The Effect of Time during Post Weld Heat Treatment (PWHT) on Mechanical Properties of Copper Alloy with Gas Metal Arc Welding (GMAW)

By

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14822

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical)

MAY 2015

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Malaysia

CERTIFICATION

CERTIFICATION OF APPROVAL

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Approved by,

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(DR.TURNAD LENGGO GINTA)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(N.DIVINIYA NASINDRAM)

ABSTRACT

In this project the effect of time during post weld heat treatment on the mechanical properties of copper alloy was studied using gas metal arc welding (GMAW) technique. Gas metal arc welding technique is a welding technique that uses heat energy to combine metal parts. Copper aluminum also known as aluminum bronze is selected as the representative for copper alloy electrode in this study. It is an inevitable fact that mechanical properties of a material changes when it undergoes heat treatment. In this project, post weld heat treatment at a constant temperature and varying time period were conducted upon welding to 6 test samples. The effect of time during post weld heat treatment on the welded joint was studied using Charpy Impact test in accordance with ASTM E23. Furthermore, hardness test and microstructure observation have been conducted on the welded material to observe the changes in the mechanical properties of the welded material at the weld joint and heat affected zone. The size and pattern of the microstructure at the joint are the primary factors that affect the impact strength of the joined metal parts. The results obtained from this study shows that the impact toughness increases at the weld joint when the time of post weld heat treatment is increased. The hardness at the weld joint is improved significantly with increase in time of post weld heat treatment and only a slight increase in hardness is observed at the base metal close to the welded joint. In the microstructure observation it is observed that grain growth has occurred and grain migration have occurred reducing the residual stresses at the joint.

ACKNOWLEDGEMENT

I dedicate the success of this project to my Final Year Project Supervisor, Dr.Turnad Lenggo Ginta, UTP technicians, Mr.Azizan, certified welder from Boustead Naval Shipyard Lumut and all lecturers who have ever thought me.

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Copper alloy is widely used in many industries because of its high resistance to chemical. It is one of the most suitable types of metal to be used for under water equipment, heat exchangers turbines and many mechanical machines. GMAW is used for a wide variety of applications in the fields of industrial manufacturing, agriculture, construction industry, shipbuilding, marine and ground vehicle industries and mining. This joining process is also used in building construction weld pipe, pressure vessels, structural steel components, furniture, automotive components and numerous other products. The vast applications of copper alloy in many high risk and crucial mechanical sectors have placed high importance to the impact strength of the copper alloy at weldments especially. During welding the metal near to the weldment area will become soft due to the changes in microstructure at the heat affected zone. This will result in a relatively lower impact strength compared to the impact strength of the base metal. In this study, the effect of post weld heat treatment on weldments of copper using copper alloy electrode with gas metal arc welding is studied to increase the impact strength in applications at weldments area. The post weld heat treatment selected in this study is annealing. In annealing heat treatment, the work piece is heated to a high temperature below its melting point and cooled down slowly. This process will change the arrangement of microstructure of the work piece leading to higher impact strength. The annealing temperature is kept constant to examine the effect of the annealing time on the impact strength.

1.2 Problem Statement

When copper alloys are welded they are prone to softening at the heat affected zone leading to low hardness, strength and hence is a weak link (Mohanadas et. al, 1999). Failure due to weldment is becoming a concerning factor in industries. However, literatures on the effect of post weld heat treatment on the mechanical properties of copper alloys are limited therefore making this study important to understand the behaviour of copper alloy under this condition. The effect of time during post weld heat treatment is an important factor that needs to be considered because it can significantly affect the mechanical properties of the metal. Post weld heat treatment helps to reduce distortion in components and maintain the dimensional stability of the microstructure. As the time during post weld heat treatment is increased grain growth will occur leading to superior mechanical properties.

1.3 Objectives

- To investigate the effect of time during post weld heat treatment on the impact resistance and hardness distribution of copper with gas metal arc welding (GMAW) using copper alloy electrode.
- To study the relationship of time during post weld heat treatment on the microstructure of copper welded with gas metal arc welding (GMAW) using copper alloy electrode

1.4 Scope of study

The deliverables of this project compasses developing a theory between the effect of post weld heat treatment time on the mechanical properties of copper alloy. The welding technique that is used in this study is gas metal arc welding (GMAW) because copper alloy is suitable to be welded using GMAW. Copper- aluminum alloy is used in this study as a representative of copper alloy electrodes to investigate this theory. There might be slight variance in the result obtained when different copper alloy electrodes are used however the relationship will remain as the dominant element in copper alloy is copper. The effect of post weld heat treatment on the mechanical properties of copper alloy is studied using two mechanical tests which are Charpy impact test and Rockwell hardness test. Microstructure observation is also performed to explain the behavior of the test samples. Copper-aluminum alloy electrode was chosen to be used in this study because of its vast uses in industries and availability.

CHAPTER 2: LITERATURE REVIEW

2.1 Fundamentals of Welding

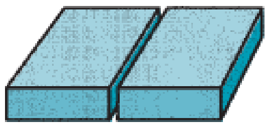
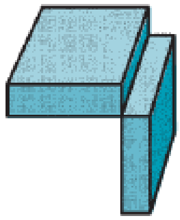
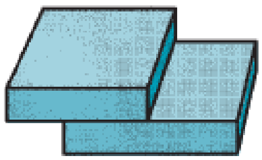
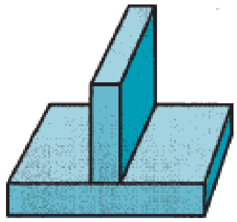
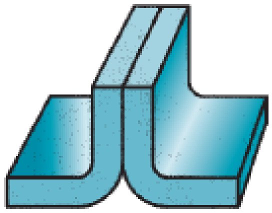
Groover (2010) defined welding as a process joining materials in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure. Most welding processes are accomplished by heat alone, some by a combination of both pressure and heat also others by pressure alone. Filler material is added in some welding processes to facilitate coalescence. The assemblage of parts that are joined by welding is called weldments (Groover, 2010). Welding process can be used for joining both metal parts and plastics. In this study, the discussion of welding will be focused on metal parts specifically copper alloy.

Welding provides a permanent joint and the welded parts become a single entity. The welded joints can be stronger than the parent materials if the filler metal used has strength properties superior to that of the parent material also when proper welding techniques are applied (Groover, 2010). There are 50 different types of welding operations cataloged by the American Welding Society and each uses various types of combinations of energy to provide the required energy. Groover (2010) highlights that welding processes can be divided into two major groups which are fusion welding and solid-state welding.

Groover (2010) explains that fusion welding processes use heat to melt the base metals. Some of the types of fusion welding are arc welding (AW), resistance welding (RW), oxyfuel gas welding (OFW), electron beam welding and laser beam welding. Solid state welding refers to joining processes in which coalescence results from application of pressure alone or a combination of heat and pressure (Groover, 2010). No filler metal is required too. Some examples of solid state welding are diffusion welding (DFW), friction welding (FRW), and ultrasonic welding (USW).

