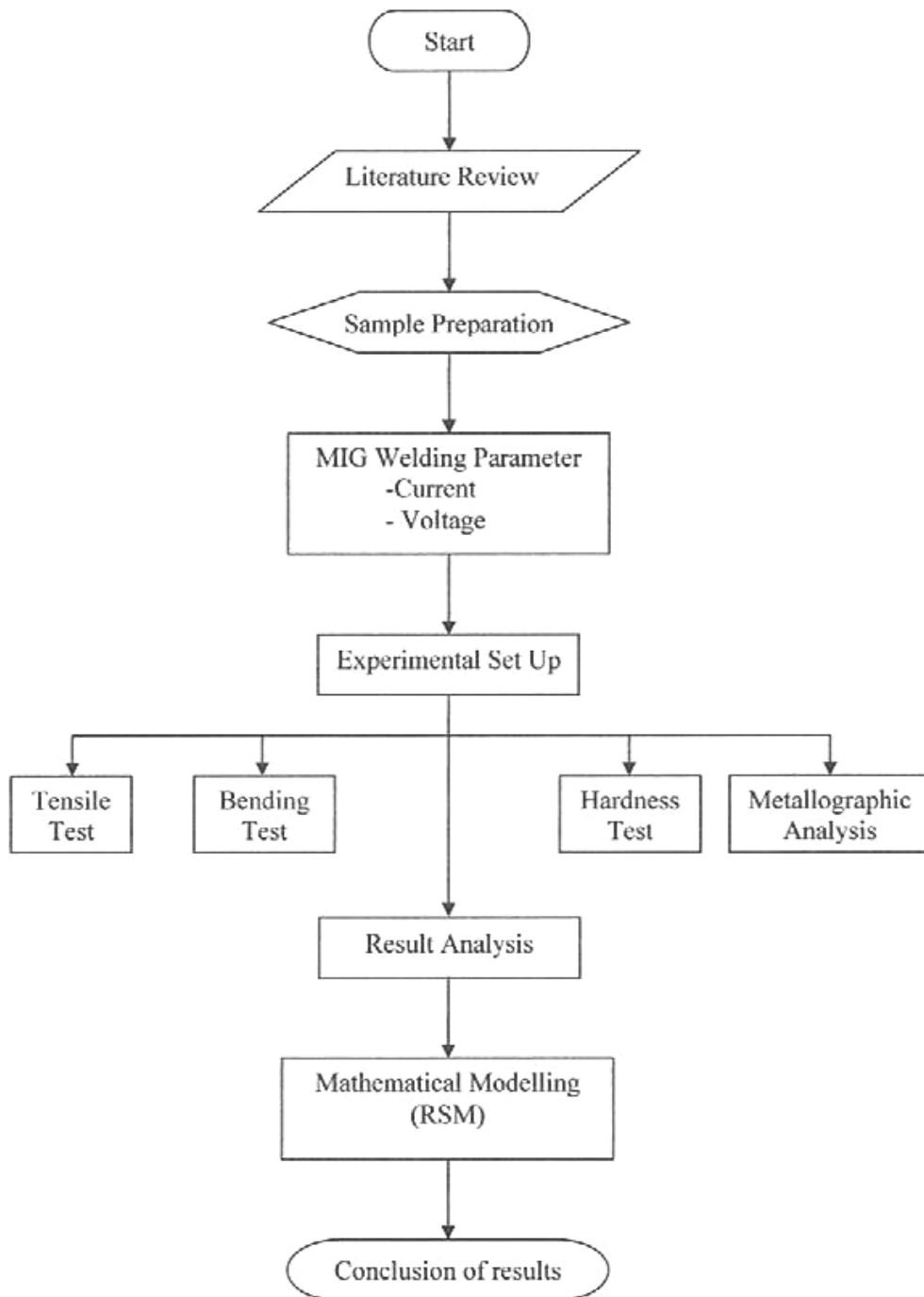
3.0   METHODOLOGY

Figure 3.1 Schematic diagram of experimental setup

13

3.1 Welding Machine

The experiment is conducted by using MIG robot welding DR 4000 series (Figure 3.2). Robot welding was chosen because it can perform repetitive weld and welding speed is consistent.

