B. TECH. PROJECT REPORT

On

Study on the effect of processing parameters on microstructural and mechanical properties of CMT Welded AA6063.

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DISCIPLINE OF METALLURGICAL ENGINEERING AND MATERIALS SCIENCE

INDIAN INSTITUTE OF TECHNOLOGY INDORE

December 2019

Study on the effect of processing parameters on microstructural and mechanical properties of CMT welded AA6063 joints.

A PROJECT REPORT

Submitted in partial fulfillment of the
requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
In

METALLURGICAL ENGINEERING AND MATERIAL SCIENCE

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December 2019

CANDIDATE’S DECLARATION

We hereby declare that the project entitled **“Study on the effect of processing parameters on microstructural and mechanical properties of CMT welded AA6063 joints”** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in ‘Metallurgical Engineering and Materials Science’ completed under the supervision of **Dr Jayaprakash Murugesan, Assistant Professor, Dept. of MEMS, IIT Indore** is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student(s) with date

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Signature of BTP Guide(s) with dates and their designation

Preface

This report on "Study on the effect of processing parameters on microstructural and mechanical properties of CMT welded AA6063 joints" is prepared under the guidance of Dr Jayaprakash Murugesan, Assistant Professor, Dept. of MEMS, IIT Indore.

Through this report, we have tried to give a detailed description of the study and experiments we have done with different processing parameters and conditions using CMT welding on AA6063 and try to cover every nuance of its properties by getting microstructural and mechanical properties of the weld.

We have tried to the best of our abilities and knowledge to make the report descriptive and self-explanatory.

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Acknowledgments

We wish to thank Dr Jayaprakash Murugesan who really pushed us to our limits and believed in us, exposes us with the research work and for providing us with all the necessary amenities and continuous support during our study.

We would also like to thank Mr Ankit Singh, Mr Mahesh Patel along with the whole research team of Advance Welding Lab for their help and support. We would like to extend our sincere gratitude to all the staff members of Central Workshop, IIT Indore for their technical support when needed.

Without their valuable efforts and guidance, this report would not have been possible.

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Abstract

Cold Metal Transfer (CMT) welding is a modified MIG welding process based on the short-circuiting transfer process. The CMT machine detects a short circuit which sends a signal that retracts the welding filler material, giving the weld time to cool before each drop is placed, resulting in a drop-by-drop deposit of weld material. However, the technique can be modified or combined with suitable add-ons to give better weld properties such as using Forced cooling, Vibrator, and cooling and vibrations simultaneously with CMT welding to give better weld properties. In this study, different processing parameters were varied such as the current and feed rate to obtain the best possible weld characteristics like weld bead appearance, microstructure features and mechanical properties named tensile strength and hardness. Using the optimized parameters, forced cooling using a copper backing plate with and without water circulation, effects of Vibrations and using both in combination on weld properties are studied. Aluminium alloy (AA6063) was joined with using $AlSi_5$(ER 4043) filler wire in CMT welding. Microstructural characterization was done using an optical microscope. Comparing the optimized weld parameters to find the best possible tensile strength and hardness was done. The use of forced cooling assisted welding significantly improves the weld properties. This was related to the development of smaller grains and a more homogenous distribution of the strengthening particles as forced cooling was applied. A device was used to supply vibration during cold metal transfer welding of AA6063. The application of vibration was found to increase the weld depth and weld reinforcement and decrease the contact angle. It also results in the development of smaller grains and a more homogeneous distribution of grains. This grain refining led to the increment of hardness and toughness. The results are discussed based on the microstructural features observed and mechanical properties measured.

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CHAPTER-1

Introduction, Problem Definition and Objectives

1.1. Introduction: Cold Metal Transfer welding is a modified MIG welding process based on the short-circuiting transfer process developed by Fronius of Austria in 2004. This process mostly works in short circuit (dip transfer) transfer mode which is defined by low current and voltage which signifies low heat input[1]. The important difference of CMT from the conventional GMAW is the full digital control of the welding process. The microcontroller controls the feeding of the wire for the CMT process through the feed motors, no longer dependent on the electrical characteristics[2]. An initial high pulse of current is formed which formed an arc between the advancing electrode and the substrate that melt the electrode tip[3]. The current is reduced following the pulse, as soon as a short circuit is indicated, the voltage reduces, the current is further reducing to a low background value and the wire is retracted, which leads to detachment of the molten droplet[4]. Thus, this process is named CMT due to the metal transfer takes place when the current is very low[5]. Figure 1 shows the different CMT phases. During welding, temperature variation in welds and parent metals have important effects on material characteristics, residual stresses as well as on dimensional and shape accuracy of welded products[6]. There are two main features of the CMT process: one is at the point of short circuit with low current corresponding to low heat input, another is the short circuit occurrence in a stable controlled manner.

The CMT process is characterized by the innovative solution for the weld drop detachment. Unlike in a conventional pulsed arc, the droplet is notched by a current impulse, rather it is a defined rearward motion of the welding wire which brings about controlled droplet detachment as shown in the figure below.

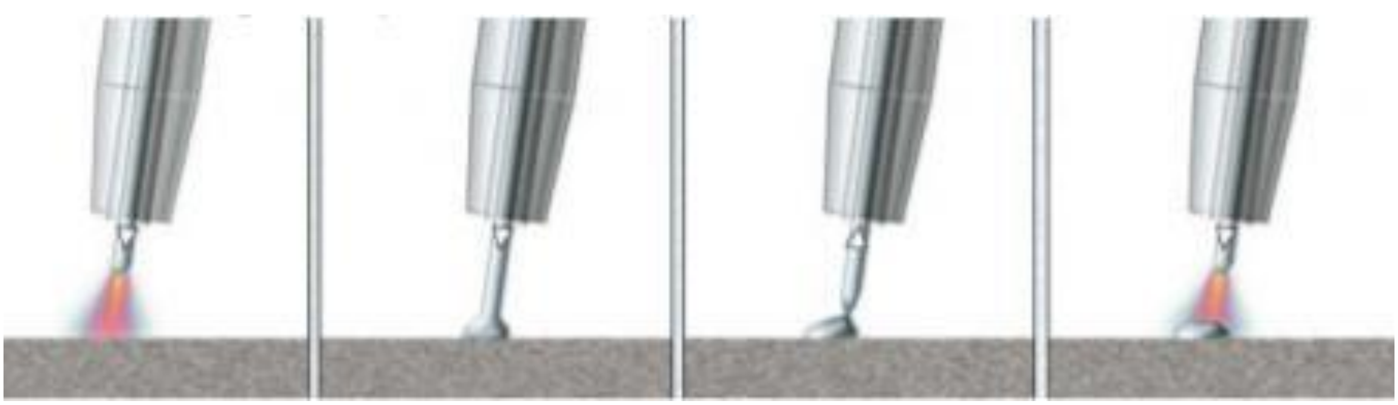


Figure 1.1: Different CMT phases, a) arc ignition b) Short circuit phase c) inversion of wire feed direction d) arc re-ignition, adapted from Rodrigues Pardal (2016).

In Figure 1.1 are represented the different phases that characterize this process:

- During the arcing period, the filler metal moves towards the weld-pool.
- When the filler metal dips into the weld-pool, the arc is extinguished. The welding current is lowered.
- The rearward movement of the wire assists droplet detachment during the short circuit. The short-circuit current is kept small.
- The wire motion is reversed and the process begins all over again[7].

As mentioned above, Cold Metal Transfer Welding is one of the potential welding processes with low heat input welding. Of course, the term "cold" has to be understood in terms of a welding process: when set against conventional GMAW, CMT-GMAW is indeed a cold process with its characteristic feature of alternating thermal arc pool, i.e. hot when an arc is initiated and cold when the arc is extinguished and the wire is retracted [8].

Different terms associated with welding[9]:

- Alternating Current - With alternating current, amplitude and polarity change cyclically. Welding power sources are operated on a single or three-phase alternating current grid and usually supply direct current for welding.
- Aluminium - This is a light metal that is silvery-white in color. Its distinguishing features include corrosion resistance, electrical conductivity, and low weight.
- Anode - An anode is a pole that receives electrons or the pole to which the electrons flow. For welding, this is therefore always the positive pole.
- Arc - The arc burns during welding between the electrode and the workpiece. Due to its high plasma temperatures, it fuses the parent material and melts away the filler metal.
- Arc characteristics - The arc characteristic indicates the relationship between the arc voltage and the arc current.
- Arc length - The arc length refers to the distance between the point where the arc touches the wire electrode until the point of reaching the workpiece. The voltage is a characteristic dimension for the arc length.
- Arc welding - In arc welding, an electric arc (welding arc) burns between the workpiece and electrode. Depending on the welding process, this can melt and act simultaneously as the filler metal or be non-consumable.
- Butt Joint - Butt joints are used to join workpieces positioned on the same plane, that is, at an angle of 180 degrees to one another.

- Cathode - The cathode is the negative pole in the welding circuit.
- Cleaning Effect - The cleaning effect in aluminum welding means the destruction of the aluminum oxide layer. This process is caused by the positive polarity of the tungsten electrode (during TIG welding).
- CMT (Cold Metal Transfer) - It is a dip transfer welding process where the heat input is kept very low. Due to the reversing wire movement, the CMT process has a completely new type of droplet detachment. This leads to significantly improved dip transfer arc characteristics. CMT Advanced is a variant of the CMT welding process. A cyclical change in polarity of the welding current takes place in the short circuit phase, in conjunction with the reversing wire movement. This additional degree of freedom allows the heat input to be reduced again.
- Corrosion - Corrosion describes a reaction of a material with its environment, which causes a measurable change in the material and can impair the function of a component or system. In metals, chemical corrosion is particularly significant. The best-known type of chemical corrosion in metals is rust, that is, the oxidation of iron.
- Cracks - Cracks are weld seam faults that occur under tensile stresses. The two main groups are cold and heat cracks.
- DC Voltage - DC voltage is an electrical voltage where the polarity does not change.
- Degassing - Degassing refers to the escape of gases from liquid material during the welding process.
- Direct Current - Direct current is an electrical current where the amperage and polarity do not change.
- Efficiency - The efficiency describes the relationship between the power input and power output. Examples include the electrical efficiency of a welding system or the thermal efficiency of the arc.
- Electrical Current - Electrical current is the directed movement of negatively charged charge carriers (electrons). The unit of measurement is an ampere (A). The formula symbol I describe the quantity of current that flows through a line within a given time period. In order for current to be able to flow, it requires an electrical voltage.
- Electrical Voltage - The electrical potential difference is referred to as voltage and is between the positive and negative pole.
- Electrode - The rod electrode is a coated metal rod that is used for electrode welding. It acts both as a conductor for the arc and the filler metal at the same time. A distinction is made between basic (B), rutile (R), and cellulose (Cel) coating types.
- Electrode holder - Secures the rod electrode during manual welding and allows the current to be transferred to the electrode.
- Fusion - Fusion indicates the mixture percentage of the parent material with the weld layer applied.

- Gas pre-flow - The gas pre-flow is a way to obtain better shielding gas cover at the start of welding. A fixed period of time is defined here during which the gas solenoid valve should open before welding starts.
- Grounding cable - The grounding cable is the current return cable in the welding circuit. It is secured to the component.
- Grounding Clamp - The grounding clamp is a quick-release mechanical connection between the workpiece and the current-return cable in the welding circuit.
- Heat input - Heat input refers to the energy that is introduced into the component during welding. The heat input is calculated based on the electrical energy input per wield, reduced by the total efficiency.
- Inert Gas - Inert gases are non-reactive noble gases. They are used in metal inert gas welding (MIG) and tungsten inert gas welding (WIG). Inert gases include argon, helium, and mixtures of these.
- Intermediate Arc - The intermediate arc is characterized by a coarse droplet, short-circuited droplet transfer. The advantages include positional freedom and relatively deep penetration. In contrast, however, is the increased spattering.
- Inverter - Inverting means transforming. This concerns converting DC into AC current and vice versa. In the case of the inverter power source, the transformer is driven by a very high frequency, whereby the volume of the transformer can be kept extremely low. This reduces the weight and the power source is mobile. In addition to direct current, inverters can also generate sinusoidal and square wave alternating current for special requirements.
- Joining - Joining is the permanent connection of two or more materials. Some of the most important joining processes include welding, brazing, bonding, riveting and screwing.
- Lack of Fusion - Lack of fusion occurs if there is no secure join between the weld metal and the parent material.
- Mechanical Properties - The mechanical properties of parent material or a welded joint act as the basis in the static calculation for supporting structures. They are crucial for choosing the parent material and filler metals to be used. Mechanical properties are hardness, tensile strength, impact energy, toughness, etc.
- Open Circuit Voltage - This is the voltage that is applied to the welding sockets prior to welding, for example from the ignition of the rod electrode.
- Outgassing - Outgassing refers to the escape of gases from liquid or solid material during the welding process.
- Oxide Film - Aluminum forms a protective layer that is called an oxide film. The oxide film has a destructive effect during welding and must be broken up. This is done during TIG welding with

alternating current (AC). The melting point of the oxide film is approximately 2100°C, in contrast to aluminum that has a melting point of approximately 660°C depending on the alloy.