Groover (2010) specifies that welding produces a solid connection between two pieces, called a weld joint. A weld joint is defined as the junction of the edges of surfaces of parts that have been joined by welding. There are two important information related to a weld joint which are namely types of joints and the types of welds used to join the pieces that form the joints. Types of welded joints are shown in TABLE 2.1.

TABLE 2.1. Types of weld joints (Grover, 2010)

Type of weld joints	Example
Butt joint	
Corner joint	
Lap joint	
Tee joint	
Edge joint	

Differences among weld types are in geometry and welding process (Groover, 2010). Two common types of welds are fillet weld and groove weld. Fillet welds are used to fill in the edges of plates created by corner, lap and tee joints. Groover (2010) points out that filler metal is used to provide a cross section approximately the shape of a right triangle. It is most common weld type in arc and oxyfuel welding because it required minimum edge penetration. Groove welds usually require that the edges of the parts be shaped into a groove to facilitate weld penetration (Groover, 2010).

2.2 Gas Metal Arc Welding (GMAW)

In this study, the discussion will be focused on gas metal arc welding (GMAW). GMAW is a type of arc welding process. Gas metal arc welding is also known as metal inert gas (MIG) welding or metal active gas (MAG) welding. Ates (2007) defines GMAW as a welding method that yields coalescence of metals by heating with a welding arc between continuous filler metal (consumable) electrode and the workpiece. The continuous wire electrode, which is drawn from a reel by an automatic wire feeder, and then fed through the contact tip inside the welding torch, is melted by the internal resistive power and heat transferred from the welding arc (Ates, 2007). Heat is concerted by the welding arc from the end of the melting electrode to molten weld pools and by the molten metal that is being transferred to weld pools. FIGURE 2.1 shows the schematic representation of GMAW process.

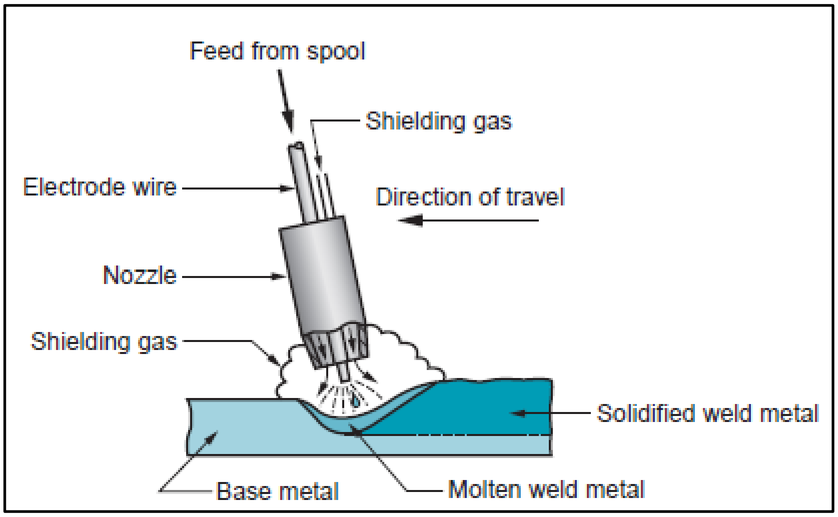


FIGURE 2.1. Schematic diagram of gas metal arc welding (GMAW) (Groover, 2010)

Ates (2007) explains that molten weld pools and electrode wire were protected from contaminants in the atmosphere by a shielding gas obtained from various combinations. Naturally, the common variations of shielding gases, power supplies, and electrodes in GMAW have significant effect resulting in several different and important process variables (Ates, 2007). According Ates (2007), all commercially prime metals such as carbon steel, stainless steel, aluminum and copper can be welded with this process in all positions by choosing the appropriate shielding gas, electrode and welding condition. The composition of a shielding mixture in arc welding depends highly on the kind of materials to be welded. Suban & Tusek (2000) point out that the selection of the shielding gas should, by all means, take into account chemical metallurgical processes between the gases and the molten pool that occur during welding.

Ates (2007) also mentions argon and helium as the most common purging gases that are used as shield gases to reduce the defects and have good weldability also they play an important role reduction of generation of defects as well as protection of weld pool. There is a vast range of shielding gases available for arc welding. The gases vary from the pure gases to complex quaternary mixtures based on argon, helium, oxygen, and carbon dioxide. Ates (2007) explains that the shielding gas for arc welding must be easily ionized to ensure that the arc can be sustained at a reasonably low voltage. Additional requirement for shielding gases are to stabilize the arc, efficient shielding of weld pool and adjacent area and good weld penetration with a smooth weld bead profile (Groover, 2010).

In GMAW the quality of weld is influenced by various factors like electrode, shielding gas, and process variables which include current, welding metals and heat treatment. Wahab (2001) informs that electrode wire diameter ranges from (0.8mm to 6.5mm) are typically used in GMAW, the size depending on the thickness of the parts being joined and the desired weld metal deposition rate. In this study, this parameter will be kept constant to study the effect of post weld heat treatment.

Arc voltage and current can affect many features of weld such as weld geometry, weld metallurgical characteristics, transfer mode of melting droplets, residual stresses, weld stability, weld defects and weld quality in general (Anzehaee & Haeri , 2011). Based on the study conducted by Kim, Son, Kim, Kim & Kim (2003) welding current and arc voltage have been found to greatly affect bead penetration in CO2 arc welding process. As weld current is increased, weld bead depth and depth of penetration increases with increase of heat generated (Singh, Singh & Singh, 2013). Weld bead geometry influences the mechanical properties of weld joint but welding parameters influences the weld bead geometry. Ghazvinloo, Raouf & Shadfar (2010) found in their study that welding heat input increases by increasing welding current and decreasing welding speed. Concurrently, impact energy of weld metal increases slightly and then drops significantly as welding heat input is increased.

Wahab (2001) states that when the voltage and wire feed are kept constant, the changes in the gun position causes a change in the welding current due to a change in the electrode extension. For example, when the gun-to-metal distance is suddenly increased the arc length momentarily becomes longer. Longer arc length causes a reduction in current, thus reduces the electrode melt-off rate (Wahab, 2001). Since the feed rate is kept constant, the arc length decreases and the current increases until the melt-off rate again equals the feed rate. Essentially, the resistance heating (I^2R) of the electrode extension has increased and arc heating at the electrode tip has decreased (Wahab, 2001). Consequently, the arc heating of the metals, as well as weld penetration is decreased.

2.3 Post Weld Heat Treatment.

Heat treatment is an essential step in the final fabrication process of many engineering component. Using heat treatment it is possible to impart high mechanical properties to metal parts and tools for sophisticated applications. Deng et al. (2014) highlights that heat treatment is considered to be very important tool of the metallurgist by which it can alter the properties of metal easily. A same type of metal can have a very wide range of mechanical properties if subjected to different heat treatment. The changes in the properties of metal after heat treatment are due to the phase transformations and structural changes that occur during the heat treatment (Lu et al., 2014).

