# Study on Induction Welding of Copper and Stainless Steel (AISI304L) in Atmospheric Condition

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**Abstract**— Industries based on high thermal and electrical conductive properties with strength enhancement application used the copper-stainless steel system. The combined properties of both materials exploited the new dimension of the tailored properties-based applications. There are some industries like marine industry, nuclear industry, and electrical industry used the bi-metallic combination of copper-stainless steel system. The aim of research work is to study on induction welding of copper and stainless steel (AISI304L) in atmospheric condition. In this context, experimental study has been performed by using different current and load setting. The mechanical strength of copper-stainless steel welded specimen was investigated by tensile test. Micro-hardness distribution of copper-stainless steel welded specimen showed that the hardness at the centre line or interface line was more than the copper base metal hardness and stainless-steel base metal hardness. However, the change in current setting for welding caused a particular change in tensile strength and micro-hardness. From the present investigation, it has been observed that the tensile strength of welded specimen increased with increase in current. Even the change of load application for welding caused the particular change in tensile strength. Tensile strength increased till the load kg. and after that it decreased. Somehow 2 kg. Load has been found to be optimum load. Same pattern had found in micro-hardness for current variation but for load it increased till the 2.5kg. Load. Optical microscope showed no crack in weld zone of copper-stainless steel welded material with diffusion line.

**Keywords**—Induction welding, Welding Technology.

## I. INTRODUCTION

Induction welding is a form of welding that uses electromagnetic induction to heat the workpiece. The welding apparatus contains an induction coil that is energized with a radio-frequency electric current. This generates a high-frequency electromagnetic field that acts on either an electrically conductive or a ferromagnetic workpiece. In an electrically conductive workpiece, the main heating effect is resistive heating, which is due to induced currents called eddy currents. In a ferromagnetic workpiece, the heating is caused mainly by hysteresis, as the electromagnetic field repeatedly distorts the magnetic domains of the ferromagnetic material. In practice, most materials undergo a combination of these two effects. The technique of induction heating has been widely used in metallic materials and also used for thermoplastic matrix composites. Nonmagnetic materials and electrical insulators such as plastics can also be induction-welded by implanting them with metallic or ferromagnetic compounds, called susceptors, that absorb the electromagnetic energy from the induction coil, become hot, and lose their heat to the surrounding material by thermal conduction. Induction welding is used for long production runs and is a highly automated process, usually used for welding the seams of pipes. It can be a very fast process, as a lot of power can be transferred to a localized area, so the faying surfaces melt very quickly and can be pressed together to form a continuous rolling weld. The depth that the current, and therefore heating, penetrates from the surface is inversely proportional to the square root of the frequency. The temperature of the metals being welded and their composition will also affect the penetration depth. This process is very similar to resistance welding, except that in the case of resistance welding the current is delivered using contacts to the workpiece instead of using induction [1,2]. These so-called eddy currents dissipate energy and bring about heating. The basic components of an induction heating system are an induction coil, an alternating Current (ac) power supply, and the workpiece itself. The coil, which may take different shapes depending on the required heating pattern, is connected to the power supply. The flow of ac current through the coil generates an alternating magnetic field which cuts through the workpiece. It is this alternating magnetic field which induces the eddy currents that heat the workpiece. Because the magnitude of the eddy currents decreases with distance from the workpiece surface, induction can be used for surface heating and heat treating. In contrast, if sufficient time is allowed for heat conduction, relatively uniform heating patterns can be obtained for purposes of through heat treating, heating prior to metalworking, and so forth. Careful attention to coil design and selection of power-supply frequency and rating ensures close control of the heating rate and pattern. A common analogy used to explain the phenomenon of electromagnetic induction makes use of the transformer effect. A transformer consists of two coils placed in close proximity to each other. When a voltage is impressed across one of the coils, known as the primary winding or simply the "primary," an ac voltage is induced across the other coil, known as the "secondary." In induction heating, the induction coil, which is energized by the ac power supply, serves as the primary, and the workpiece is analogous to the secondary.