Figure 3.2 MIG robot welding DR 4000 series

3.1.1 Welding Parameters

Filler wire ER 4043 with diameter 1 mm is used, the welding speed 15 mm/min and shielding gas is pure argon (99%) with flow rate 15 lit/min. The current between 170-190 Ampere and the voltage variations were 16-20 volt. Welding speed and torch angle are kept constant.

3.2 Tensile Strength

The tensile tests were carried out using ASTM standards (B-557M-02) (Figure 3.3) and evaluation of the mechanical properties of the joints obtained in the different welding parameter were done using Trapezium 2 software. The test was conducted using Universal Testing Machine (Figure 3.4). The force was reset to zero before the test start. The purpose of this test is to investigate the tensile strength and yield strength. The test provides data of the weldment ductility. The maximum stress

© Universiti Teknikal Malaysia Melaka

obtained from the test result will be analyzed to determine the effect of welding parameter on the weldment structure.
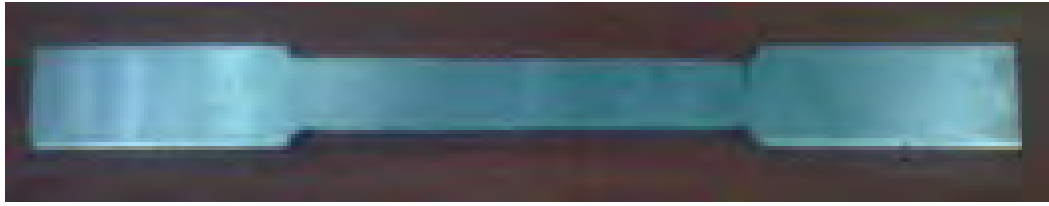
Figure 3.3 Standard tensile specimen according to ASTM standards (B-557M-02)

Figure 3.4 Tensile Test Machine

3.3   Bending Strength Tests

The test was conducted using Universal Testing Machine (Figure 3.5) according to ASTM standards (E-290-02). The force was reset to zero before the test start. The mechanical properties of the joints of the different welding parameter were evaluated and analysis was done by using trapezium 2 software.

15

Figure 3.5 Universal Testing Machines

3.4 Characterization of Micro Structural Change

For subsurface analysis, samples were preserved at each test. Once test samples were sectioned by wire EDM, they were mounted in a thermosetting polymer resin, Buehler Epomet molding compound such that the subsurface microstructures could be examined. This material is particularly suited for hard metal samples, where edge rounding is a problem. The samples were then rough grinding manually with a progressively grit paper start from 2000 to 4000 grit paper. Fine polishing was then performed using Supreme Polycrystalline Diamond Suspension, 2 μm and finally with alumina slurry 1 μm grit size. After polishing, samples were etched with chemical solution for 5 seconds and finally viewed with an optical microscope and SEM for further microstructural analysis. The microstructure and the phase composition were investigated using Optical Microscopy, SEM and X-Ray diffraction.

16

Figure 3.6 Optical Microscopy

3.5 Response Surface Methodology

Response surface methodology is used to model, analyzes the data and predict the mechanical properties (tensile strength and bending), the model was checked by ANOVA technique. This method can provide 99% of confidence level (Balasubramanian, Jayabalan & Balasubramanian, 2007; Balasubramanian, 2008a)