Post weld heat treatment is a type of heat treatment. High level residual stresses can occur in weldment due to restraint by the parent metal during weld solidification (Lu et al., 2014). The stresses may be as high as the yield strength of material itself. When the residual stresses are combined with normal load stresses these may exceed the design stresses. The removal of residual stresses takes place due to the fact that the thermal energy received by the metal allows for grain boundary sliding and removal of metallurgical defects like dislocations, vacancies and slip plane. Lu et al, (2014 points out that a most important aspect of post weld heat treatment is to prevent brittle fracture. Post weld heat treatment softens the hardened zones and makes the machining easy. Removal of residual stresses becomes necessary where dimensional stability is required. This heat treatment consists of stress-relief, annealing or solution annealing depending upon the requirements. Both (Zhu et al,. 2014) and (Malarvizhi, Raghukandan & Viswanathan, 2008) agrees that post weld heat treatment can improve the impact toughness of the welded joint.

2.4 Copper alloy

American Welding Society (1997) justifies that copper and most of its alloy is made up of face-centered cubic lattice which results in good formability and malleability. In its natural state copper has a density of 0.32 lb/in^3 (8.94Mg/m^3) which is about three times of aluminum's density. Copper has electrical and thermal conductivity slightly lower than silver but one and half times of aluminum (American Welding Society, 1997). In applications, copper and copper alloys are preferred for their electrical and thermal conductivity, corrosion resistance, metal-to-metal wear resistance and distinctive aesthetic appearance. There are various copper alloys like high copper alloy, copper zinc alloy, copper tin alloy, copper aluminum alloy, copper nickel alloy and copper silicon alloy.

American Welding Society (1997) physical properties of copper alloys are important to welding process including melting temperature range, coefficient of thermal expansion, and electrical and thermal conductivity. As the alloying element is increased in the copper alloy electrical and thermal conductivity is reduced significantly which is preferred to enhance weldability (American Welding Society, 1997). In this study, copper aluminum alloy will be selected because of its convenient availability. Copper aluminum alloy may contain up to 15 percent aluminum also additions of iron, nickel, tin and manganese. The aluminum in copper is 7.8 percent soluble and this can be increased with the usual addition of iron. When aluminum is less than 8 percent in the alloy, the alloys are single-phase (Americam Welding Society, 1997). The alloy system will become two-phase when the aluminum is in the range of 9 and 15 percent and it is capable of either a martensitic or a eutectoid type of transformation. American Welding Society (1997) implies that increasing the amount of aluminum increases tensile strength, increase yield strength and hardness and decrease elongation of the alloy. Heat treatment is used to strengthen two-phase alloys by producing a martensitic type structure and tempered to obtain desired mechanical properties (American Welding Society, 1997). The composition of the alloy and desired mechanical properties determines the specific heat treatment required. According to American Welding Society (1997) gas metal arc welding (GMAW) is the best method for joining copper aluminum alloys. FIGURE 2.2 is the phase diagram of copper aluminum and the microstructure of copper aluminum undergoes changes with accordance to this phase diagram when it is heat treated.

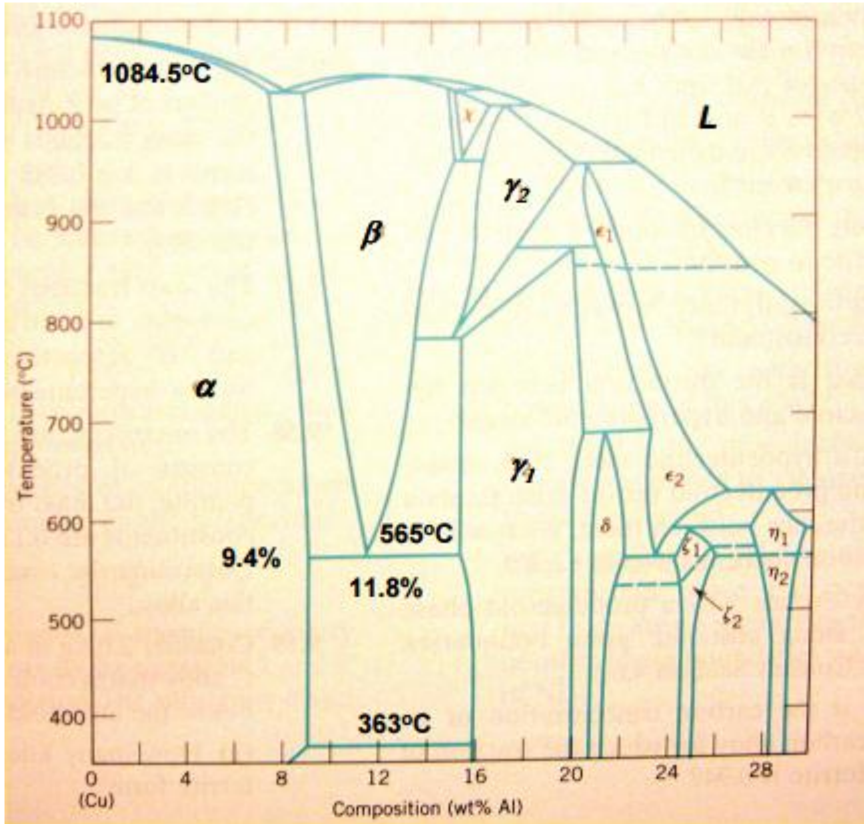


FIGURE 2.2. Phase diagram of copper aluminum alloy (Structure and Properties of Engineering Alloys, 1993)

CHAPTER 3: METHODOLOGY

3.1 Research Methodology Flow Chart

FIGURE 3.1 shows the flow of the research methodology used in this project.