- Oxide formation - Surface scaling is called oxide formation. This occurs especially during the manufacturing of steel or slightly in the case of poor shielding gas cover.
- Penetration - Penetration refers to the depth of the melted zone in the parent material.
- Pore Formation - Pore Formation refers to the gas inclusions in the weld seam. Pore formation is a welding fault that is caused by contamination or insufficient shielding gas cover.
- Power Source - The function of a welding power source is to convert a high input voltage into low welding voltage and high welding current. There are different types of models, whereby the controlled type inverters have mostly established themselves.
- Preheating - With preheating, the components are heated up and then kept at a specific temperature in order to influence the cooling speed during welding.
- Reversed Polarity Ignition - A reversed polarity ignition is a polarity reversal of the tungsten electrode to the positive pole in the ignition phase, in order to achieve a more accurate and stable ignition.
- Robotic welding - In robotic welding, an industrial robot guides the welding torch within a pre-programmed track.
- Shielding Gas - Shielding gas refers to a gas or gas mixture that is designed to suppress the air in the earth's atmosphere during welding. Shielding gases influence the penetration form, penetration, and welding speed and need a corresponding characteristic during MIG/MAG welding.
- Short Circuit - If during MIG/MAG welding, the wire electrode or during SMAW, the rod electrode hits the surface of the material, this produces an electrical short circuit. This must be overcome at the start of welding and broken up during continuous welding by means of a short circuit treatment.
- Slag-Rod electrodes have a coating that melts away in the arc and partially vaporizes. It forms shielding gases and slag. The slag protects the weld metal from the atmosphere and rapid cooling speed covers the weld seam and must be removed after cooling. Certain flux core wires contain a welding powder that also forms a slag when it melts.
- Slag Inclusions - Slag inclusions are weld seam faults caused by fixed inclusions made up of slag residues that were not washed to the surface. They affect the strength of the connection.
- Thermal Conductivity - Thermal conductivity is a material value that describes how well a material conducts heat. Materials with high thermal conductivity are difficult to weld and need a special welding start treatment (e.g., aluminum) or require a high preheating temperature (e.g., copper).

- Virtual Welding - Virtual Welding is a welding simulator that allows beginners and experts alike to learn and improve their welding torch skills in a way that is realistic, safe, and conserves resources. Different welding tasks can be practiced with MIG/MAG, TIG, and electrode welding.
- Welding Equipments - Welding equipment consists of different tools, such as faceguard, welding gloves, wire brushes, chipping hammers, electrodes, and grounding cables.
- Welding Filler Metals - The welding filler metals melt during the welding process and form the weld seam. The selection of welding filler metals is primarily dependent on the parent material and the use of the component. The corresponding characteristic must be selected in a material-specific and diameter-dependent way in MIG/MAG welding.
- Welding Torch - The welding torch consists of a handle with connections, controls, valves, and replaceable gas nozzles. It is connected to the power source by a hose. The welding torch is used to transfer the welding current, and to transport the gas and the filler metal to the workpiece.
- Wire Retraction - Wire retraction withdraws the currentless filler metal from the liquid weld pool after the welding process is complete.

1.2 Problem Definition: The growing demand for the CMT joining for lightweight design which provides sufficient strength while remaining light in weight such as in automobiles where fuel consumption can be brought down by decreasing the weight. There is a need to develop new techniques or at least improvement in the existing technologies. Among different material, iron-based and aluminium-based alloys are the most significant materials which find its applications in various industries. However, for joining these materials a reliable or a sort of credible welding technique for industrial applications is yet to be established.

CMT welding with very low heat input, wherein heat-affected zone is reduced as compared to conventional MIG welding is ideal for aluminium joints. Other than that it also has some advantages like stable arc, spatter free, high welding speed, improved weld quality, increase in manufacturing and efficiency.

Using CMT welding with additional equipments such as forced cooling and vibrator can further improve the weld quality which is being investigated in this study.

1.3 Literature review:

- Zhang et al. and Cao et al. concentrated on the application of the process in dissimilar alloys joining owing to the low heat input, which restrains the formation of brittle intermetallic compounds.
- Kumar et al. (2016) claimed that the width of the heat-affected zone (HAZ) decreases using CMT welding. However, there are some defects such as porosity in welded joints of Al alloys fabricated by the CMT process.
- Taghavi et al. (2009) reported that vibration has an influence on the metal solidification process.
- Chen et al. (2016) reported that the use of vibration treatment reduces the formation of coarse grains in the welding of TiAl alloy.
- Atamanenko et al. (2010) reported that vibration can refine the microstructures of Al alloys.
- Kanemaru et al. (2012) developed TIG-MIG hybrid welding process, in which the TIG and MIG arcs were established respectively between electrode and steel plate by employing two independent power sources.
- Shuhei Kanemaru et al (14) studied weld bead appearance of butt welded joint of similar material and point out MIG arc is stable in Ar gas atmosphere in presence of TIG torch and shows the effect TIG torch on the depth of penetration.

1.4 Research gap:

- Limited studies were found on the Effect of CMT welding with different cooling rates and with vibrations on hardness, tensile strength and microstructure of weld bead.
- Studies are found where vibrations in CMT welding are used but using vibrations in addition with forced cooling is yet to be studied.
- The study on the effect of change in vibration frequency on weld properties is yet to be studied.

1.5 Objectives of the Project:

1.5.1 To study the joining of aluminium alloy (AA6063) by CMT welding and

1) To investigate the effect of process parameters like:

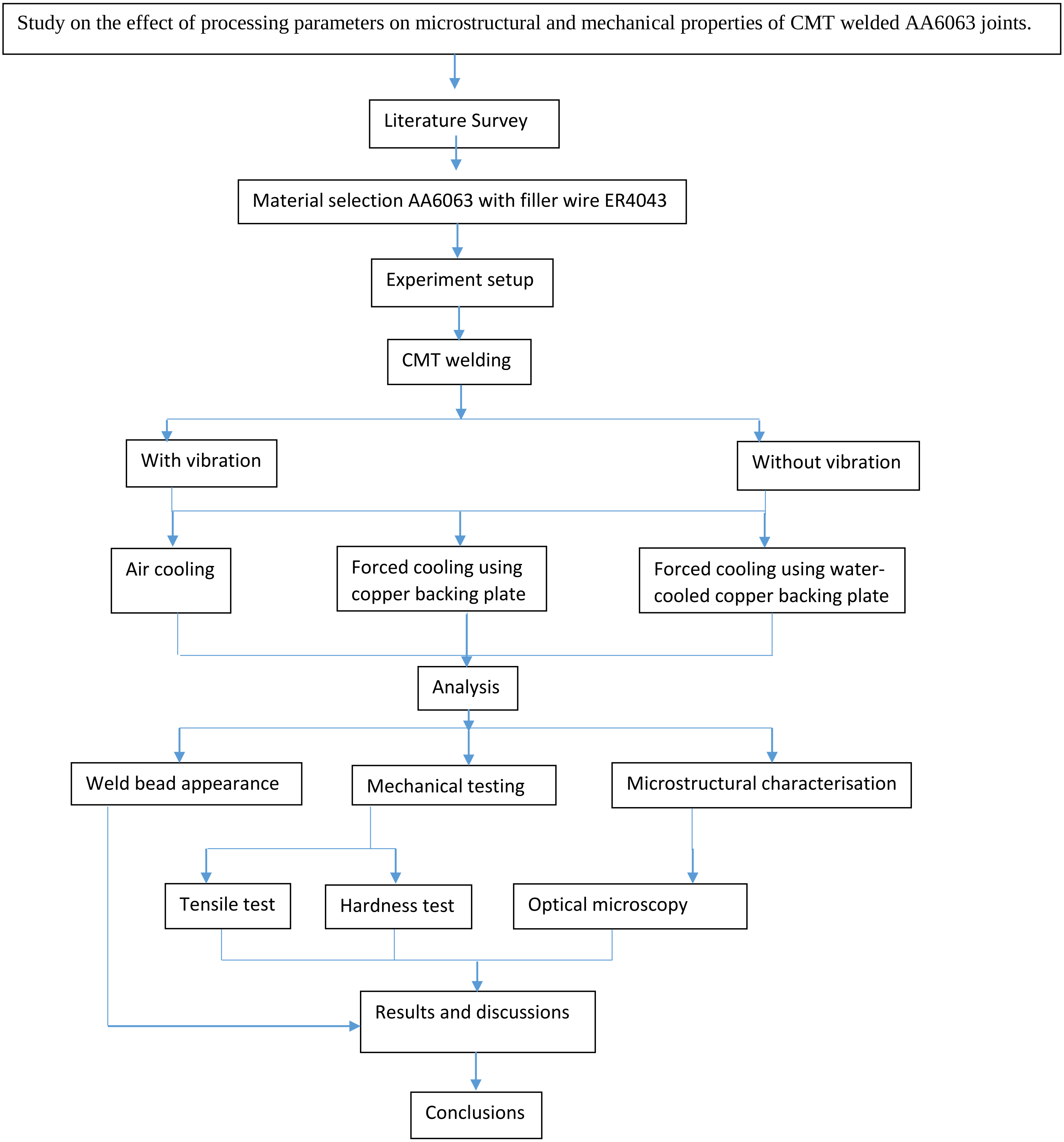
- Welding heat input.
- Effect of forced cooling by using a water-cooled copper backing plate.
- Effect of cooling by copper block.
- Effect of vibrations by using a vibrator.

2) On the weld properties like:

- Microstructure.
- Weld bead appearance.
- Mechanical properties (Tensile strength and hardness).

1.5.2 To compare the techniques based on the quality of the weld joint produced by optimizing the parameters on the above techniques with forced cooling and vibrations.

1.6. Experiment plan flowchart:



CHAPTER-2

Experimental Methodology

The material used in the experiment is AA6063 and Filler used is AlSi5 (ER4043).

Material properties:

Table 2.1. Material properties of the material used.

MATERIAL	TENSILE STRENGTH	MELTING POINT
AA6063	241 MPa	616°C
ER4043 Filler wire	200 MPa	630°C

Composition (wt.%) of materials used in the experiment:

Table 2.2. Composition of the materials used.

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	C	S	P	Al
AA6063	0.2-0.6	0.35	0.1	0.1	0.45-0.9	0.1	0.1	0.1	-	-	-	Bal.
Filler wire (ER4043)	4.5-6.0	0-0.8	0-0.3	0-0.05	0-0.05	-	0-0.1	-	-	-	-	Bal.

The etchant used in the experiment:

The samples were etched using Keller's solution (190ml water, 2ml HF, 3ml HCl and 5ml HNO3) was used [10].

2.1. Experimental Setup:

We have made a water-cooled copper backing plate to force cool the welded sample to study the effects which it brings in mechanical properties and microstructural features.

Welding equipments: In this experiment, the aluminium alloy and galvanized steel were joined using CMT welding robot. The CMT robot used is KUKA KR 10 R1420 and for welding controller FRONIUS MAGIC WAVE 190 FRONIUS TRANSSTEEL 2200 were used respectively.

2.1.1. CMT Welding: Cold Metal Transfer (CMT) welding is a modified MIG welding process based on the short-circuiting transfer process. The CMT machine detects a short circuit which sends a signal that retracts the welding filler material, giving the weld time to cool before each drop is placed, resulting in a drop-by-drop deposit of weld material.