## II. LITERATURE REVIEW

T.J. Ahmed et al. had given a comprehensive overview of the process of induction welding of thermoplastic composites. The main objective was to provide a deeper insight into the nature of the induction welding process and to summarize the investigative effort that was put into it by a large group of researchers. The main focus was put on the types of heat generation mechanisms during the induction heating process and the parameters that govern the welding process (frequency, power, pressure, residence time), as well as on the secondary phenomena that can influence the quality of the weld. P. Yan et al. had explained that the Steel line pipes produced by high frequency induction welding can result in a low-toughness zone at the weld junction, even after a heat treatment which reaustenitises the affected region. The possible causes for low toughness were explored, including microstructure, retained austenite, inclusions and crystallographic texture. It was found that the toughness is reduced primarily by the tendency for cleavage planes of ferrite crystals to align and hence create a macroscopic plane on which cleavage can propagate easily with little resistance from grain boundaries. This mechanism suggests that an appropriate heat treatment may alter the texture sufficiently to enhance the toughness of the zone concerned.

## III. OBJECTIVE OF THE STUDY

The main focus of project is to study on induction welding of copper and stainless steel (AISI304L) in atmospheric condition.

Some of the aspects are-

- To weld Stainless Steel and Copper rods by Induction welding process.
- To carry out the welding experiments in atmospheric condition.
- To measure the mechanical properties like i.e. microhardness, tensile strength of the welded specimen.
- To observe the behavior of the mechanical properties like i.e. microhardness, tensile strength with respect to current and load.
- To study the micro structure of the welded joint.

## IV. INDUCTION HEATING BACKGROUND

Induction welding is the application of induction heating, so basically it is the key to open the lock of the mystery of induction welding. Induction Heating was first noted when it was found that heat was produced in transformer and motor windings. Accordingly, the theory of induction heating was studied so that motors and transformers could be built for maximum efficiency by minimizing heating losses. The development of high-frequency induction power supplies provided a means of using induction heating for surface hardening. The early use of induction involved trial and error with built-up personal knowledge of specific applications, but a lack of understanding of the basic principles. Throughout the years the understanding of the basic principles has been expanded, extending currently into computer modelling of heating applications and processes. Knowledge of these basic theories of induction heating helps to understand the application of induction heating as applied to induction heat treating.

## V. EXPERIMENTAL DETAILS

Setup: -

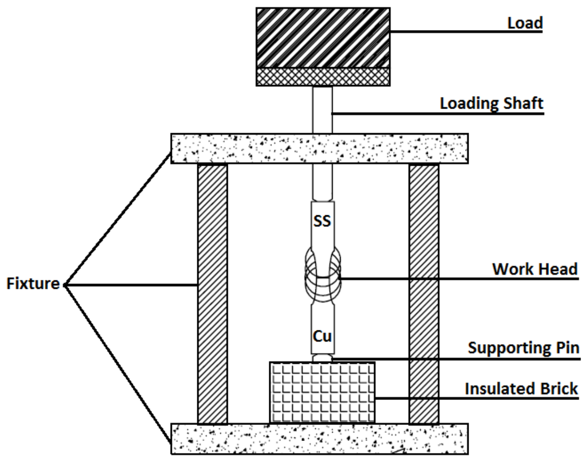



Fig.1: Induction welding setup.

The set-up consists of induction heating machine (Make: A brellInc, Model: EASYHeat8310LI) and fixture. The fixture is situated on the table with work head. It has been shown in Fig.1. that the fixture is integrated with loading shaft with loading purpose and insulated or fire brick for support purpose. Both specimens are fixed and aligned with the help of loading shaft and fire brick. Specimens are placed in between the gap of work head. Gap is needed for the movement of the work head during welding procedure. Load is applied on the loading shaft according to the need of the experiment.