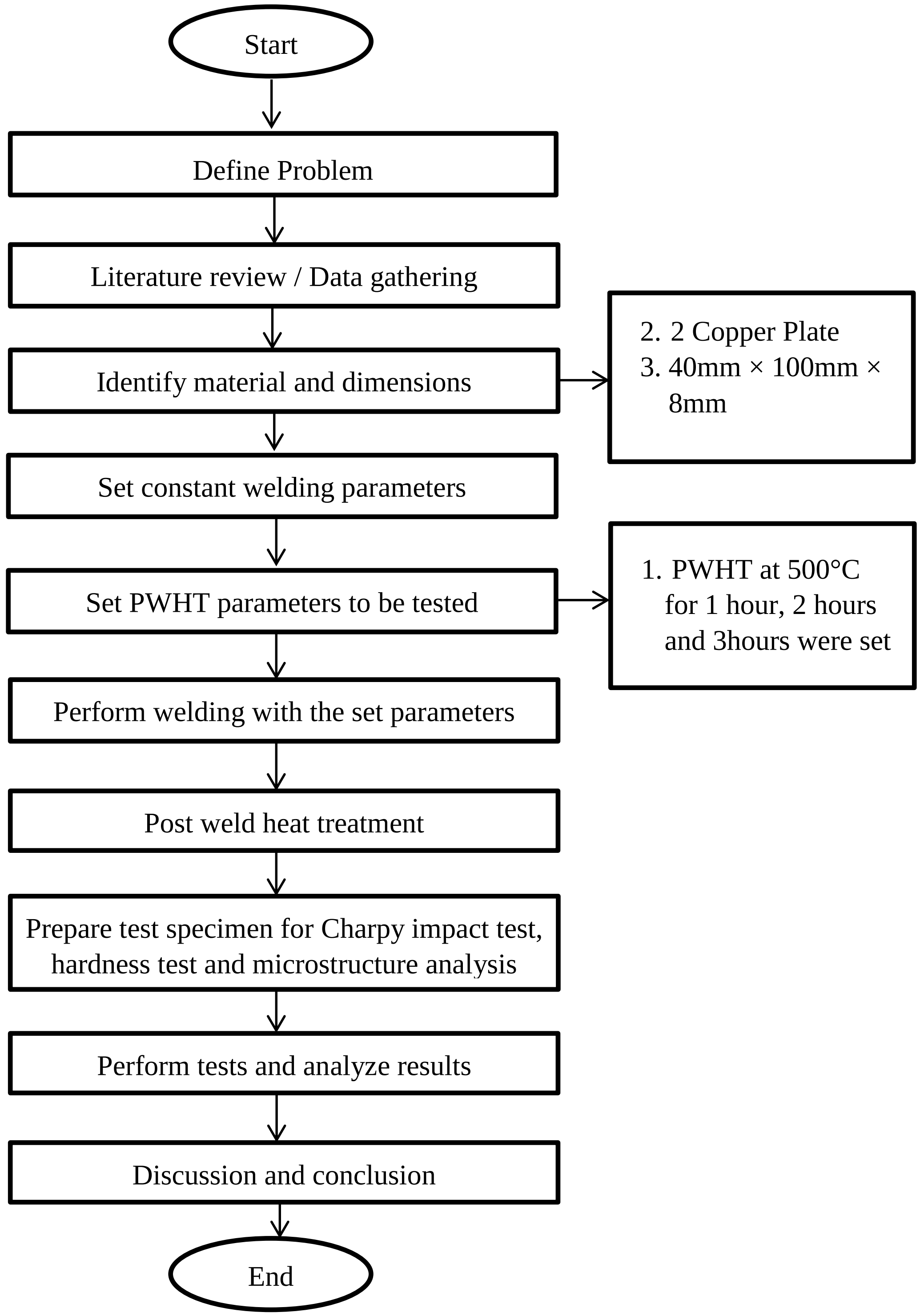


FIGURE 3.1: Research methodology flow chart

3.2 Base metal

Copper alloy plate is chosen to be used in this experiment because it is one of the most suitable types of metal to be welded using gas metal arc welding (GMAW) (American Welding Society, 1997). In this study, copper aluminum filler rod will be used as a test subject that represents copper alloy to investigate the effect of post weld heat treatment on any copper alloys. It is possible for the results to vary when different copper alloys are used to carry out the experiment. However, the results from this study can be used as a basis to define a generic relationship between post weld heat treatment and mechanical properties of copper alloy. The chemical composition of base metal (copper alloy plate) and weld metal (copper aluminum alloy) is shown in TABLE 3.1. The mechanical properties of base metal and weld metal are shown in TABLE 3.2.

TABLE 3.1. Chemical composition of copper alloy plate and copper aluminium electrode

Type of material	Copper	Al	Fe	Others
Base metal	99.95 %	-	-	min
Weld metal	90 %	8.5 %	0.75 %	min

TABLE 3.2. Mechanical properties of copper aluminum alloy

Type of material	Tensile Strength (psi)	Yield strength (psi)	Elongation (%)	Hardness
Base metal	43500	36260	12	Hv 93
Weld metal	79025	34945	24	Hv 150

After the welding is performed, the joined metal plates will be as shown in FIGURE 3.2. From the joined metal plates, 7 test samples with dimensions of 80mm × 10mm × 8mm are prepared. 6 test samples will undergo post weld heat treatment in preparation to be tested for impact resistance as well as hardness. The joined metal plates will be cut in to 7 test samples using an electric saw.

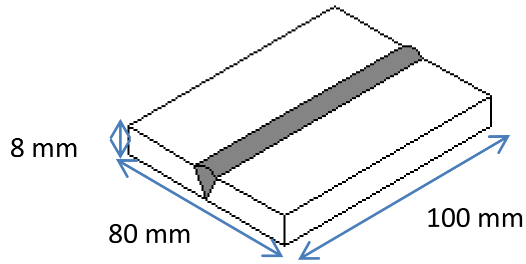


FIGURE 3.2. Dimensions of base metal

V-groove butt weld joint configuration will be used to connect the 2 base metals. The base metals are beveled as shown in FIGURE 3.3 before welding is performed. Test sample 1 with no post weld heat treatment will be tested for impact resistance after performing hardness test to be kept as the experiment constant for comparison.

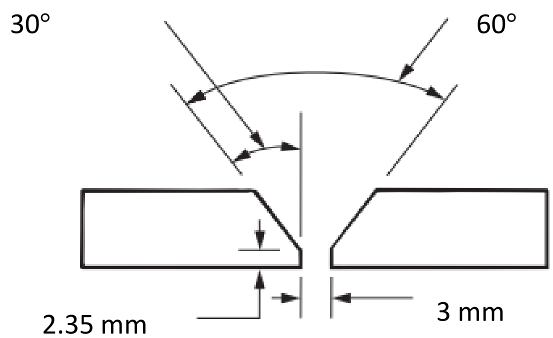


FIGURE 3.3. V-groove butt weld configuration

Two test samples will be allocated for each post weld heat treatment time. One test sample will be used for Charpy impact test and hardness test. Whereas, the second test sample will be used for microstructure observation.

3.3 Welding Parameters

Welding is affected by various welding parameters like welding current, arc voltage, welding speed, base material and filler materials used. However in this study only the effects of post weld heat treatment on the mechanical properties of copper alloy is to be studied, thus, some welding parameters are kept constant throughout the study to obtain an accurate relation between impact resistance and hardness test of copper alloy with post weld heat treatment time. The parameters kept constant are shown in TABLE 3.3.

TABLE 3.3. Welding parameters in the study

Filler wire diameter (mm)	1.6
Voltage (volts)	30
Current (amps)	200
Welding speed (mm/min)	150
Shielding gas	Argon
Gas flow rate	16 lit/min

3.4 Post weld heat treatment parameter

The parameters of the post weld heat treatment condition to be studied are listed in TABLE 3.4. Post weld heat treatment will be carried out at a constant temperature with three different heating time. The effect of the heating time at a constant temperature will be analyzed in the result.

TABLE 3.4. Post weld heat treatment parameters to be tested

PWHT Temperature	Time
500 °C	1 hour
	2 hours
	3 hours

Three test samples are heated for one hour, two hours and 3 hours respectively. All three samples will be undergo heat treatment using CWF 13/13 furnace. All the three test samples will be heated to 500 °C at once in CWF 13/13 furnace. One test sample will be removed from the furnace after an hour, the next test sample will be removed after 2 hours and the third test sample will be removed after three hours. All test samples are cooled at ambient temperature.

3.5 Impact test

Charpy V-notch impact test will be carried out on 4 test samples respectively for no PWHT, PWHT for 1 hour, 2 hours and 3 hours at 500 °C. Standard Charpy V-notch impact specimens are prepared in accordance to ASTM E23 specification (Ghazvinloo, Raouf & Shadfar, 2010). The standard Charpy test sample has a 45° V-notch with 2 mm depth and 0.25 mm root radius. The notch in impact test sample was located in center of the weld metal and it is cut using wire cut to precision. The test samples prepared for Charpy V-notch impact test will have dimensions as shown in FIGURE 3.4.