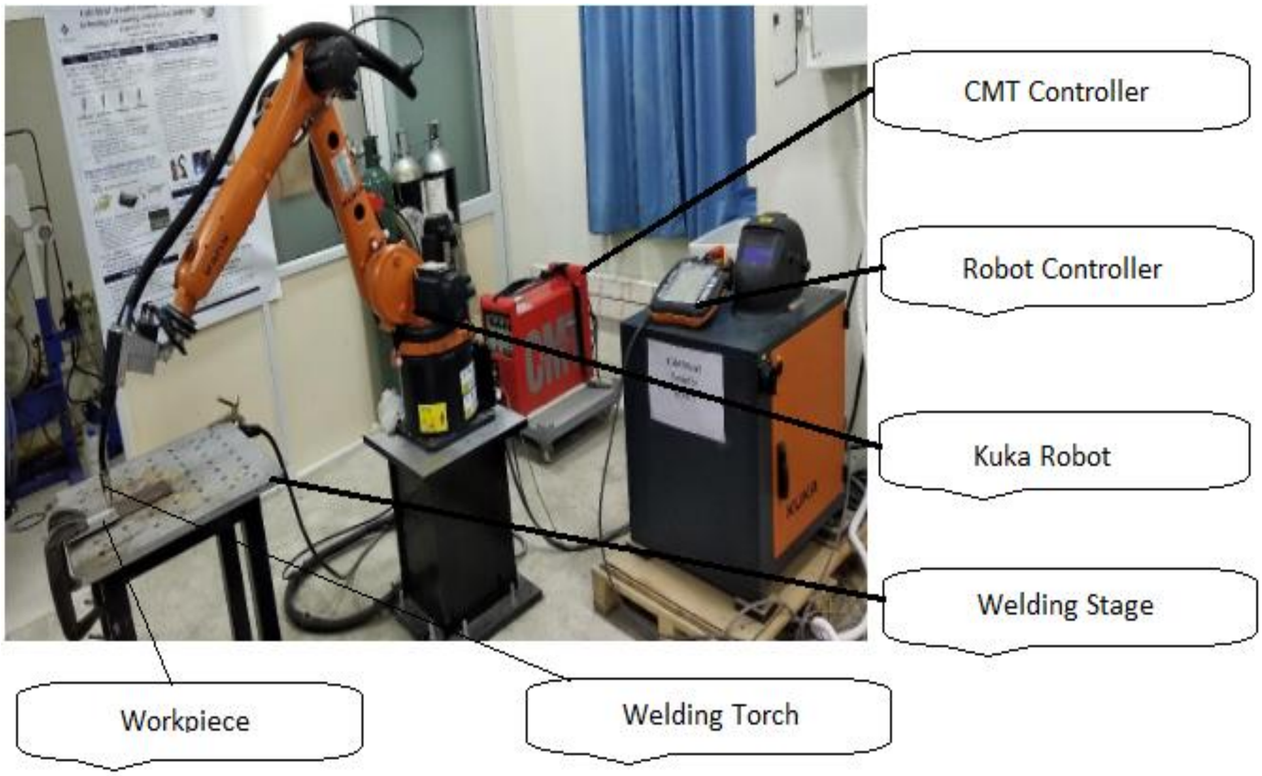


Fig. 2.1. CMT equipment on a robot.

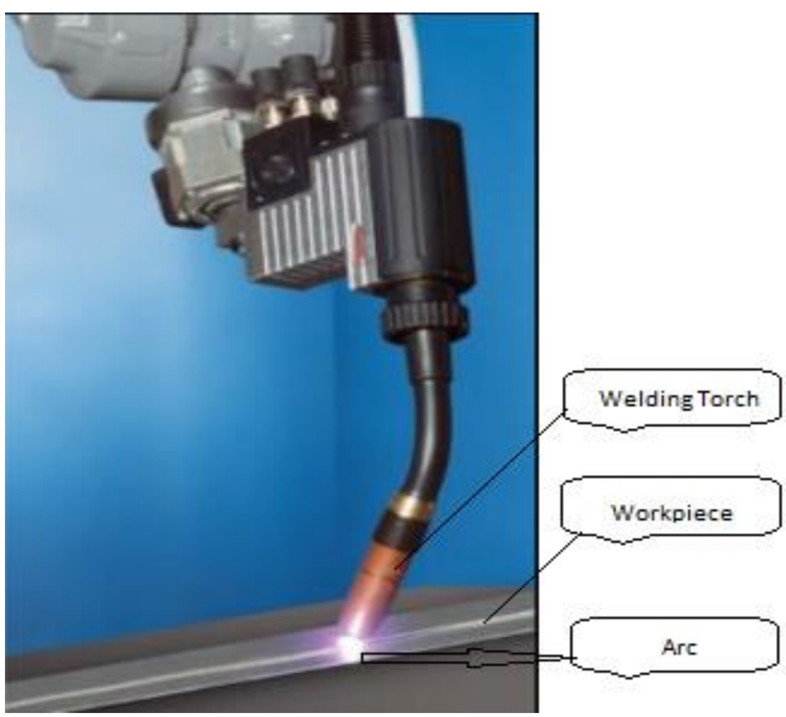


Fig. 2.2. CMT torch.

2.1.2. Water-cooled copper backing plate: A setup for CMT welding with a water-cooled copper backing plate is made. First, we cut the solid copper in the shape of a cuboid. Then we drill two holes along the length. Water through holes continuously flows is made. Water is driven by a motor from a water reservoir. Copper is used because of its higher thermal conductivity. The copper plate serves as a welding platform for the welding. Material is placed over the copper plate to provide the cooling effect while welding the materials so that the weld joints are cooled at a faster rate.

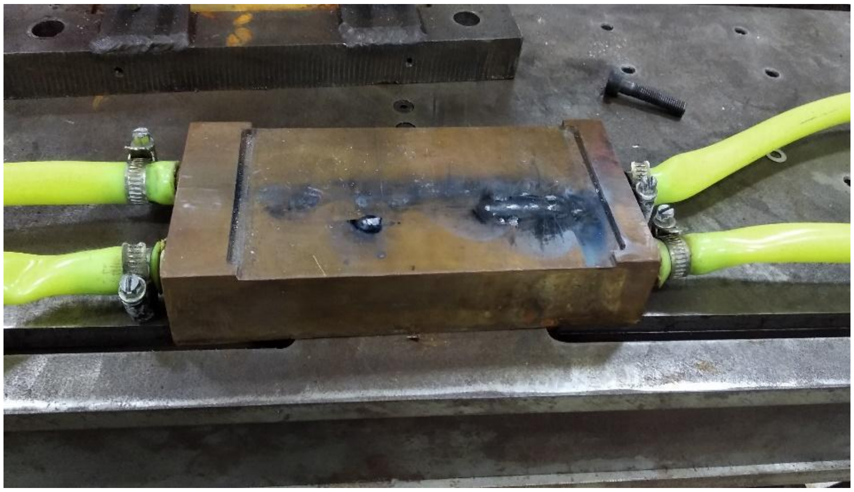


Fig. 2.3. Water-cooled copper backing plate.

2.1.3. Vibrator: We have made a setup for vibrator because it is known that it refines grain size due to multiple nucleations of grain during the shaking of the weld pool. Grain refinement will cause an increase in hardness and toughness both. The density of the weld bead is increased and we will get sound weld properties[11].

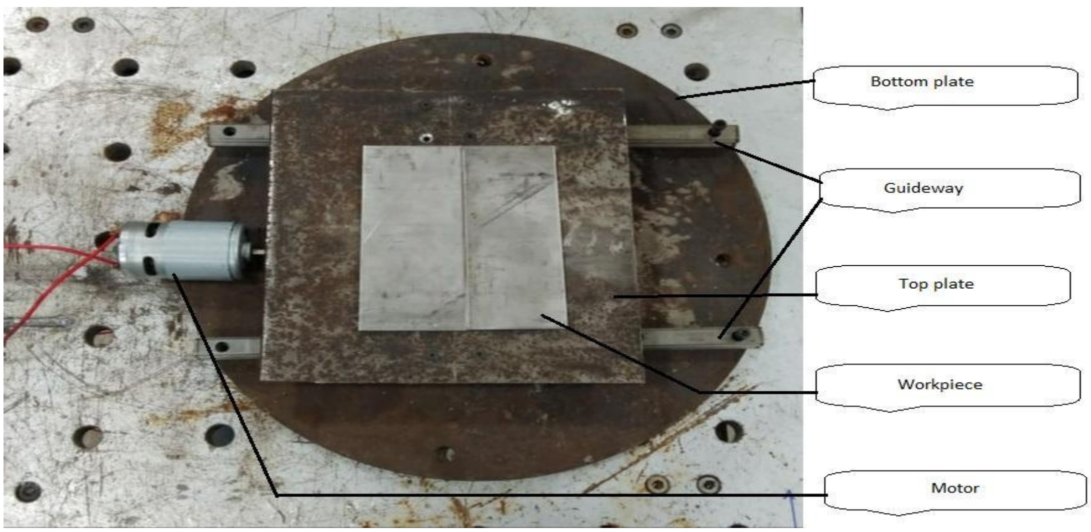


Fig. 2.4. Vibrator

Small grain size will provide more hindrance as compared to large grains. It is due to a large number of grain boundaries per unit area. Consequently, dislocations pile up at the grain boundaries and generate internal stresses. Due to this, a large force has to be applied to cause material flow.

2.2. Experimental procedure: First the samples of size 140mm x 60mm x 3mm were cut from the sheet of aluminium alloy AA6063 using the shearing machine. Then these plates were cleaned by wire brush to remove any dirt or oxide film then followed by cleaning with acetone. These plates were then placed in butt joint configuration for similar metal with V-groove in between and welding was done along the 140mm dimension. Finally, CMT welding of the AA6063 with AA6063 was done. Repetitive welding was performed by changing the various welding parameters.

The joints then were analyzed first based on weld bead appearance. Observations included continuity of weld bead appearance and wettability.

Microstructural characterization was done on the cross-section of the welded sample. The sample's cross-section was cut using Hand Hacksaw. The microstructural characterization includes the use of an inverted optical microscope [12].

The weld cross-section cut was mounted and then polished by Emery paper of grades P100, P220, P500, P800, P1000, P1500, P2000, P2500 and finally with velvet cloth with diamond paste. Then the samples were etched using two etchants, for aluminium side Keller's solution (190ml water, 2ml HF, 3ml HCl and 5ml HNO3) was used for 20 seconds.

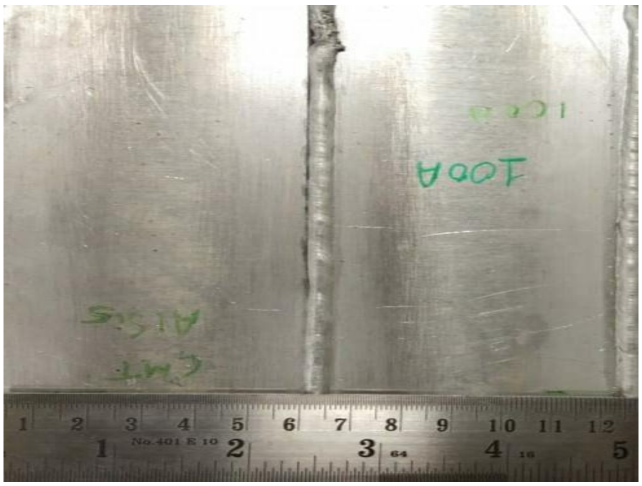
CHAPTER-3

Results and Discussions

Welded samples were analyzed using different methods. Visual inspection was done for weld bead appearance and microstructural analysis was done using Optical microscope.