## PARAMETER SETTING

It is studied that frequency, pressure, residence time, and power are the basic parameters for the induction welding. Frequency does not vary much for the particular setting of machine. In present investigation current and load were varied. Some pilot experiments were performed which helped to decide the range of the parameter. Power (Current) range decided from 450A to 650A and load decided arbitrary basis from 0.5 kg. to 2.5 kg. The parameter settings are listed in Table 1 and Table 2.

Table 1: Parameter settings.

| **S.NO.** | **Current (amp.)** | **Load (kg.)** | | | | |
|---|---|---|---|---|---|---|
| **1** | 450 | 0.5 | 1 | 1.5 | 2 | 2.5 |
| **2** | 500 | 0.5 | 1 | 1.5 | 2 | 2.5 |
| **3** | 550 | 0.5 | 1 | 1.5 | 2 | 2.5 |
| **4** | 600 | 0.5 | 1 | 1.5 | 2 | 2.5 |
| **5** | 650 | 0.5 | 1 | 1.5 | 2 | 2.5 |

Table 2**:** Parameter settings

| **S.No.** | **Load (kg.)** | **Current (amp.)** | | | | |
|---|---|---|---|---|---|---|
| **1** | 0.5 | 450 | 500 | 550 | 600 | 650 |
| **2** | 1 | 450 | 500 | 550 | 600 | 650 |
| **3** | 1.5 | 450 | 500 | 550 | 600 | 650 |
| **4** | 2 | 450 | 500 | 550 | 600 | 650 |
| **5** | 2.5 | 450 | 500 | 550 | 600 | 650 |

**INDUCTION WELDING PROCEDURE**

Copper and Stainless Steel (AISI304L) material specimens get ready with the help of power saw and lathe machine. Specimens are polished with the help of emery paper of grade (150,220,400,600,800,1000, 1200, and 1500) and cleaned the face of both specimens by using acetone. Borax used as a flux to prevent the oxidation and thin layer of borax used at the face of both specimens. Both specimens fixed and aligned in the fixture and load with the help of loading shaft and loads. Induction machine started from the direct line. In the starting, copper preheated by moving the work head and observed till the copper becomes red hot (approx.$1000^0$C). After that coil moved in stainless steel region till 8-9 seconds and then coil stayed at the junction of copper and stainless steel. First droplet of copper tells to stop the operation and machine stopped. After 8-10-minute, load removed and specimens took away for further investigation.

**MICROHARDNESS MEASUREMENT**

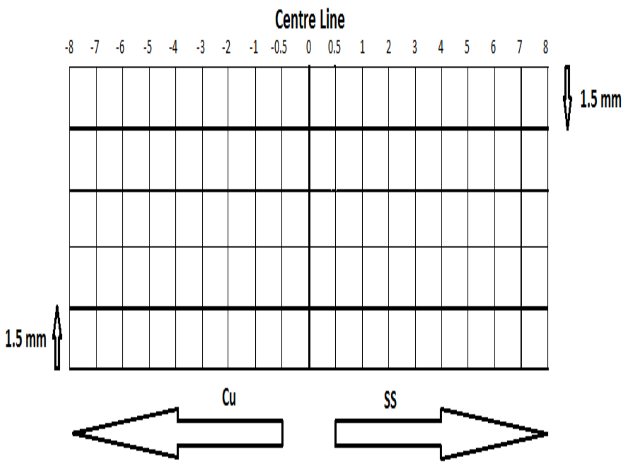



Fig.2: Orientation of microhardness measurement.

Microhardness tests were performed using a Micro-Hardness tester (Make: MATSUZAWA, Model: MMTX7B). Microhardness of the Cu-SS welded specimen is measured at the different location shown in the Fig.2. The average of microhardness values measured column vise is considered as microhardness of a particular point from the Centre line. For example, microhardness values were measured at five different points on a column situated at -0.5mm from the Centre line or interface line in the copper side. The average of these five values was taken and considered as the microhardness value at -0.5 mm distance of copper from the Centre line or interface line.