17

4.0 RESULTS AND DISCUSSION

4.1 Welding Bead penetration

Figure 4.1 shows the relationship between current and voltage that affected the penetration. Penetration increased with the increased in current. The depth of penetration values decreased with the decreased in current. The good 6.46 mm penetration was obtained at 190 A, 19 V condition and the worse was 2.28 mm penetration at 170 A, 19 V condition (Figures 4.2 to 4.3). Generally, the depth of penetration varies which depend on the combination of the current and voltage.
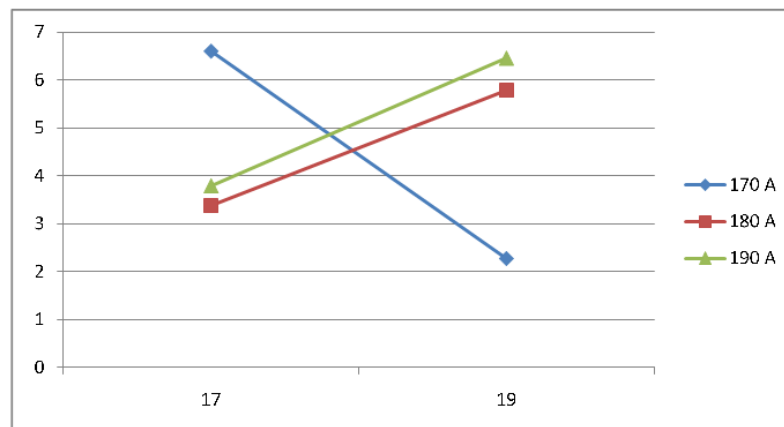

Figure 4.1 The effect of welding current and arc voltage on bead penetration

Figure 4.2 Condition 190 A, 19 v, 15 mm/min. Depth of Penetration = 6.46 mm
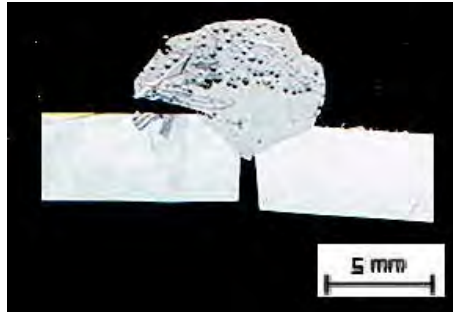
18

Figure 4.3 Condition 170A, 19v, 15 mm/min. Depth of Penetration = 2.28 mm

According to Jayaraman *et al.* (2009), better penetration, high heating rate and right welding profile are the contributing factors that affect the quality of welding joint. The welding defects influence the tensile strength and fracture of the joints and the heat input determined the quality of joining. These are influenced by welding parameters such as welding current, arc voltage, welding speed and protective gas parameters (Kim et al., 2003; Ankara and Ozturk, 1997; Ates and Turker, 1999).

4.2   Mechanical Properties of Weldment Area

4.2.1   Tensile and Bending Strength

Figure 4.4 shows the effect of welding current and arc voltage on Tensile Strength. The highest tensile strength is achieved by using 190 A, there is a significant increment as the voltage increased from 17 v to 19 v. The same phenomenon was also observed by the use of electric current 180 A, but the different result was obtained by the use of electric current 170 A, in which a significant decrease in tensile strength when the voltage increased from 17 v to 19 v.