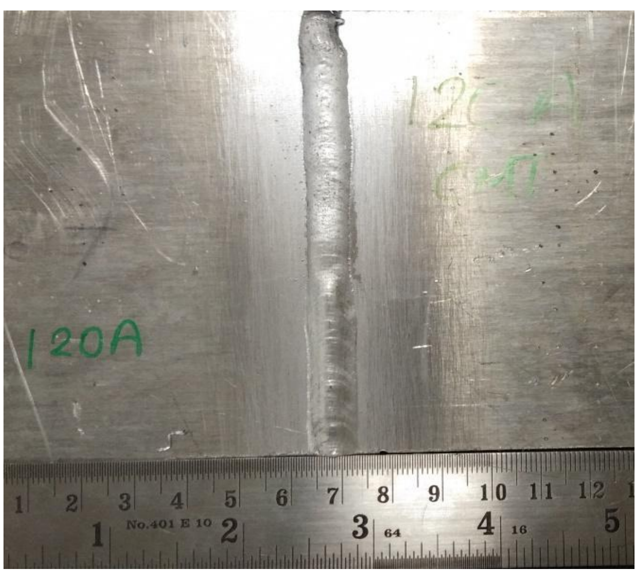
3.1. Weld bead appearance: A comparison was done to analyze the weld bead appearance of weld joints based on their appearance, wettability, weld coverage and spatter formation.

For Air-cooled welded samples:



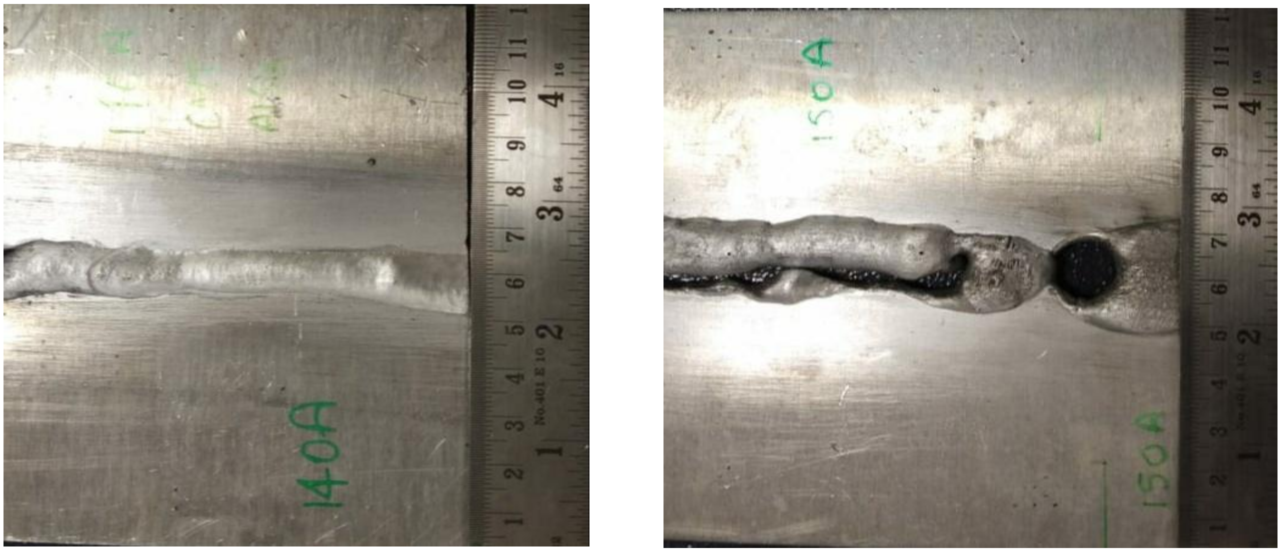
(a)

(b)



(c)

(d)

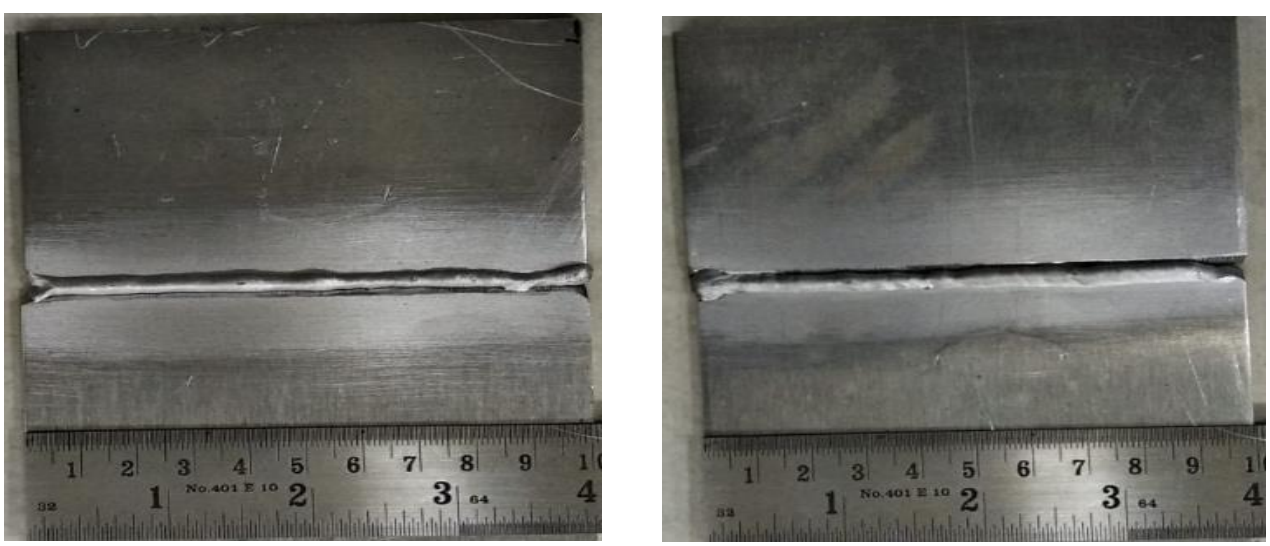


(e) (f) .

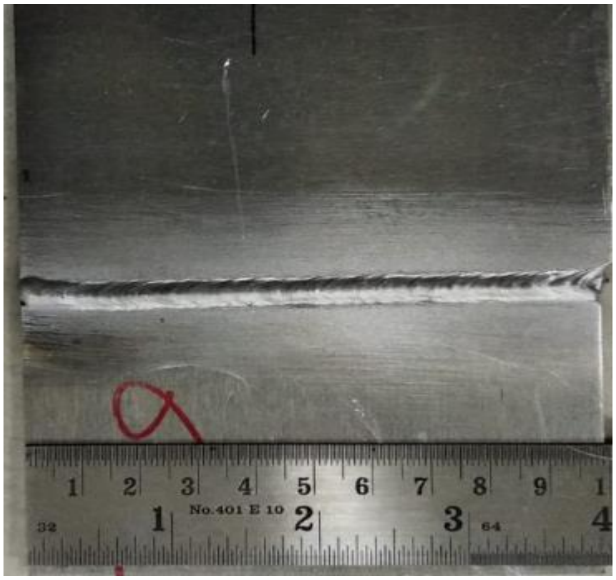
Fig. 3.1. Weld bead appearance of air-cooled samples at welding current - (a)100A, (b) 110A, (c) 120A, (d) 130A, (e) 140A and (f) 150A.

From visual inspection of weld images, we can see very less spatter or no spatter at all. As welding current or heat input is increased thickness of weld bead increases as can be seen in above figures. At 100A welding current, improper fusion takes place and weld coverage is very less. It can be seen that with increase in welding current, the weld penetration increases and high deposition is achieved [13]. The best weld bead can be seen at welding current 120A at which desired deposition without pores is obtained. With further increase in welding current extra deposition tends to take place and at 150A the base metal itself start burning and the metals could not be welded properly.

For weld samples cooled using copper plate:

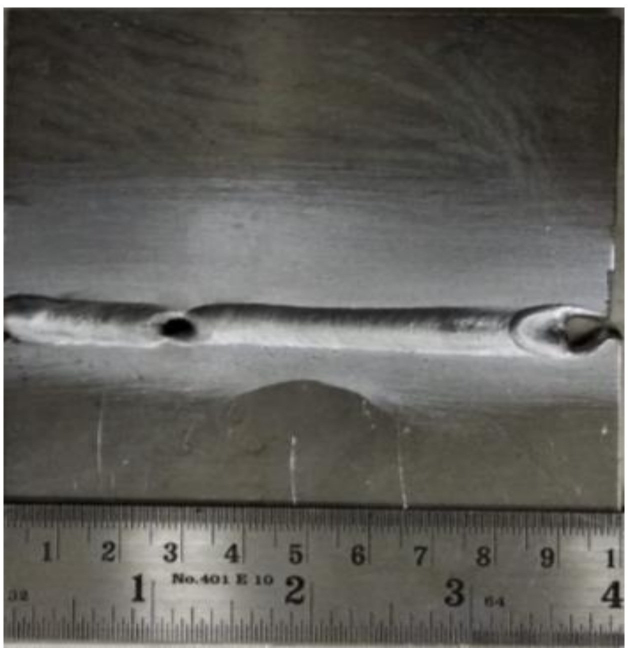


(a) (b)

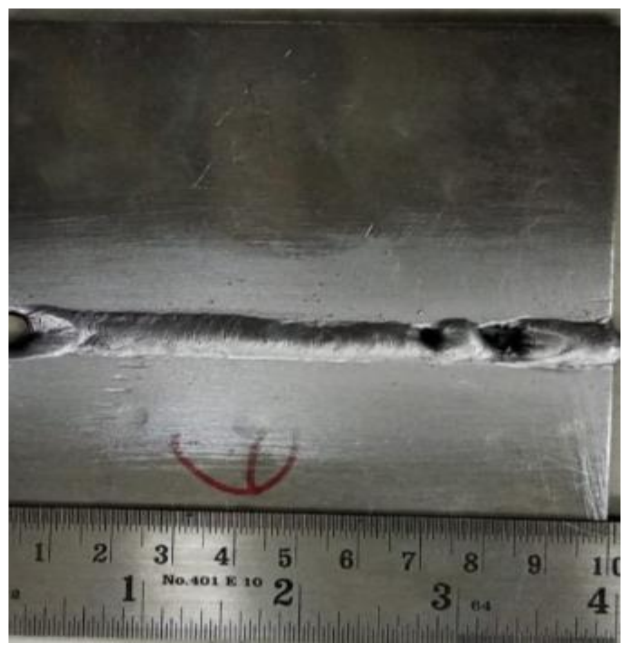


(c)

(d)



(e)

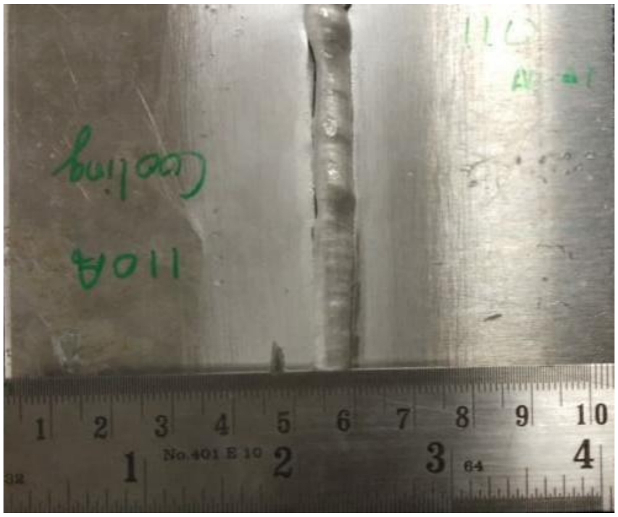


(f)

Fig. 3.2. Weld bead appearance of copper plate cooled sample at welding current - (a)100A, (b) 110A, (c) 120A, (d) 130A, (e) 140A and (f) 150A.

Similarly, from the above images, it can be seen that at lower welding current, improper fusion takes place with very less weld coverage and as the current is increased, the weld penetration increases and high deposition is achieved. The best weld bead can be seen at welding current 130A at which desired deposition without pores is obtained. This can be attributed to the extra heat extraction by copper plate which leads to faster cooling of the sample. The base metal starts burning at high welding currents.