**TENSILE STRENGTH MEASUREMENT**

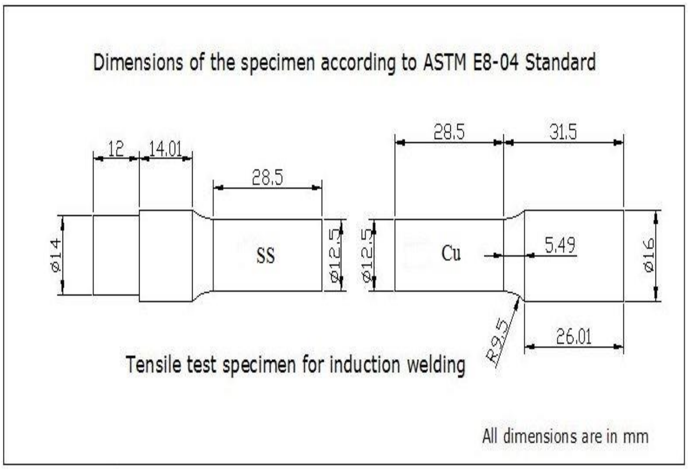



Fig.3: Dimension of Tensile specimen according to the ASTM E8-04 Standard.

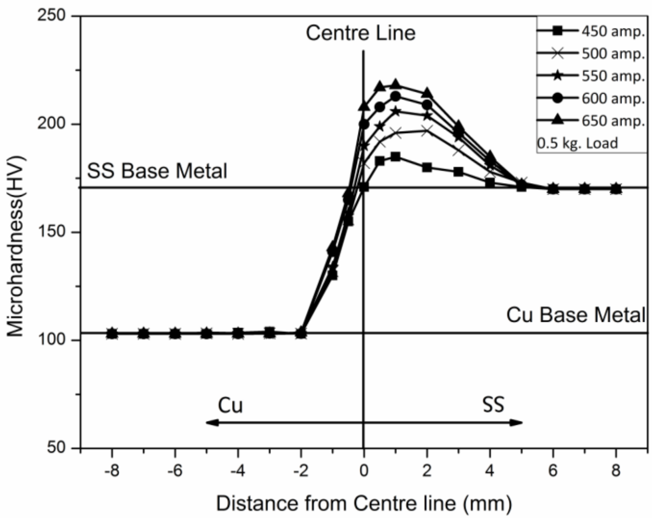
Tensile tests were performed using a hydraulic type universal testing machine (Make: HEICO, Model: HL-59020). Fig.3. shows the dimension taken for the tensile specimen according to the standard ASTM E8-04.

**MICRO-STRUCTURAL STUDY**

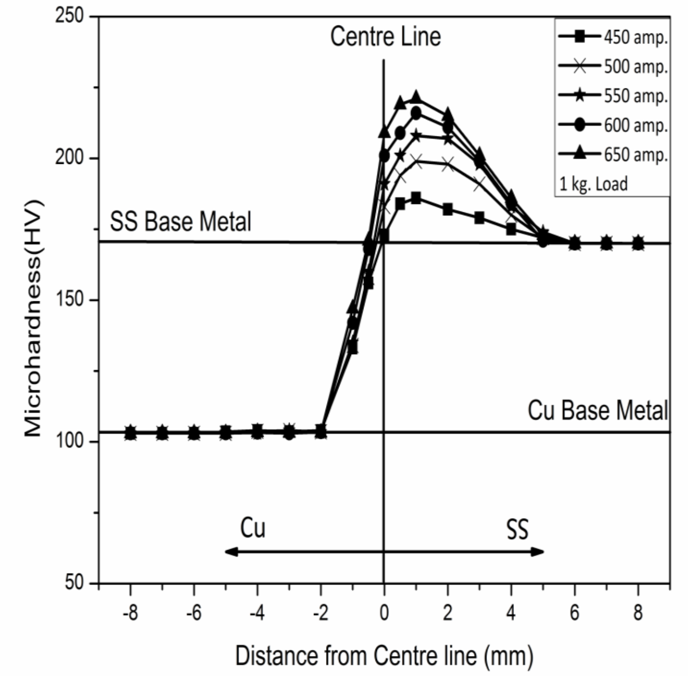
Micro-Structure tests were performed using optical microscope (Make: LEICA, Model: DMI3000M). Specimens were cold mounted for polishing process with the help of emery paper and diamond paste. Specimens were ultrasonically cleaned in alcohol bath and used the different etchant for both materials/ After all of these specimens were observed in optical microscope.