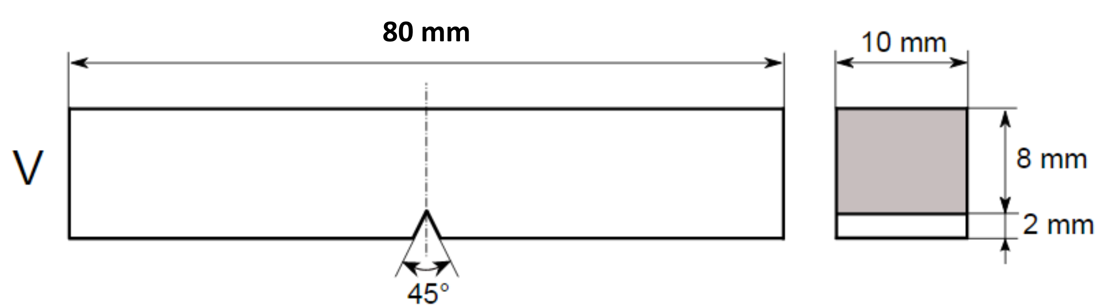


FIGURE 3.4. Standard Charpy impact test specimens' dimensions (ASTM E23)

3.6 Hardness test

The hardness distribution across the weld surface was measured using Rockwell hardness tester. The hardness profile was measured at the center of the test sample as shown in FIGURE 3.5. Before using hardness tester, it was calibrated using calibration block.

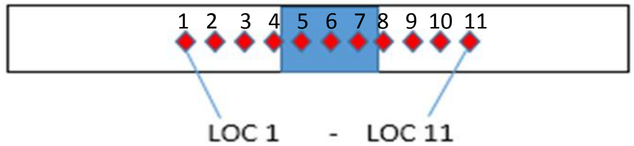


FIGURE 3.5. Schematic diagram shows hardness profile along welded plate at different zones

Location 1 to 3 and Location 9 to 11 is the base metal hardness. Location 4 and 8 are taken on the heat affected zone. Location 5, 6 and 7 hardness are taken on the weld metal. Hardness test was carried out in accordance with the test methods described in ASTM E 18. The standard describes the setup and procedure for determining the Rockwell Harness number. The selection of hardness scale is based on the material to be tested. In this study, 1/16" ball with 100 HRB scale was used to carry out this experiment because it is the suitable scale for testing copper alloy as stated in ASTM E18. The surfaces of test samples are smoothened by milling before performing hardness test to remove scratches and uneven surface to improve the accuracy of the test.

3.7 Microstructure observation

Microstructure observation is carried out to investigate the influence of post weld heat treatment (PWHT) time on level of microstructure of the test samples. Microstructure observation is carried out in accordance to ASTM 112. Four test samples including the test sample with no post weld heat treatment is prepared. The microstructure observation is carried out using an optical microscope.

The first preparation step for microstructure test is mounting. After that, grinding and polishing are done very carefully to remove all the scratches from the surface of the test sample. The samples also need to be etched using the right solution. In this experiment, 30ml of distilled water and 30ml of nitric acid are used as the etching solution. Etching solution is used to expose the grain boundaries of the test sample. Surface of metal will be etched between seconds until the surface becomes dull. These steps are repeated for each test samples to analyze the microstructure of test samples using microstructure test.

3.8 Tabulation and analysis of results

The results will be tabulated in the following format in TABLE 3.5.

TABLE 3.5. Impact toughness obtained from Charpy impact test

PWHT Temperature	Time	Impact Toughness
500 °C	1 hour	
	2 hours	
	3 hours	

The image of the microstructure at the welded joint will be compared for post weld heat treatment with different time. The hardness obtained from the hardness test will be reflected upon the impact toughness of the welded metal parts.

3.8 Gantt Chart and Key Milestones for FYP 1 & FYP 2

Gantt Chart with Key Milestones for FYP 1 and FYP 2

No	Task	FYP1														FYP2													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic selection	■																											
2	Problem definition		■*																										
3	Background study and literature review			■	■	■	■*	■																					
4	Extended proposal submission								■*																				
5	Investigation/ Data gathering									■*																			
6	Proposal defense									■																			
7	Parameter definition										■	■																	
8	Determine the parameters for investigation												■																
9	Prepare experiment apparatus													■															
10	Submission of Interim Report													*	■														
11	Model experiment															■*	■												
12	Carry out experiment on identified parameters																■	■*	■	■									
13	Divide the sample for testing																			■	■								
14	Perform microstructure and hardness test																				■	■	■						
15	Perform Chapry impact test																					■	■						
16	Data/result analysis																						■	■	■				
17	Alter experiment if identified parameter does not meet requirement																							■	■	■	■		
18	Define relationship from experiment																										■	■*	
19	Final report																											*	■

* = Key Milestones

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Hardness Test

Hardness test was performed to characterize the Rockwell hardness (HRB) profile along the surface of the test sample. The hardness profile of GMAW welded copper alloy plate was tested as shown in FIGURE 3.3. It shows the effect of annealing time on the hardness of weld metal. From FIGURE 4.1, we can see that specimen with annealing for 3 hours under 500 ℃ has the higher hardness at the weldments compared to the specimens annealed for 1 hour and 2 hours. Theoretically, higher post weld heat treatment time in some cases will effectively relieve residual stresses. However, from the graph obtained we can see that the hardness at the heat affected zone (HAZ) is the lowest because it has large residual stresses in that region. It is observed that increasing post weld heat time increases the hardness at HAZ (Loc 4 & Loc 8) at a very minimal rate. It shows that, increasing post weld heat treatment time cannot significantly increase the hardness at the heat affected zone. Meanwhile, the lowest hardness was without heat treatment.