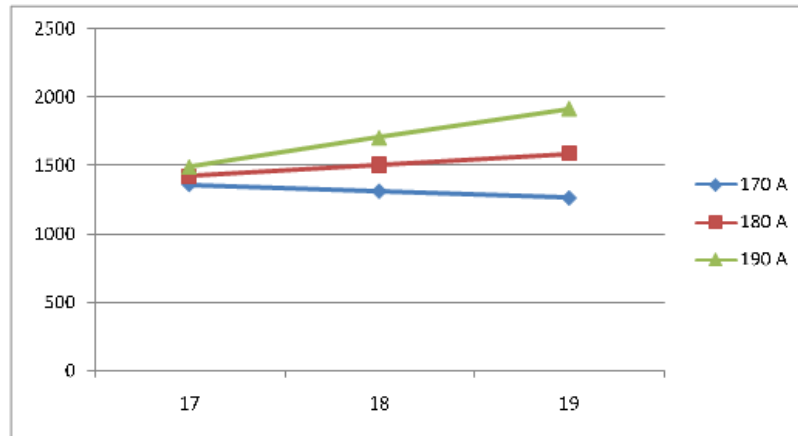© Universiti Teknikal Malaysia Melaka

Figure 4.4 The effect of welding current and arc voltage on Tensile Strength

Figure 4.5 shows the effect of welding current and arc voltage on bending strength. The relationship between bending strength and parameter involved in robot welding is related to heat input that produce the penetration of weldment area, increase of current and voltage will increase the bending strength (180 A and 190 A; voltage 17-19v), in the other hand, the tensile strength decreased with increasing voltage and current which is between 100582.96 Mpa to 82001.91 Mpa.
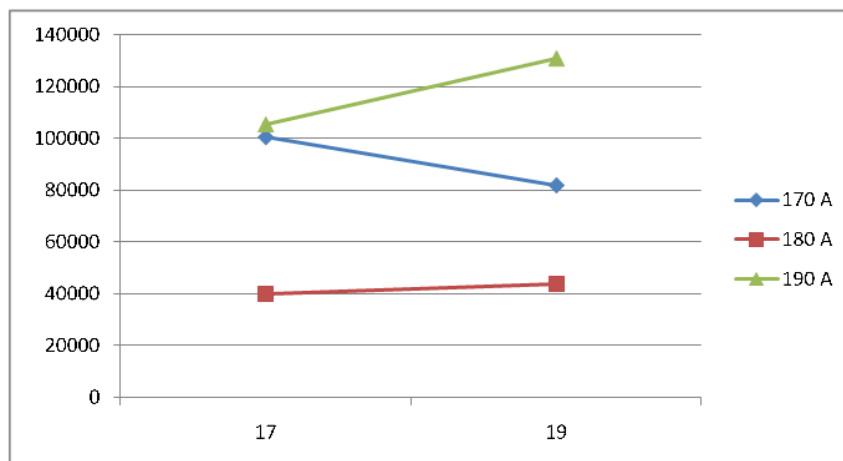

Figure 4.5 The effect of welding current and arc voltage on bending strength

20

The results showed that the bending strength increased with the increase in current and voltage (Figure 4.6). The use of low current and low voltage produces lack of fusion which gives poor adhesion of the weld bead to the base metal. Rampaul & Hoobasar, (2003) found that the cause of incomplete penetration is due to the defects occurred when the welding procedures are not adhered to; possible causes include the current setting, arc length, electrode angle, and electrode manipulation. The cross-sections show a certain number of pores occurred and this is mainly disturbance in the welding process due to the fusion caused in metal inert gas (MIG) robot welding.

Figure 4.6 The cross section showed a certain amount of pores

4.2.2 Hardness Test

Figure 4.7 shows the variation of Vickers hardness measured at 0.5mm distance range on one side with a distance of 0-5 mm from the weld center line and from that figure shown the decreasing hardness in the HAZ region. The optimum hardness at HAZ is achieved with 180A and 19v. Kumar *et al.* (2009) also reported the decreasing hardness in the HAZ region that caused by heat input below the temperature reversion has made precipitate not return to its original shape when the solidification.
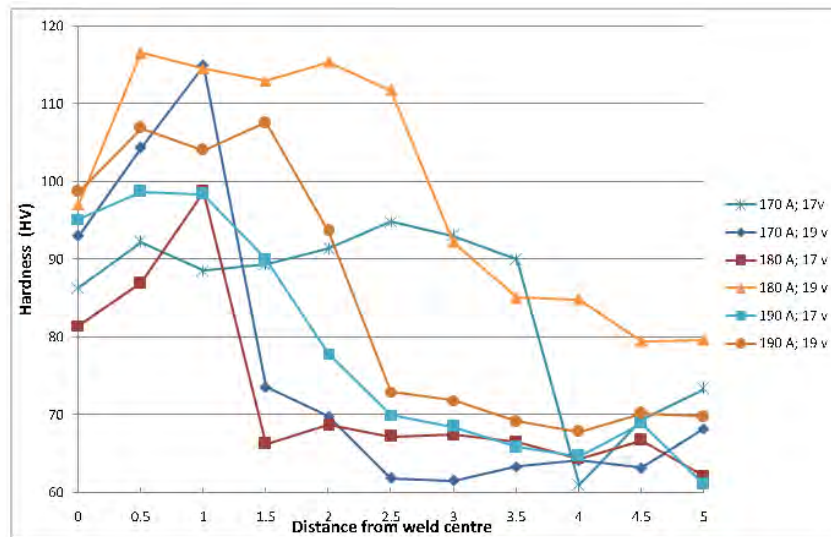
Figure 4.7 Hardness Distributions on the Weldments Area