For weld samples cooled using water-cooled copper plate:



(a)

(b)

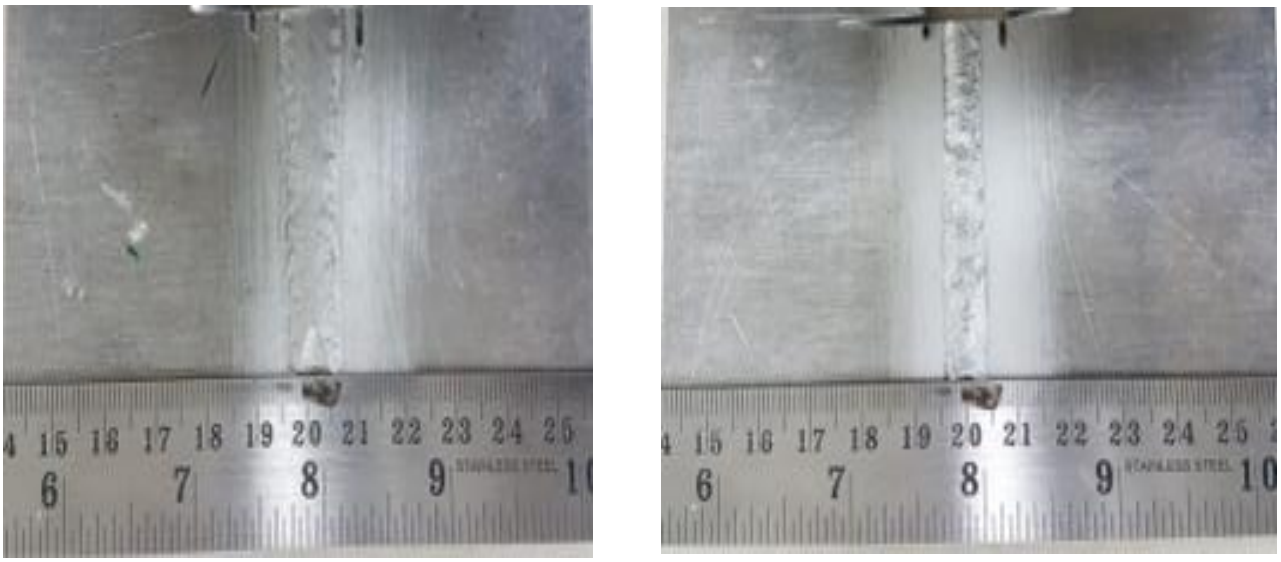
(c)

(d)

Fig 3.3. The weld bead appearance of the water-cooled copper plate cooled sample at welding currents – (a) 110A, (b) 120A, (c) 130A and (d) 140A.

In the above figures, it can be seen that at lower welding current, improper fusion takes place with very less weld coverage and as the current is increased, the weld penetration increases and high deposition is achieved. Further, increase in current lead to further increase in heat input and better fusion. Weld pool will have a high temperature in comparison to previous samples. High-temperature weld pool will take more time to get cooled down and due to high fluidity, weld bead will have proper coverage. The best weld bead can be seen at welding current 130A at which desired deposition without pores is obtained. This can be attributed to the extra heat extraction by copper plate which again is cooled using running water which leads to faster cooling of the sample. Further increase in temperature above optimum value melts the sample.

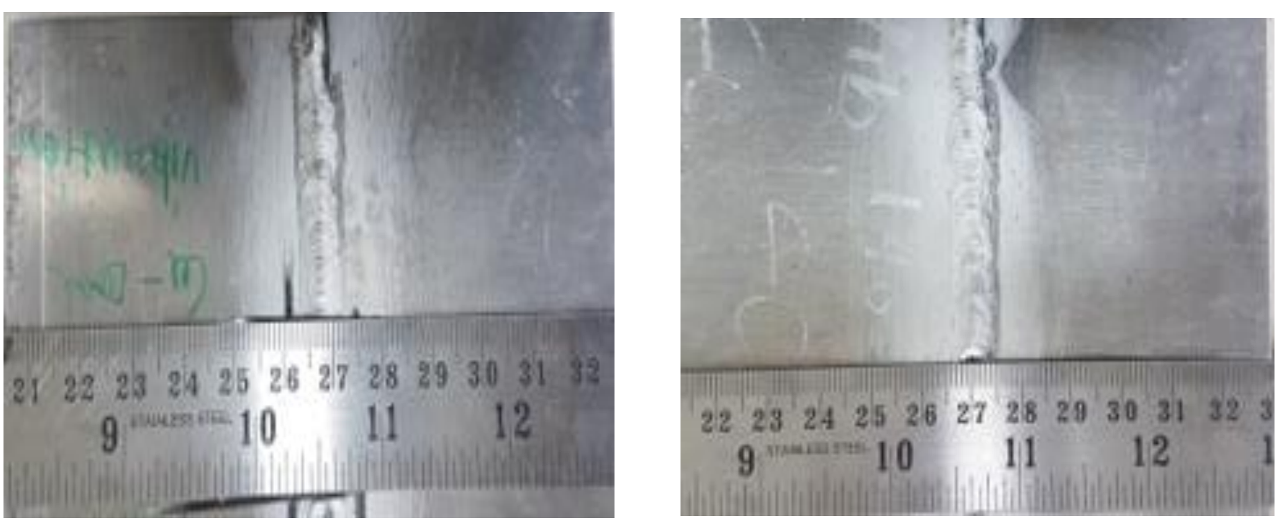
For vibration assisted air cooled welding:



(a) (b)

Fig 3.4. Weld bead appearance of samples air-cooled with vibration at different current - (a) 120 A and (b)130 A.

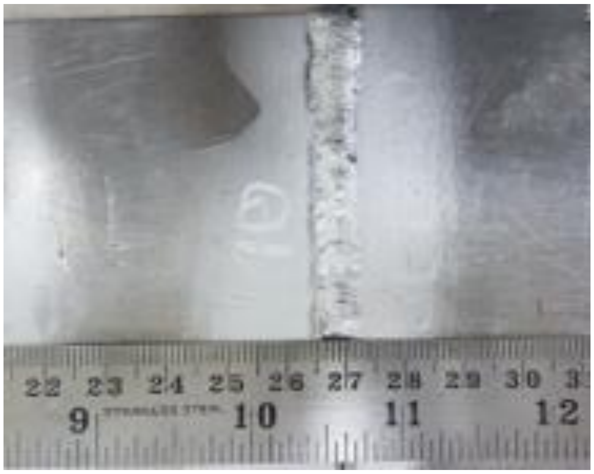
For vibration-assisted copper plate-cooled welding:



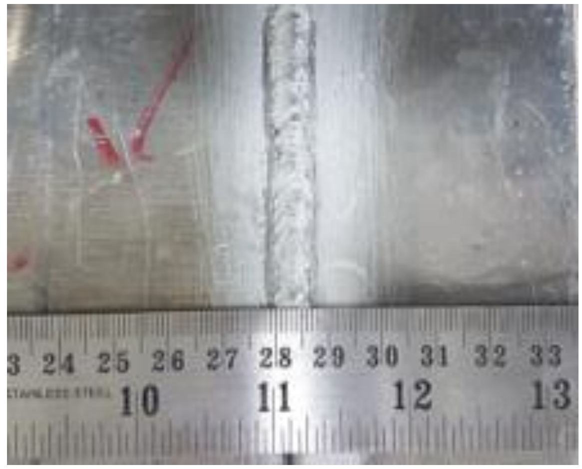
(a) (b)

Fig 3.5. Weld bead appearance of samples copper plate cooled with vibration at different current - (a) 130 A and (b)140 A.

For vibration assisted and water-cooled copper plate welding:



(a)



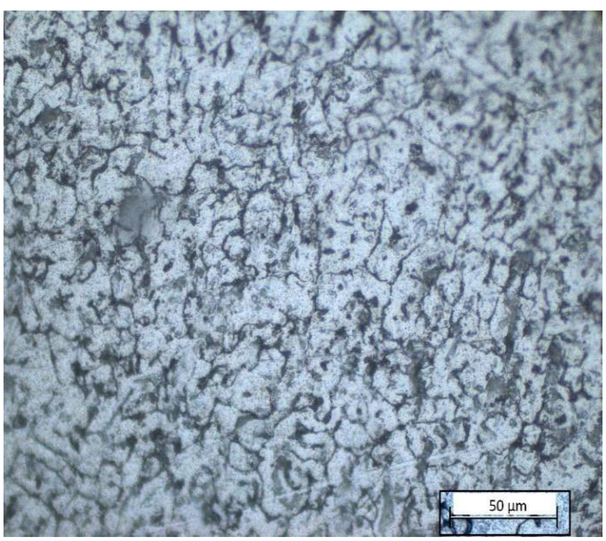
(b)

Fig 3.6. Weld bead appearance of sample by water-cooled copper plate cooling with vibration at different current - (a) 120 A and (b)130 A.

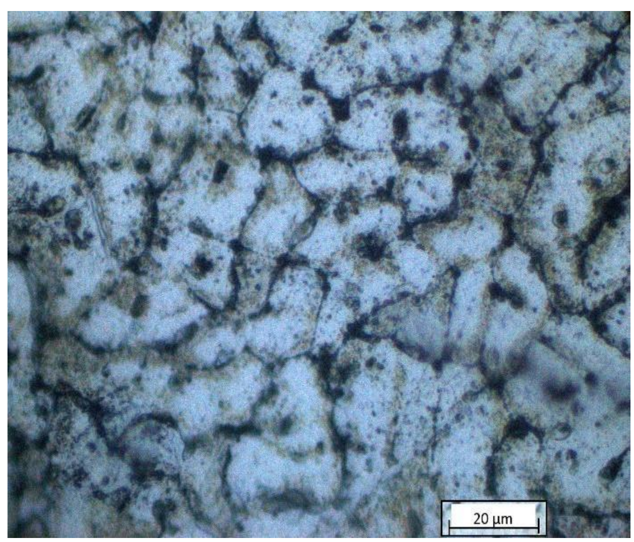
From fig. 3.4, fig. 3.5 and fig. 3.6, it can be observed that weld coverage is significantly improved when welding was assisted with vibrations. Also, weld penetration was improved and surface finish of the weld joint was better that those weld samples where vibrations were not used.

3.2. Microstructure analysis (Optical Microscope):

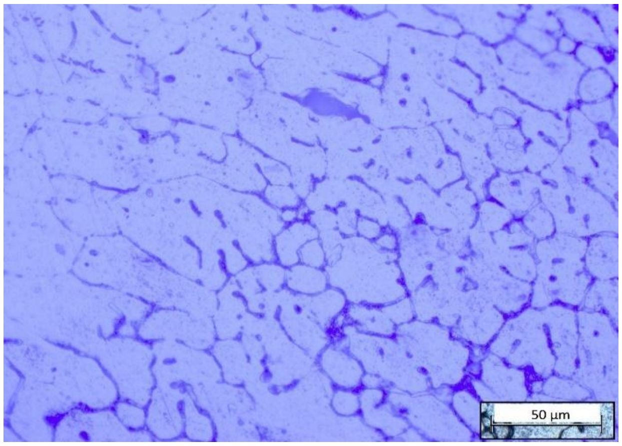
For air-cooled samples:

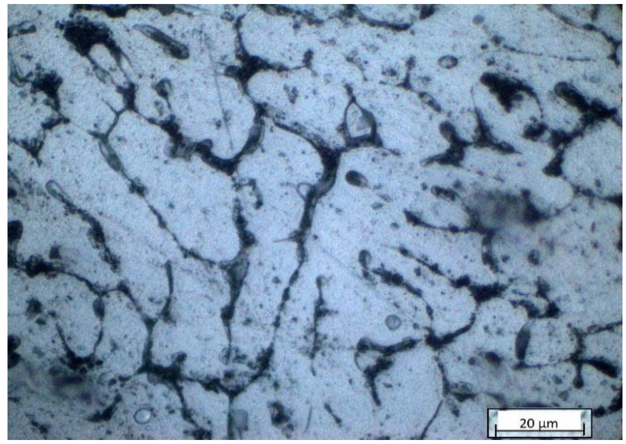


(a)