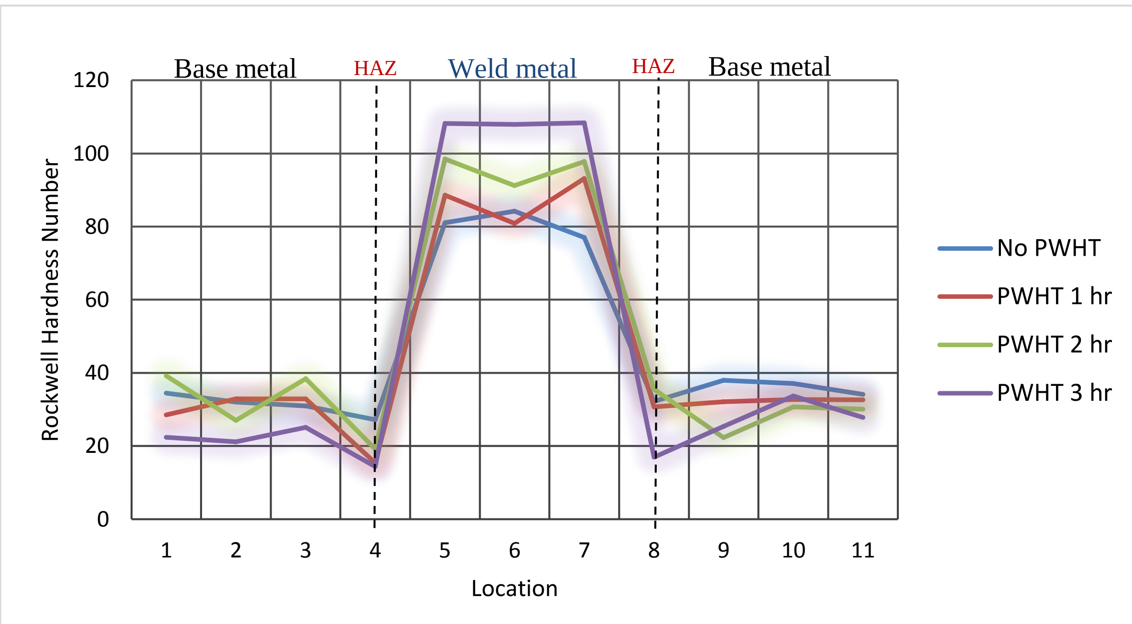


FIGURE 4.1. Hardness profile of GMAW welded copper alloy

4.2 Impact Test

As a result of the Charpy impact test the test samples broke into two. The specimen was hit by a pendulum with an impact of 299.751 J with an impact speed of 5.23 m/s from an angle of 150°. Impact toughness of a material is defined as the energy dissipated in breaking the test sample from the amount of swing of the pendulum (Budinski & Budinski, 2009). Impact test measures the energy absorbed by the broken test sample which is also the impact toughness of the material.

In the experiment conducted for the impact toughness, energy dissipated in breaking the specimen can be obtained directly from the impact test machine. Actual consumed impact work, Av is obtained directly from the impact test machine. It indicates the energy used to break the test sample. Therefore the impact toughness of each test sample is taken as Av value.

TABLE 4.1. Impact toughness of test samples with different PWHT conditions

Test Sample	Condition	Impact Toughness (J)
1	No PWHT	8.71
2	PWHT (500 ℃) for 1 hour	11.097
3	PWHT (500 ℃) for 2 hour	17.742
4	PWHT (500 ℃) for 3 hour	24.501

It can be observed that the impact toughness of the welded metal joint increase drastically starting from the condition of post weld heat treatment for 2 hours. The results as shown in TABLE 4.1 are achieved because the residual stresses developed during welding at the heat affected zone during solidification prior to welding have been reduced with post weld heat treatment. FIGURE 4.2 is a graphical representation of the pattern observed in the changes in impact toughness with increase in time during post weld heat treatment.

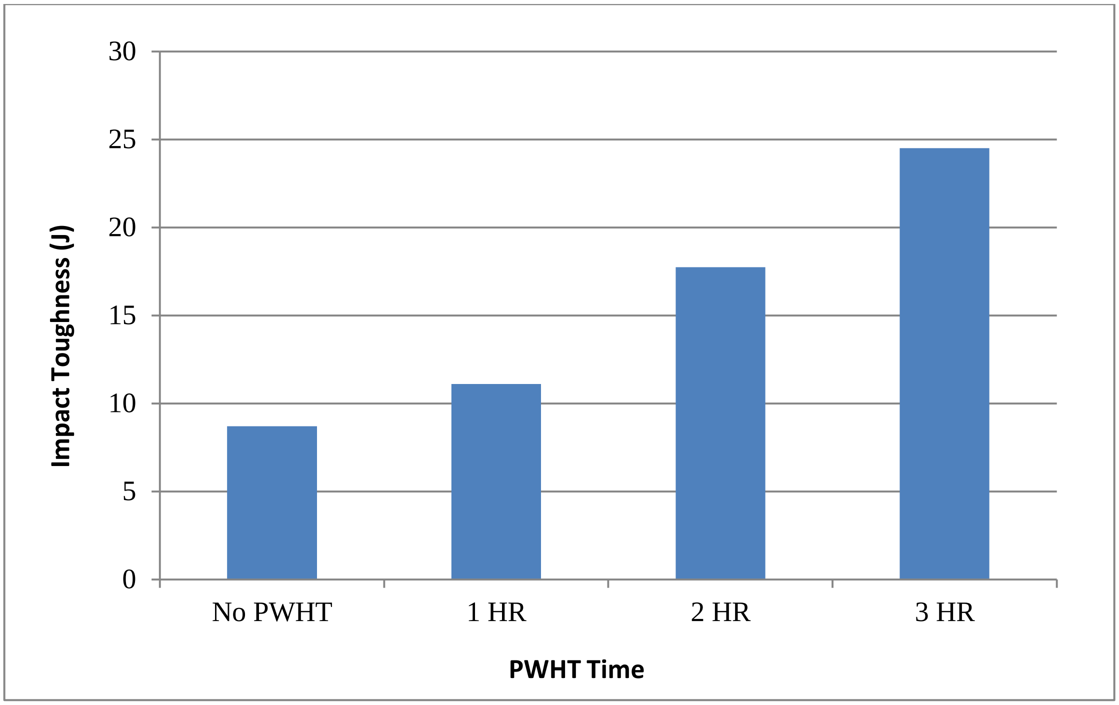


FIGURE 4.2. Impact Toughness of Test Samples with different PWHT time

4.3 Microstructure Observation

Microstructure of all the joints was examined at different locations but the optical micrographs taken at weld metal region and heat affected zone (HAZ) alone have been displayed in figures below. The microstructure at the weld metal region before and after heat treatment was observed using optical microscope as shown in FIGURE 4.4. It is observed that the grain boundaries of weld metal are increasing with increasing post weld heat treatment time which can increase the hardness of metal. This explains why the hardness and impact toughness of test sample annealed for 3 hours with 500^{o}C is the highest at the weld metal. The increase in post weld heat treatment time arranges the microstructure from course columnar grain to fine columnar grain. This in turn reduces the residual stresses. It can also be observed from the microstructure observation that there are gas holes in the weld area. This gas holes are often formed due to poor welding which can reduce the impact toughness of the welded joint.