4.3   Analysis of Microstructure of Heat Affected Zone (HAZ)

The microstructures of aluminium alloys 6064 joints are exhibited in the micrographs in Figure 4.8 and it is showing a columnar solidification structure close to the fusion line was also reported in studies by Hu (2004). Figure 4.8also shown the precipitates which occur because the solubility of alloying elements exceeded at the lower temperature when it solidifies. The heat input caused the precipitation of aluminium alloys 6064; the precipitation induces the depletion zone at the adjacent grain boundary. Balasubramanian, Ravisankar & Reddy (2008) reported the simple aging treatment applied to the joints caused noticeable changes in the formation of precipitates and their distribution.
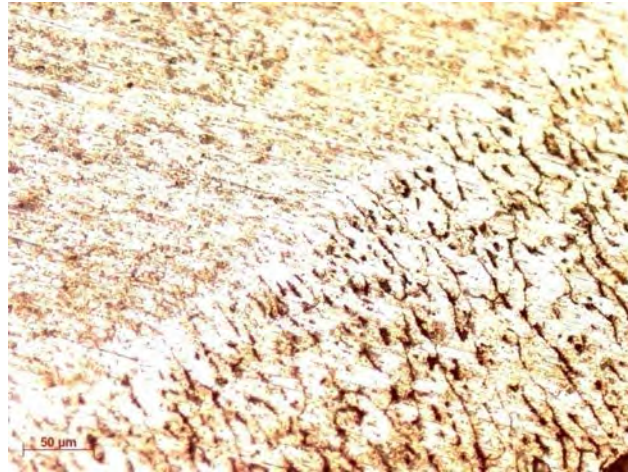
Figure 4.8 Microstructure of weldment area (200X)

4.4 Mathematical Modeling of the Weldment Area strength

The analysis of RSM is conducted by using Design Expert version 7.03 software packages. The analysis involves Analysis of Variance (ANOVA), interpretation lack of fit and the sequential model sum of squares. The experimental result of tensile strength is presented in Table 4.1below.

Table 4.1 Experimental Results of Tensile Strength Test

Run	Current (A)	Voltage (V)	Tensile Strength (Mpa)
1	170	20	893.75
2	180	15	609.375
3	180	18	1462.5
4	194	18	2334.38
5	170	16	1796.88
6	190	20	1615.63
7	180	18	1578.13
8	180	18	2034.38
9	180	18	1034.38
10	180	18	1271.88
11	190	16	1468.75
12	180	21	2034.38
13	166	18	1506.25

From the sequential model sum of squares and lack of fit test it showed that the 2 factor Interactions (2FI) is suggested do describe the relationship between current and voltage.

Table 4.2 Sequential Model Sum of Squares

Source	Sum of squares	df	Mean Square	F value	p-value Prob>F
Mean vs Total	29673517.05	1	29673517.05		
Linear vs Mean	529028.6698	2	264514.3349	1.161990354	0.3518
2FI vs Linear	275630.25	1	275630.25	1.239865064	0.2944
Quadratic vs 2FI	355065.44	2	177532.72	0.755139609	0.5047
Cubic vs Quadratic	1010928.885	2	505464.4425	3.981505101	0.0924
Residual	634765.5342	5	126953.1068		
Total	32478935.83	13	2498379.679		

Table 4.3 Lack of Fit Test

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F
Linear	1717296.222	6	286216.0369	2.047713583	0.2543
2FI	1441665.972	5	288333.1943	2.062860645	0.2514
Quadratic	1086600.532	3	362200.1772	2.591337057	0.1901
Cubic	75671.6467	1	75671.6467	0.541387759	0.5027
Pure Error	559093.8875	4	139773.4719		