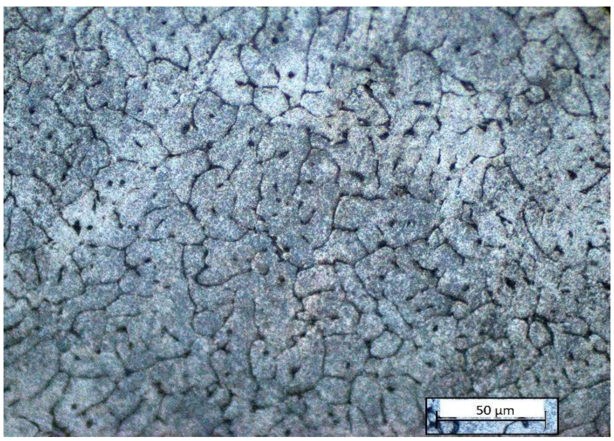


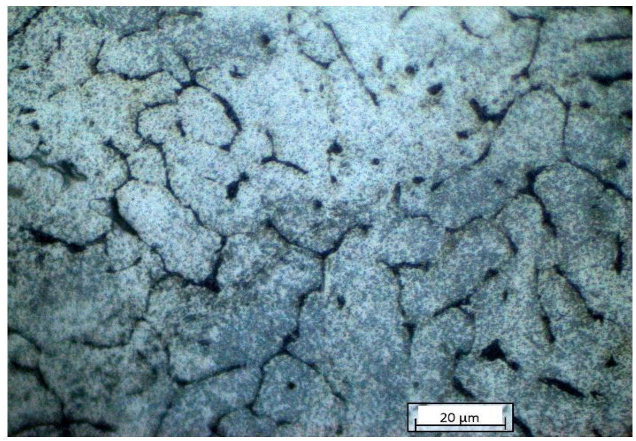
(b)



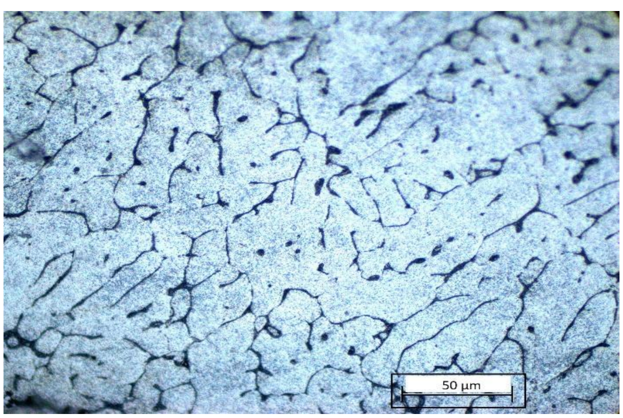


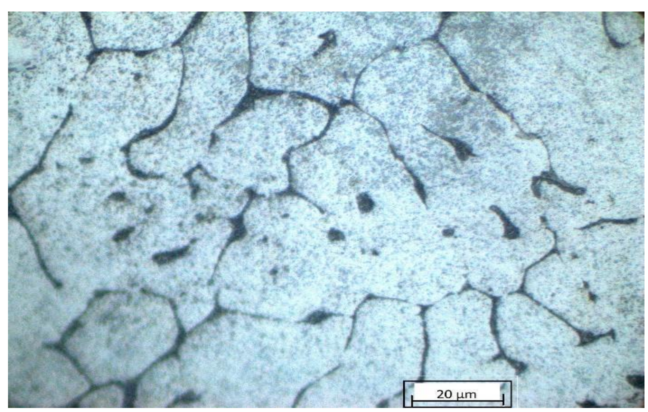
(c) **(d)**





(e) **(f)**





(g) **(h)**

Fig. 3.7. Shows the micrograph of the weld area of air cooled sample at welding current and magnification – (a) 110A 50X, (b) 110A 100X, (c) 120A 50X (d) 120A 100X, (e) 130A 50X, (f) 130A 100X, (g) 140A 50X, (h) 140A 100X.

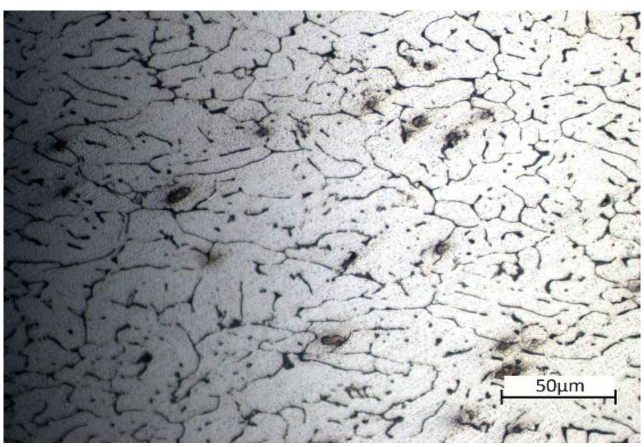
Grain size determination (by line intercept method): Calculation of grain size from the microstructure of the above weld zone. There is some columnar nature in the grains. The grain size is calculated by the line intersection method.

Table 3.1. The average grain size of the grains present in the weld zone at different welding currents in air-cooled samples.

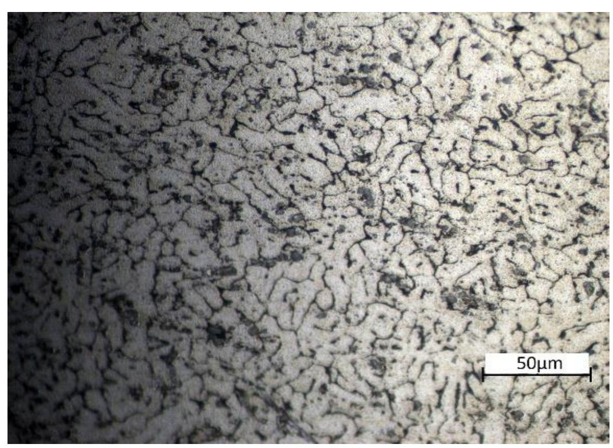
CMT Current (ampere)	Grain size (µm)		
	D1	D2	D(diameter of circle)
100	16.30	15.98	16.14
110	17.87	18.09	17.98
120	18.33	18.53	18.43
130	19.42	19.86	19.64
140	21.56	21.10	21.33

The above grain size table shows that with an increase in welding current, the average grain size of the fusion zone increases. This can be attributed to the increase in total heat input that increases with an increase in welding current. With the increase in heat input with current, the quantity of weld pool melted will increase with an increase in current. With the increase in heat input, the temperature of the weld pool will also increase which will further give more time for cooling. The weld pool which gets more time for cool will have a larger grain size than the other one.

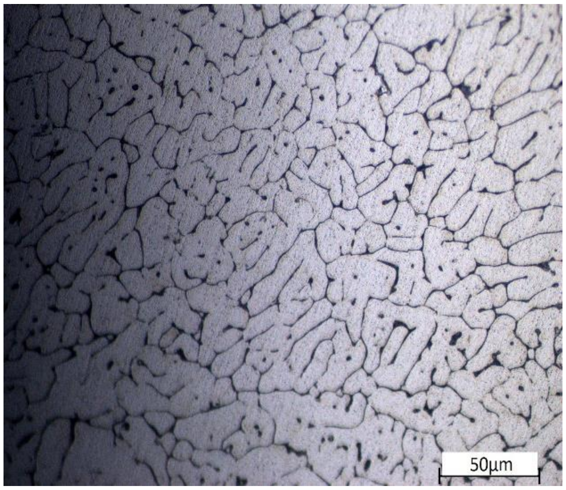
For weld samples cooled using copper plate:



(a)



(b)



(c)

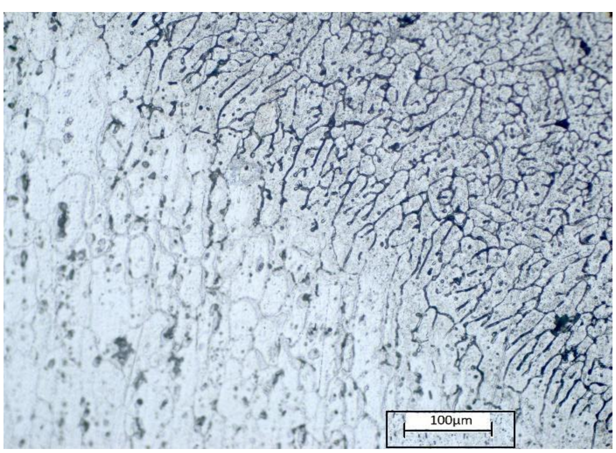
Fig.3.8. Shows the micrograph of the weld area of sample with copper plate cooling at welding current and magnification – (a) 100A 50X, (b) 130A 50X, (c) 160A 50X.

Grain size determination (by line intercept method):

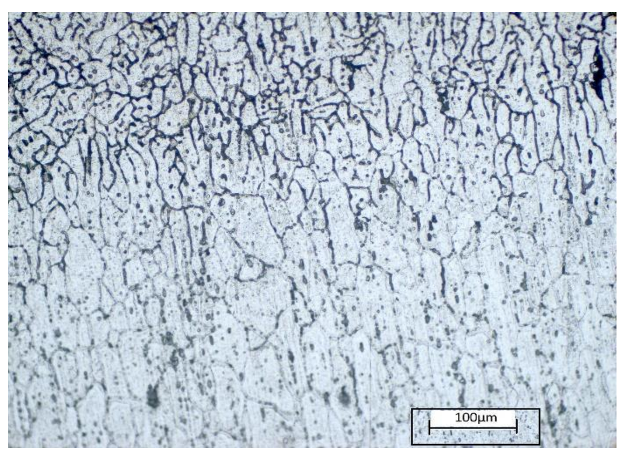
Table 3.2. The grain size of weld bead at different welding current in copper plate cooled samples.

Welding Current(A)	Grain Size (µm)		
	D1	D2	Average D
100	12.22	12.466	12.343
130	12.847	13.169	13.025
160	16.75	16.78	16.765

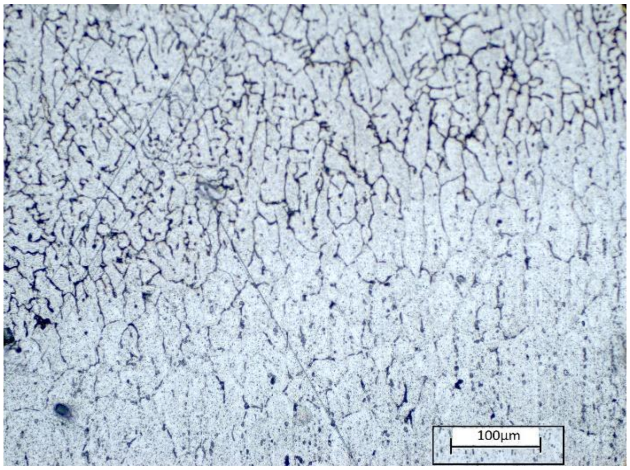
For weld samples cooled using water-cooled copper plate:



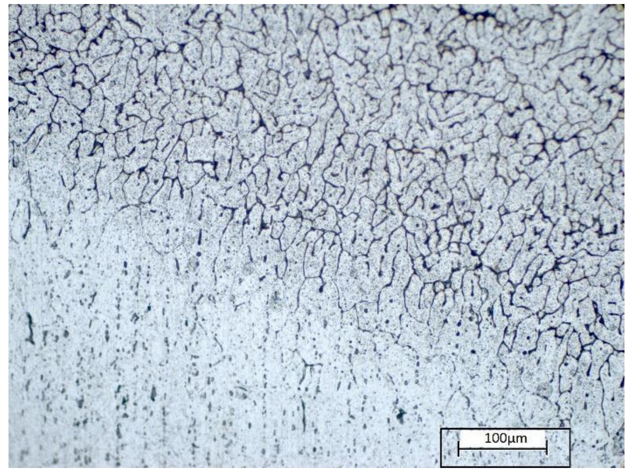
(a)



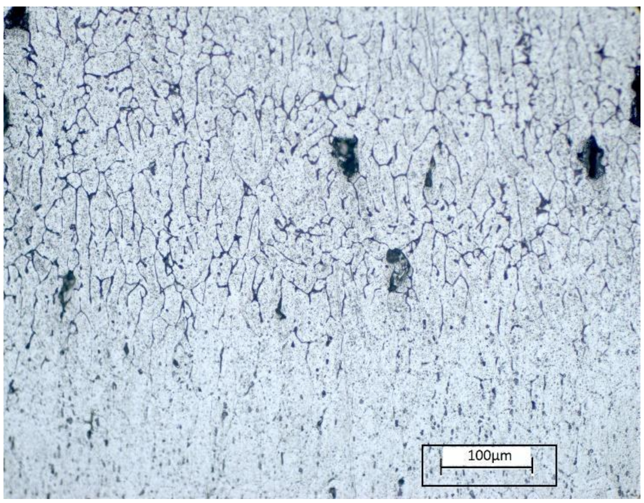
(b)



(c)



(d) .