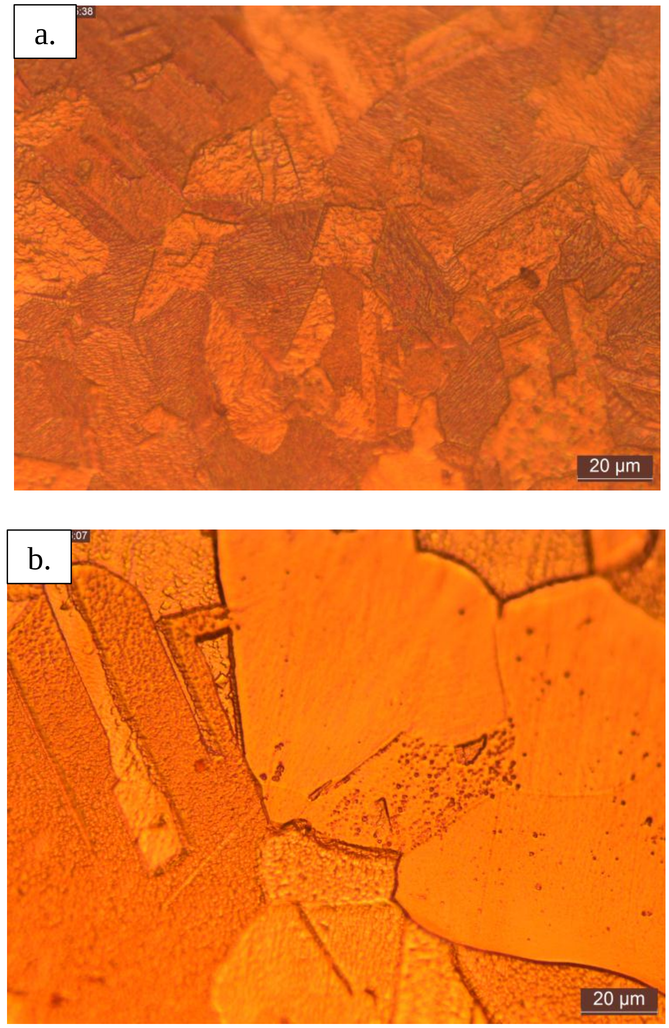


FIGURE 4.3. Microstructure of copper alloy (base metal) (a) before welding (b) after welding without heat treatment

Based on the microscopic observation as shown in FIGURE 4.3 the grain size has elongated after welding compared to before the copper alloy is welded. This is due to the high heat energy applied during welding. The elongated grain size in the base metal close to the weld metal region will increase the residual stresses. During solidification of the molten pool of weld metal the grains will apply forces on surrounding grains to maintain the original position and arrangement. Thus, the elongated grain size at the region close to the weld metal will increase the residual stresses in the joint.

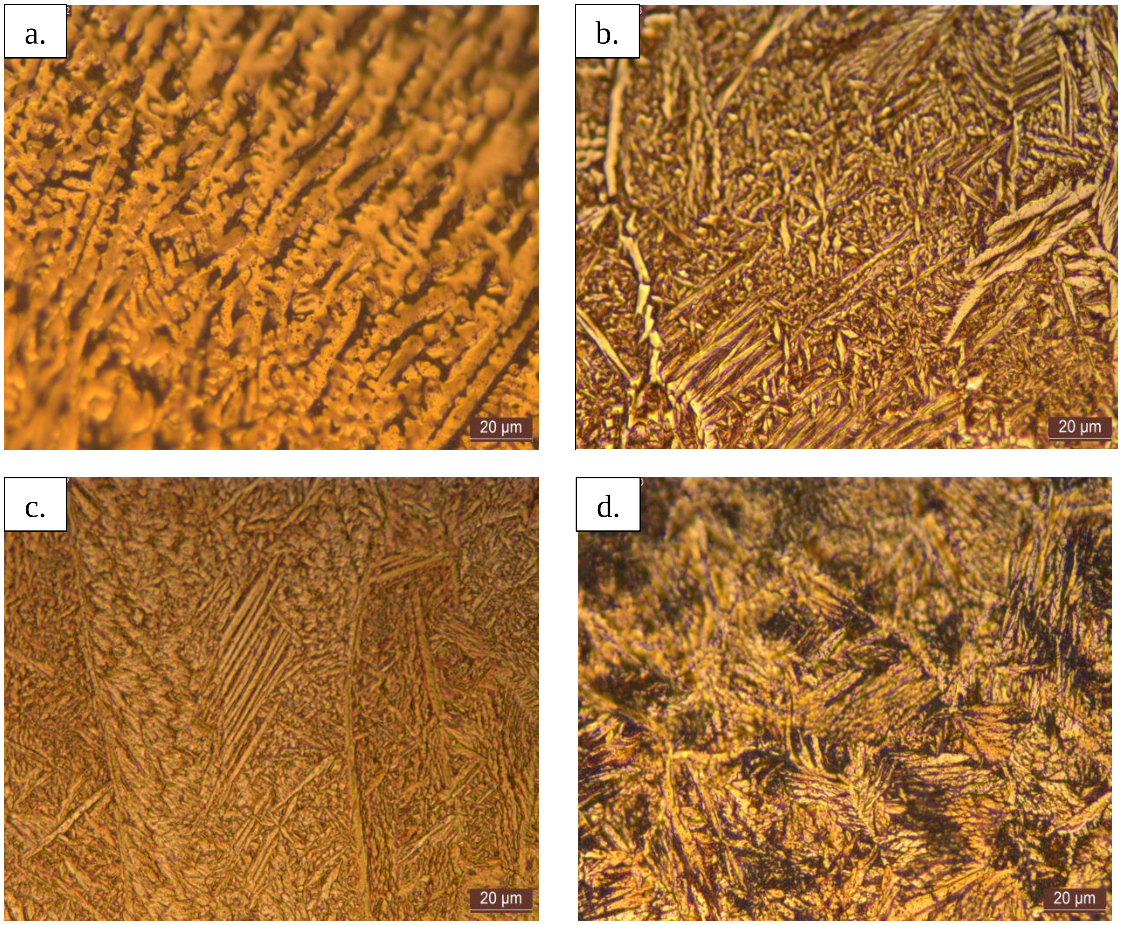


FIGURE 4.4. Microstructure of GMAW welded copper alloy at weld metal region (a) without heat treatment (b) 500 ℃ for 1 hour (c) 500 ℃ for 2 hour (d) 500 ℃ for 3 hour

FIGURE 4.4 shows that grain boundaries increases from the test sample without heat treatment to test sample annealed for 3 hours under 500℃. Starting from FIGURE 4.4 (b), (c) and (d) a Herringbone shape can be observed in the optical micrograph. The inclinations of the Herringbone shaped grains indicate the region with high heat exposure. With increase in post weld heat treatment it can be observed that the course columnar grain in FIGURE 4.4 (a) transforms into fine equi-axed grains starting from FIGURE 4.4 (b), (c) and (d).