## VI. RESULTS AND DISCUSSIONS

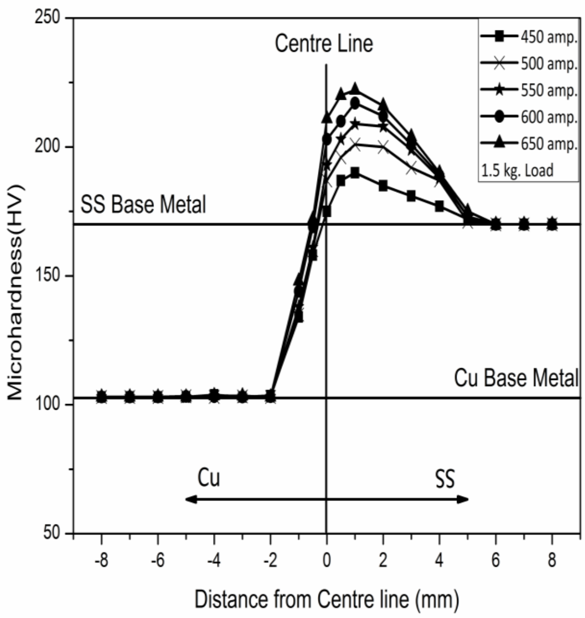
**EFFECT OF CURRENT ON MICROHARDNESS VALUES**



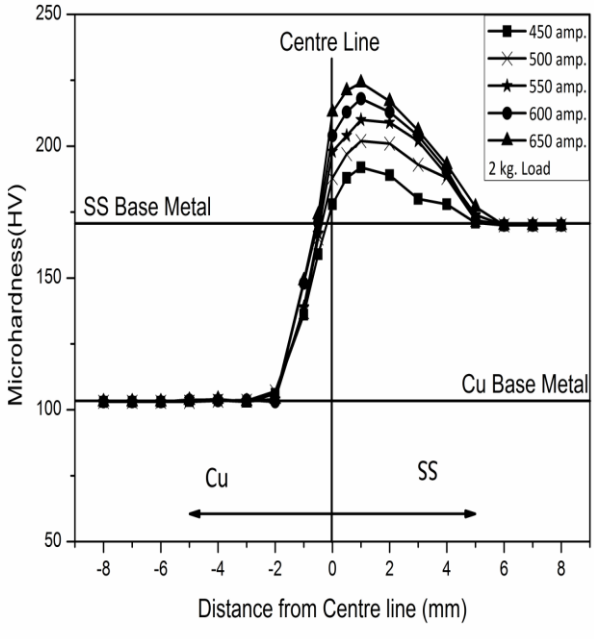
(a)


Centre Line
450 amp.
500 amp.
550 amp.
600 amp.
650 amp.
1 kg. Load
SS Base Metal
Cu Base Metal
Cu
SS
Microhardness(HV)
Distance from Centre line (mm)

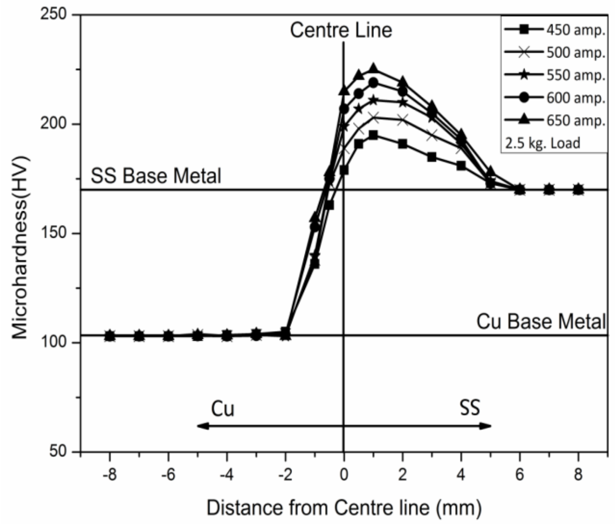
(b)