(e)

Fig. 3.9. Shows the micrograph of the weld area of sample with water-cooled copper plate cooling at welding current and magnification – (a) 110A 50X, (b) 120A 50X, (c) 130A 50X, (d) 140A 50X, (e) 150A 50X.

In the above micrograph, it is visible that there is elongation in the grains of Heat affected zone as compared to the normal base metal and the increment is proportional to the increase in welding current.

Grain size determination (by line intercept method): The grains observed were columnar in nature. Grain growth is in the direction of weld speed. We observe some porosity in grain due to the presence of atmospheric gas.

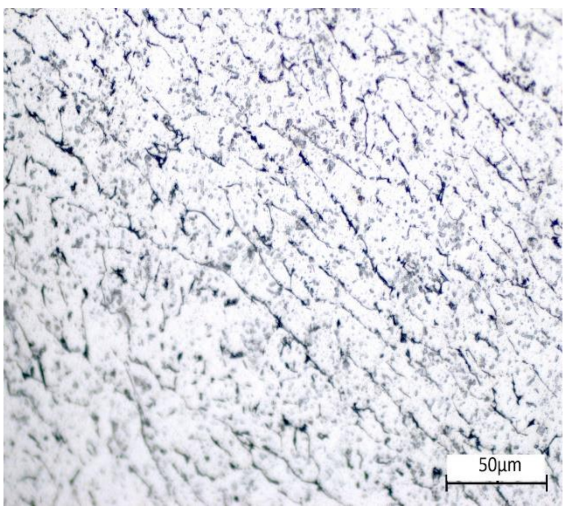
Table 3.3. The grain size of weld bead at different welding current in water-cooled copper plate cooled samples.

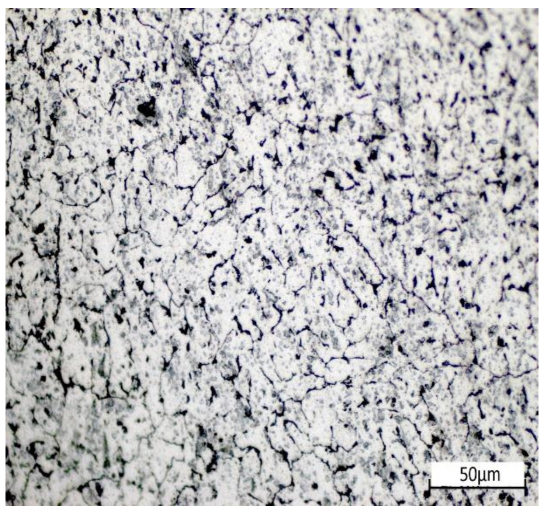
CMT Current (ampere)	Grain size (µm)		
	D1	D2	D(diameter of circle)
100	13.30	12.98	13.14
110	14.87	15.09	14.98
120	15.33	15.53	15.43
130	16.42	16.86	16.64
140	18.56	18.10	18.33

The grain size of weld bead in forced cooled sample in CMT welding is very slightly lower than the air-cooled sample but there is no significant decrease in grain size. This can be attributed to the already very less heat input in CMT welding.

The grain size of the best weld bead in the air-cooled sample is 22.67 µm at 120A. In forced cooled sample at 120A current is 22.43 µm.

For vibration-assisted air-cooled welding:





(a) **(b)**

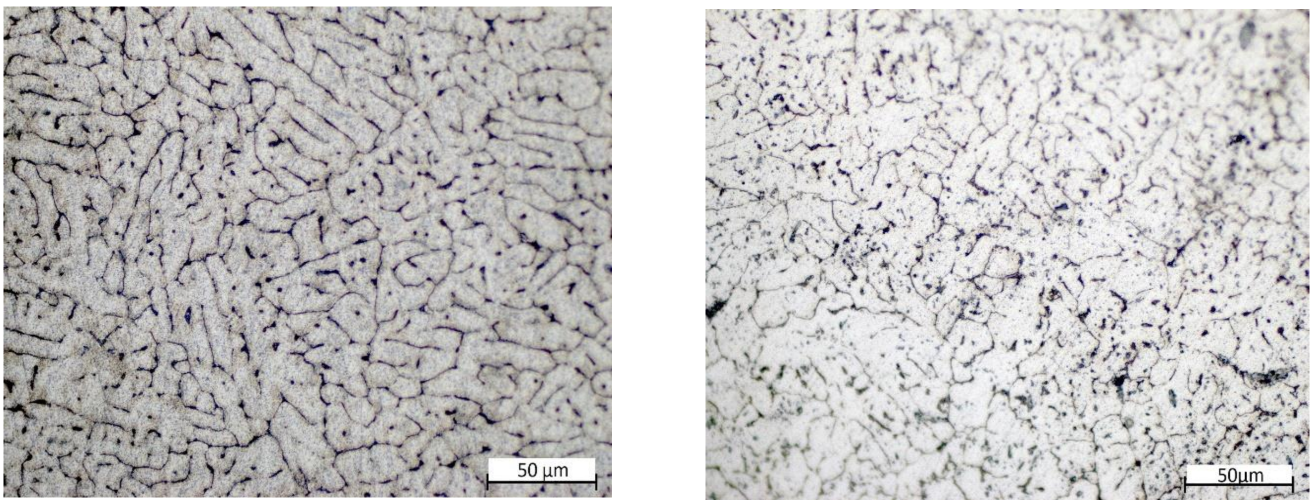
Fig.3.10. Shows the micrograph of the weld area of sample with vibration and air cooling at welding current and magnification – (a) 120A 50X, (b) 130A 50X.

Grain size determination (by line intercept method):

Welding Current(A)	Grain Size(µm)					
	L1	L2	Average L	D1	D2	Average D
120	15.3368	15.86	15.5984	17.312	18.23	17.771
130	16.5104	17.83	17.17054	18.634	20.124	19.379

Table 3.4. The grain size of weld bead at different welding current in vibration-assisted air-cooled samples.

For vibration-assisted copper plate-cooled welding:



(a) **(b)**

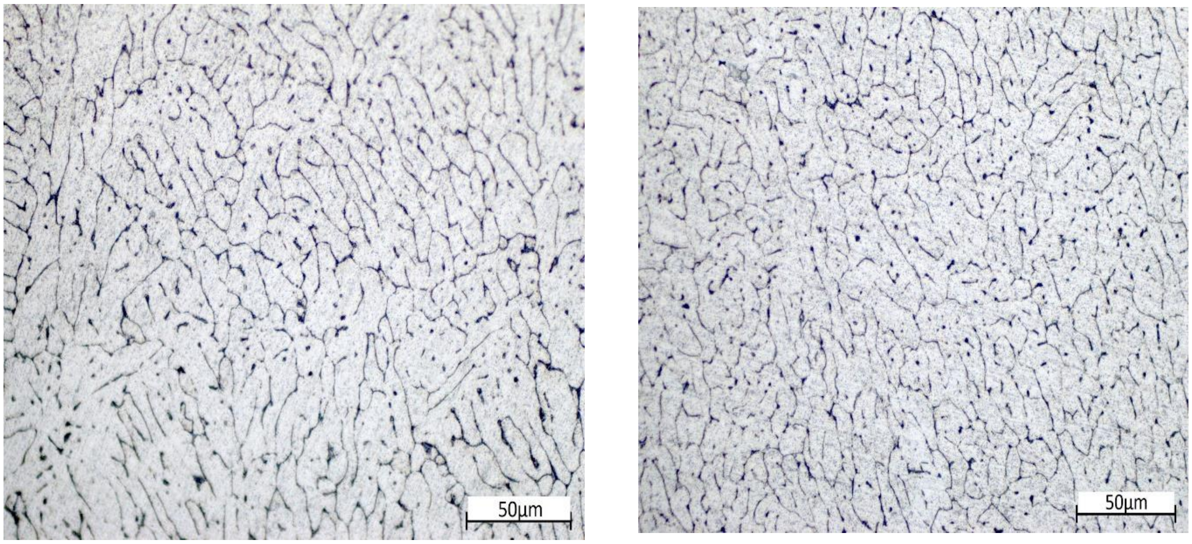
Fig.3.11. Shows the micrograph of the weld area of sample with vibration and copper plate cooling at welding current and magnification – (a) 130A 50X, (b) 140A 50X.

Grain size determination (by line intercept method):

Table 3.5. The Grain size of weld bead at different welding current in vibration-assisted copper plate-cooled samples.

Welding Current(A)	**Grain Size (µm)**		
	D1	**D2**	**Average D**
130	12.7233	12.861	12.7956
140	16.3908	16.496	16.4434

For vibration-assisted water-cooled copper plate welding:



(a) **(b)**

Fig.3.12. Shows the micrograph of the weld area of sample with vibrations and water-cooled copper plate cooling at welding current and magnification – (a) 130A 50X, (b) 140A 50X.

Grain size determination (by line intercept method):

Table 3.6. The Grain size of weld bead at different welding current in vibration-assisted water-cooled copper plate cooled samples.

Welding Current(A)	Grain Size (µm)			
	Average L	D1	D2	Average D
130	18.713	16.17	16.15	16.32
140	16.165	17.92	17.82	17.87

3.3. Hardness (Brinell method):

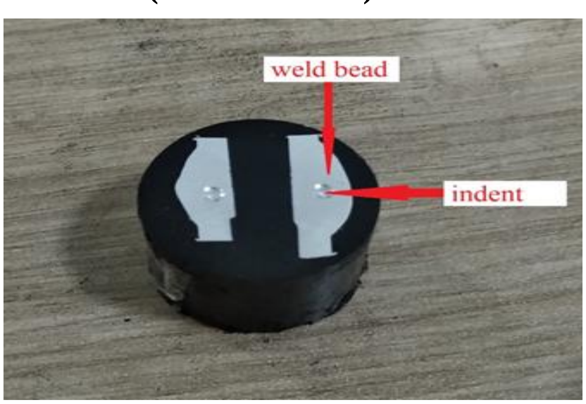


Fig. 3.13. Sample after Brinell hardness test with indent.

- Load applied-250 Kgf
- Ball Indenter Diameter-5mm

For Air-cooled welded samples: The hardness of the weld bead decreases with the increase in heat input.

Table 3.7. The hardness of weld bead at different welding currents for air-cooled samples.

Current (A)	**Diameter1 (µm)**	**Diameter2 (µm)**	**Average Diameter (µm)**	**BHN(HB)**
110	2368.55	2423.06	2395.805	52.09185569
120	2371.5	2426.45	2398.975	51.94469395
130	2379.91	2431.85	2405.88	51.62613943
140	2385.75	2440.54	2413.145	51.29390507

For weld samples cooled using copper plate: The hardness of weld bead decreases with increase in heat input. Here hardness is more as compare to normal weld.

Table 3.8. The hardness of weld bead at different welding currents for copper plate cooled samples.

Current(A)	**Diameter1 (µm)**	**Diameter2 (µm)**	**Average Diameter (µm)**	**BHN(HB)**
110	2371.38	2365.54	2368.46	53.3857740
130	2411.55	2351.1	2381.325	52.77151
150	2429.15	2500.27	2464.71	49.0190281

For weld samples cooled using water-cooled copper plate: The hardness of weld bead decreases with increase in heat input. Here hardness is more as compare to normal weld and weld by Cu cooling plate (without water circulation).

Table 3.9. The hardness of weld bead at different welding currents for water-cooled copper plate cooled samples.