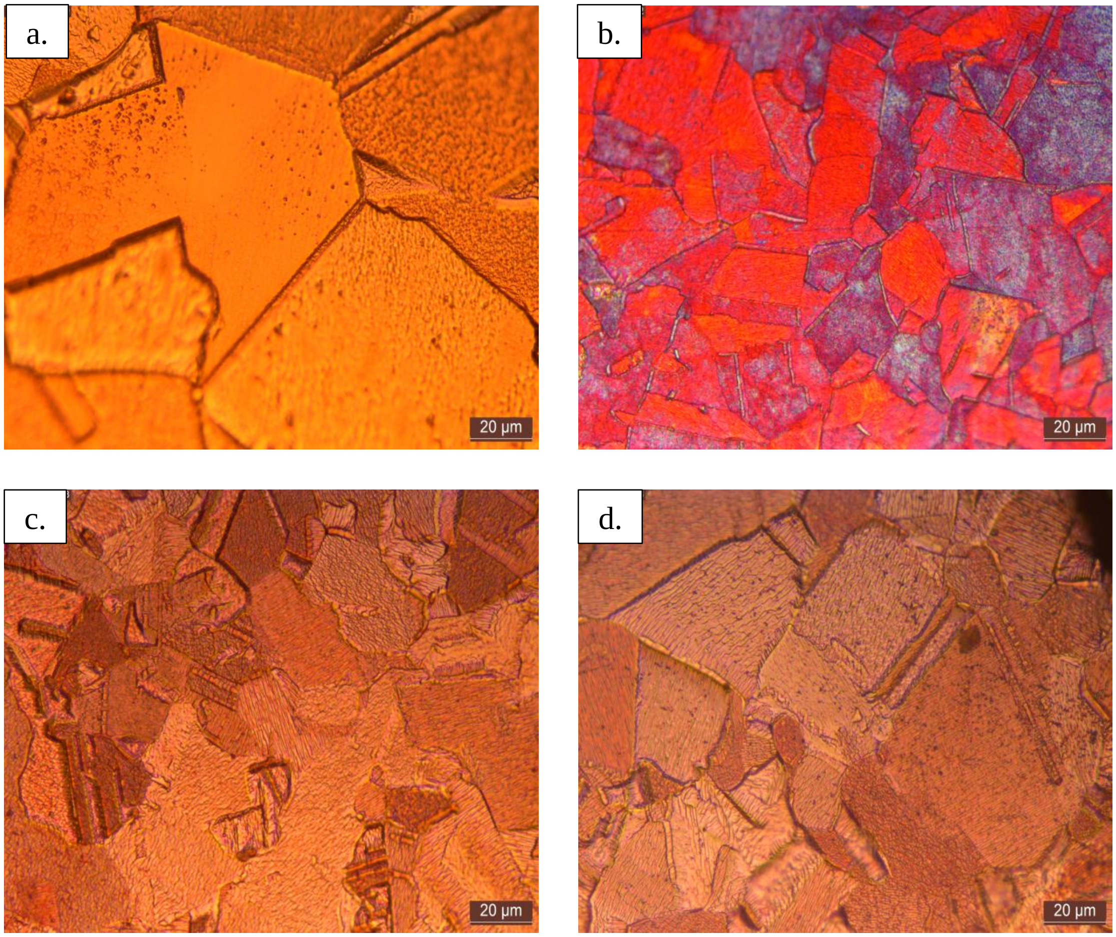


FIGURE 4.5: Microstructure of GMAW welded copper alloy at HAZ (a) without heat treatment (b) 500 ℃ for 1 hour (c) 500 ℃ for 2 hour (d) 500 ℃ for 3 hour

FIGURE 4.5 show the changes in microstructure at the heat affected zone for no post weld heat treatment, heat treatment for 1 hour, 2 hours and 3 hours respectively. The figures above show more on migration of grain boundaries at the HAZ which happen at 1 hour, 2 hours and 3 hours under 500^{o}C. This arrangement of microstructure shows why the hardness profile for test sample annealed for 3 hours under 500^{o}C is generally lower at the heat affected zone. It can be observed from the microstructure images above that the microstructure becomes smaller when it undergoes PWHT for 1 hour compared to when it is not heat treated as in FIGURE 4.5 (a). This is because the microstructure is undergoing recrystallization and after 1 hour the microstructure start to increase in PWHT for 2 hours and 3 hours.

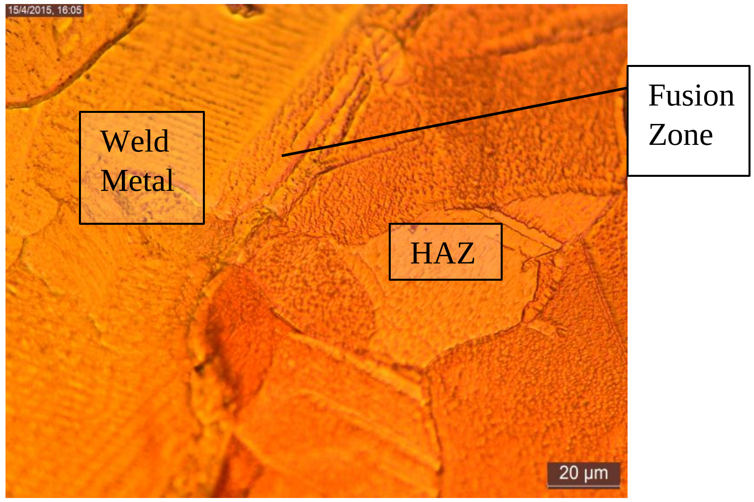


FIGURE 4.6. Different regions at the welded joint

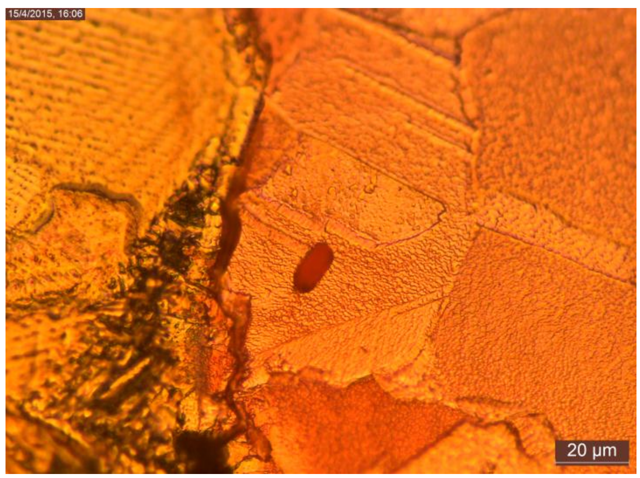


FIGURE 4.7. Discontinuities between the base metal and the weld metal

In FIGURE 4.6 different regions at the welded joints are shown. Figure 4.7 shows the discontinuities than occurred during the sample preparation between the base metal and the weld metal. Based on the observation in FIGURE 4.7 it can be seen that there are several region where the fusion between the base metal and weld metal did not occur perfectly and this can be classified as a welding defect known as crack. This defect however did not affect the impact test or hardness test result of this experiment because this test sample was only used for microstructure test.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In conclusion, using the methodology outlined in this experiment the effect of time during post weld heat treatment on the mechanical properties of copper alloy has been studied accordingly. Copper aluminum also known as aluminum bronze was chosen as a representative for copper alloys in this study. This alloy is chosen because it is most suitable to be welded with gas metal arc welding (GMAW) technique. It is possible that the results may vary slightly for different types of copper alloy however the fundamental will remain the same. It is concluded from this experiment that the impact strength of copper alloy will increase with the increase in time during post weld heat treatment. This relation is closely governed by the phase diagram of the material. From the results obtained from the hardness test it is observed that the hardness at the weld increases with increasing post weld heat treatment time. However the hardness at the HAZ does not improve with increase in post weld heat treatment time. Based on the observation of the microstructure at the weld area and HAZ it is clear that the grain boundaries increase with increase in post weld heat treatment time which in turn reduces the residual stresses. It can also be observed that grain growth has occurred with increase in time during post weld heat treatment which improves the microstructural arrangement of the grains to fine equi-axed grains. This shows that the mechanical properties of copper alloy can be improved with increasing post weld heat treatment time. In order to obtain a more accurate result some modifications can be made in the above experiment. One of the ways is to use a base metal which has the same composition as the weld metal. It is also very important to perform welding with minimal defect to ensure that the result is accurate and not influenced by external factor.

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