Centre Line
450 amp.
500 amp.
550 amp.
600 amp.
650 amp.
1.5 kg. Load
SS Base Metal
Cu Base Metal
Cu
SS
Microhardness(HV)
Distance from Centre line (mm)

(c)




(d)




(e)

Fig.4: Microhardness versus distance from centre line for different currents and constant load setting of (a) 0.5kg., (b) 1kg., (c) 1.5kg., (d) 2kg., (e) 2.5kg.

The measured microhardness of the welded specimen from the Centre line in the both side copper and stainless steel for different currents from 450A to 650A were plotted for the constant load 0.5 kg., 1 kg., 1.5 kg., 2 kg, and 2.5 kg. These are shown in Fig. 4(a), 4(b), 4(c), 4(d), and 4(e) respectively.

Experimentally it has been observed that the microhardness value in the copper side is not varying from the Centre line beyond around 1mm and this pattern is also found from all the figures. However, the microhardness value is increasing towards the Centre line for all the condition. Experimentally it has been observed that the microhardness value in the stainless-steel side is increasing from the Centre line up to around 1.2 mm distance and then it decreased till the stainless-steel base metal microhardness value reached. Originally stainless steel has better microhardness as compared to copper. During induction heating, stainless steel and copper, both melted at the interface zone and because of this material is diffused in both side but more amount of stainless steel would be diffused in copper side due to gravitational effect since stainless steel is kept above the copper. Consequently, the microhardness value in the copper side near to the Centre line is improved. It is quite common that diffusion rate of the copper towards stainless steel would be reduced but it is diffused up to certain extent. So this phenomenon may lead in reduction of the microhardness in stainless steel side near to the Centre line but the microhardness in stainless steel side is higher as observed from the Fig. 4(a) to Fig. 4(e). It is observed from the Fig. 4(a) to Fig. 4(e) that microhardness value near to the Centre line in stainless steel side for the current of 650A is higher than the other currents and it is gradually decreased with the reduction in current values. This is due to the fact of heat treatment in the stainless-steel side.

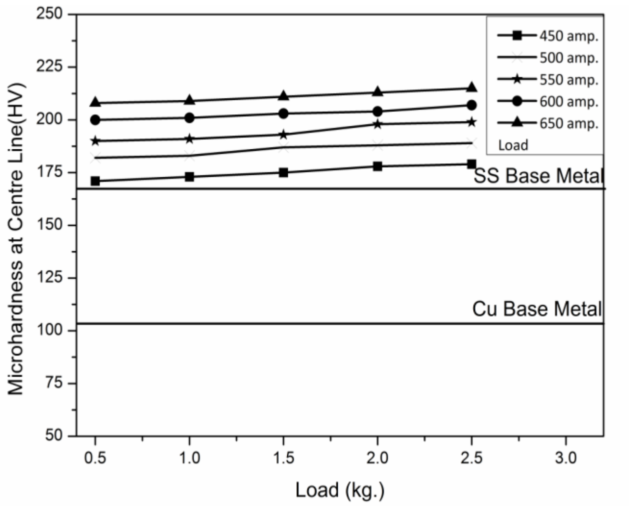
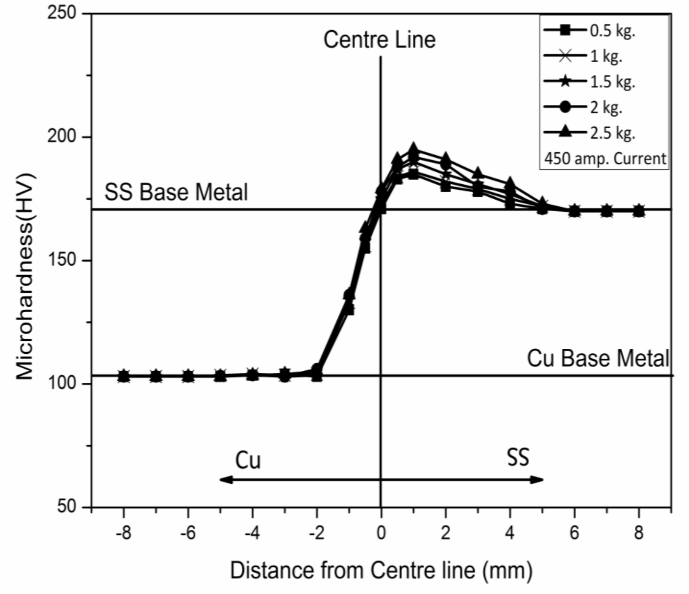