Current(A)	Diameter1 (µm)	Diameter2 (µm)	Average Diameter (µm)	BHN(HB)
110	2389.85	2330.8	2360.325	53.77935986
130	2340.84	2396.19	2368.515	53.38312678
150	2324.96	2430.5	2377.73	52.94216034

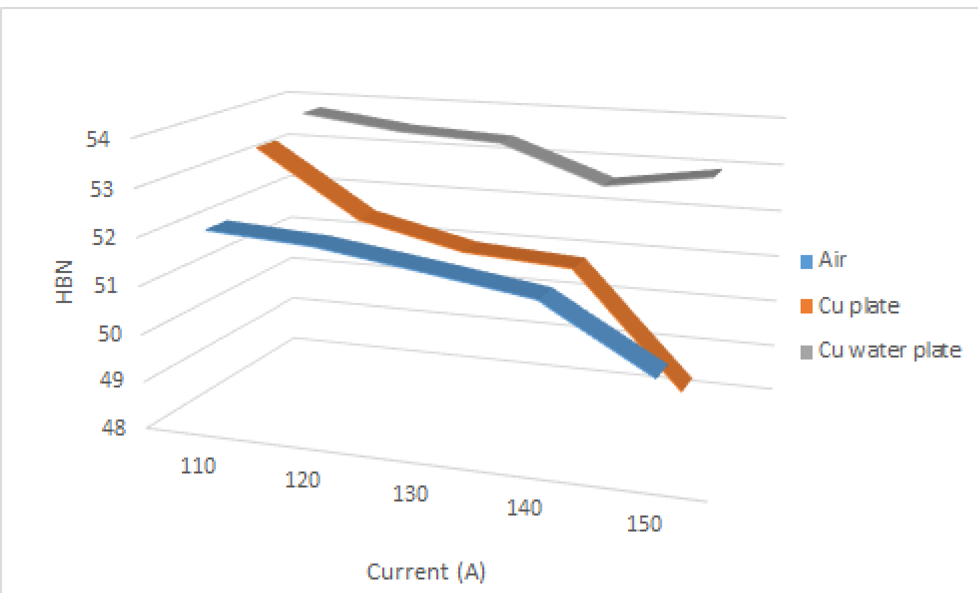


Fig.3.14. Graph showing variation of hardness with change in current and cooling medium.

For vibration assisted air cooled welding: For vibration assisted welding a setup was made using dc motor having specification of 3000 rpm. The mechanism was made such that for one complete rotation of rotor one oscillation cycle of vibrating stand was completed.

Hence frequency of vibrating stand is approximately$\simeq(3000/60)s^{-1}$ =50Hz.

Amplitude $\simeq$ 0.5mm

The hardness of weld bead decreases with increase in heat input. Here hardness is more as compare to weld bead by normal weld.:

Table 3.10. The hardness of weld bead at different welding currents with vibration for air-cooled samples.

Current(A)	**Diameter1 (µm)**	**Diameter 2 (µm)**	**Average (µm)**	**BHN(HB)**
120	2291.38	2319.54	2305.46	56.54290335
130	2336.55	2342.1	2339.325	54.81431114

For vibration-assisted copper plate-cooled welding:

Table 3.11. The hardness of weld bead at different welding currents with vibration for copper plate cooled samples.

Current(A)	**Diameter1 (µm)**	**Diameter 2 (µm)**	**Average (µm)**	**BHN(HB)**
130	2351.38	2285.4	2318.36	55.874365
140	2411.55	2340.1	2375.825	53.031294

For vibration assisted and water-cooled copper plate welding: The hardness of weld bead decreases with increase in heat input. Here hardness is more as compare to weld bead by forced cooling Cu plate with water circulation.

Table 3.12. The hardness of weld bead at different welding currents with vibration for water-cooled copper plate cooled samples.

Current(A)	**Diameter1 (µm)**	**Diameter2 (µm)**	**Average (µm)**	**BHN(HB)**
130	2318.55	2320.1	2319.325	55.82607638
140	2443.15	2405.27	2424.21	50.79358288

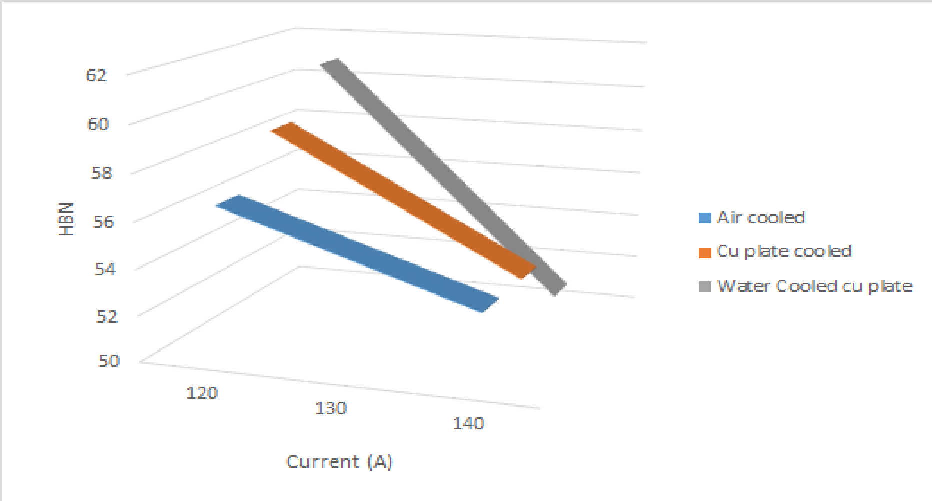


Fig.3.15. Graph showing variation of hardness with change in current and cooling medium assisted with vibration.

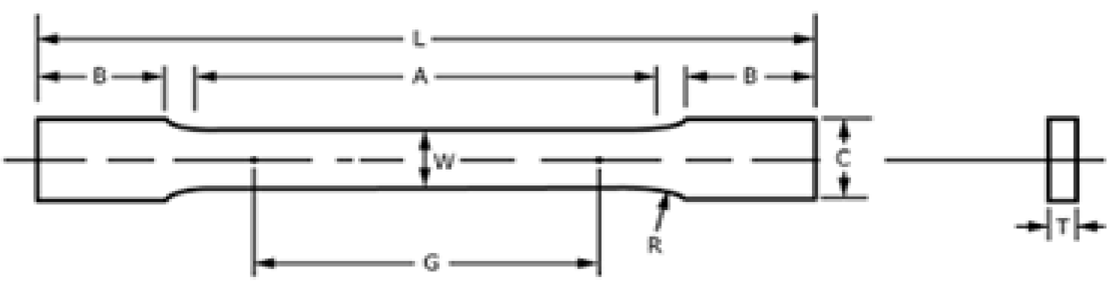
The hardness of weld bead decreases with increase in heat input. Here hardness is more as compare to weld bead by forced cooling Cu plate without water circulation.

Tensile Test:

For Air-cooled welded samples:

Fig.3.16. Tensile specimen prepared on milling machine.

Specimen according to ASTM E8 standards:



L=100mm, A=32mm, G=25mm, B=30mm, R=6mm, C=20mm, W=6mm, T=3mm

Fig.3.17. Tensile specimen dimensions.

Table 3.13. Ultimate tensile load (UTL) and Fracture load (FL) at different welding current (air cooled).

Sr. No.	Welding Current (A)	UTL (KN)	FL (KN)
1	110	1.69	1.69
2	120	4.35	3.83
3	130	3.89	3.41

Samples after the test:

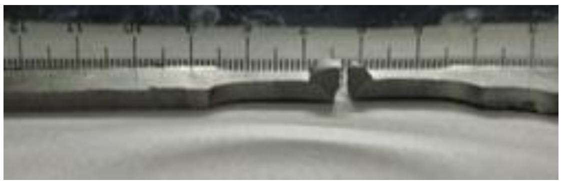


Fig.3.18. Samples after tensile test – (a) 110 A (Broken through weld) and (b) 120 A (Broken through HAZ)

For 110A, specimen has broken from the middle of weld bead but for 120 A, specimen has broken from the heat-affected zone.

Load v/s Displacement graph:

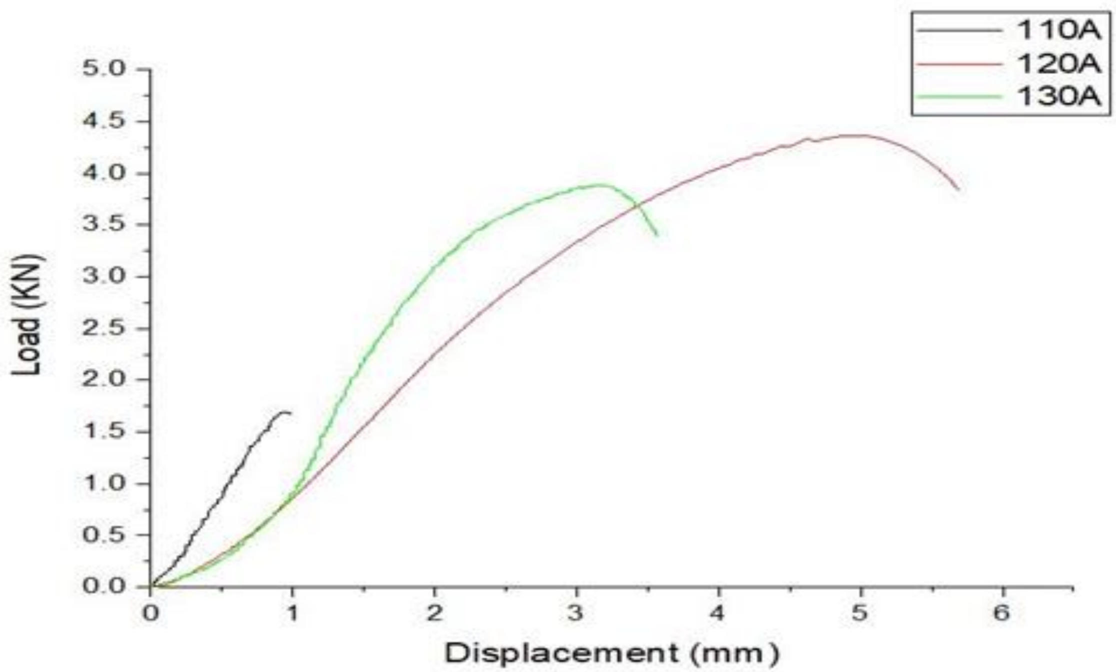


Fig.3.19. Load v/s Displacement graph.

CHAPTER-4

Summary/Conclusions

Summary: In the above experiment, we used CMT welding to join aluminium alloy (AA6063) and varied welding current from 100A to 160A with different welding conditions.

(1) The best weld joint was obtained at 130 A when welding was performed with vibration assisted water-cooled copper plate cooling followed by vibration assisted copper plate cooled sample.

(2) For air-cooled weld joints (with and without vibrations), the best weld joint was obtained at 120A.

(3) The grain size and hardness of various welded samples at the optimum welding current are summarized in following table.

Table 3.14 Summary of results.

Weld Conditions		Optimum Welding Current (A)	Grain Size (µm)	Hardness (BHN)
1. Without Vibrations	Air-Cooled	120	18.43	51.94469
	Copper plate cooled	130	13.02	52.77151
	Water-cooled copper plate	130	16.64	53.38313
2. With Vibrations	Air-Cooled	120	17.77	56.54290
	Copper plate cooled	130	12.79	55.87436
	Water-cooled copper plate	130	16.32	55.82608

(4) From the above points, we conclude the same configuration welding with copper backed cooling plate. We did not obtain any significant difference from the air-cooled CMT welded sample. This can be attributed to the already very low heat input in CMT welding.

Conclusions:

With forced cooling without vibrations:

a. The best weld joint was obtained when the sample was forced cool using water cooled copper backing plate followed by the sample which was forced cool using the copper plate.

b. Rate of heat extraction was higher when the water-cooled copper backing plate was used.

c. Forced cooling leads to a smaller heat affected zone.

d. The microstructure was refined and grain size ranged from 30.64 um at 130A and the formation of smaller grains lead to high hardness.

With introduction of vibrations:

a. Introduction of vibration during the CMT welding process increases the weld depth and the weld reinforcement.

b. Vibration can enhance the hardness.

c. Introduction of vibration leads to grain refinement.

d. The best weld joint was obtained with application of both water cooling copper backing plate and vibrations.

e. The grains refined by application of vibrations are further refined by forced cooling.

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