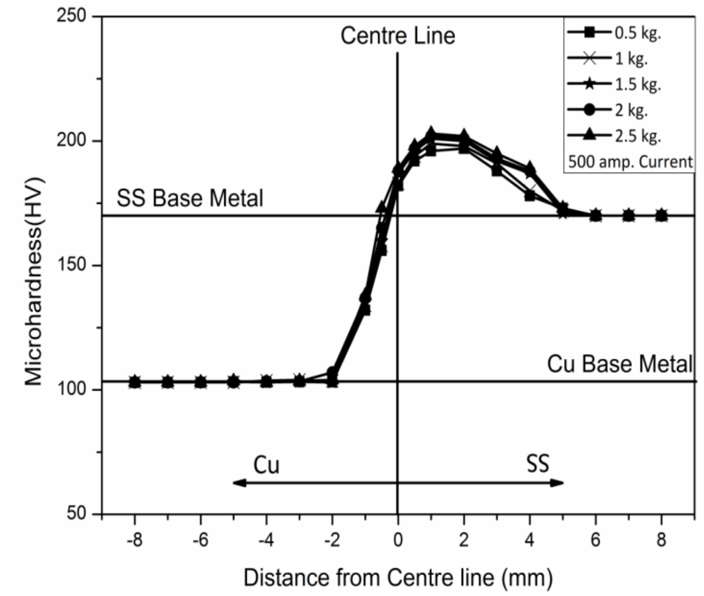

Fig.5: Microhardness versus load for different current setting.

The graph between microhardness versus loads with varying current is shown in Fig.5. It is observed from the Fig. 5 that the microhardness value for 650A at Centre line is higher than the other currents and it is gradually decreased with the reduction in current values.

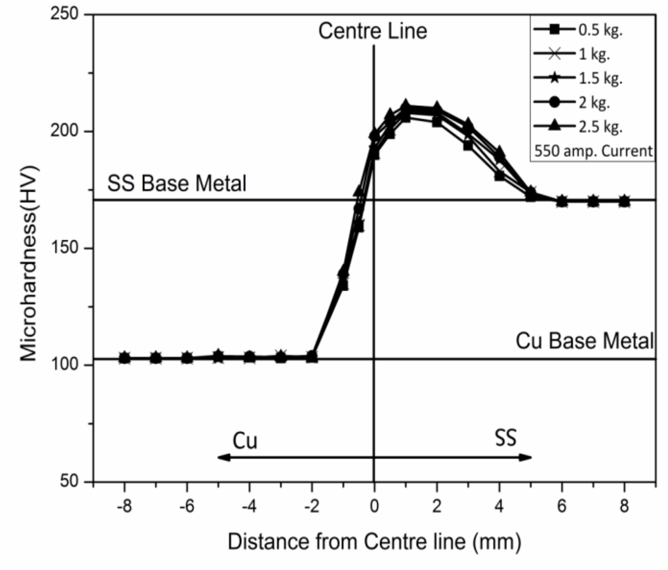
**EFFECT OF LOAD ON MICROHARDNESS**



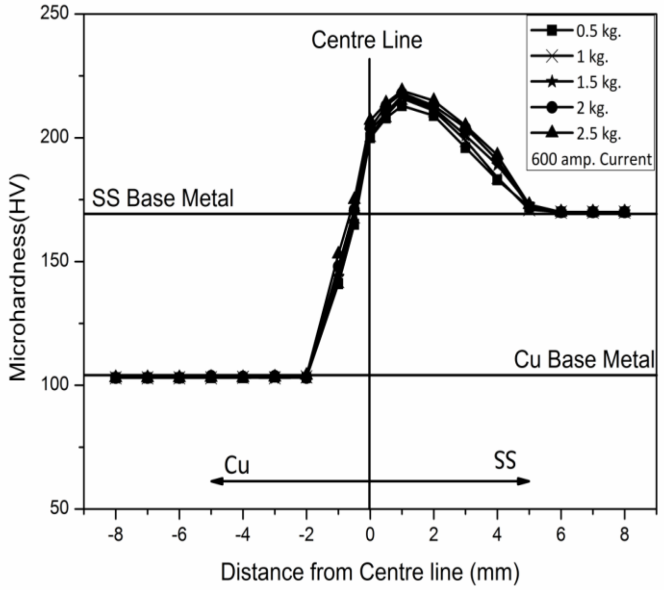

(a)



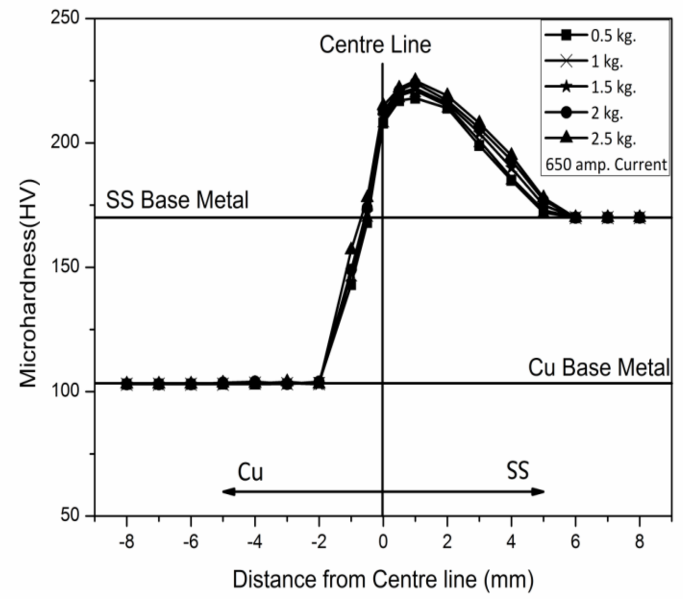

(b)


Centre Line
0.5 kg.
1 kg.
1.5 kg.
2 kg.
2.5 kg.
550 amp. Current
SS Base Metal
Cu Base Metal
Cu
SS
Microhardness(HV)
Distance from Centre line (mm)

(c)


Centre Line
0.5 kg.
1 kg.
1.5 kg.
2 kg.
2.5 kg.
600 amp. Current
SS Base Metal
Cu Base Metal
Cu
SS
Microhardness(HV)
Distance from Centre line (mm)

(d)




(e)

Fig.6: Microhardness versus distance from centre line for different loads and constant current setting of (a) 450A, (b) 500A, (c) 550A, (d) 600A, (e) 650A.

The measured microhardness of the welded specimen from the Centre line in the both side copper and stainless steel for different loads from 0.5kg.to 2.5kg. Were plotted for the constant current 450A, 500A, 550A, 600A, and 650A. These are shown in Fig. 6(a), 6(b), 6(c), 6(d), and 6(e) respectively.

Experimentally it has been observed that the similar pattern is getting as it was in current variation. The higher value of microhardness achieved in 2.5 kg. load and it is gradually decreased with the reduction in load values.

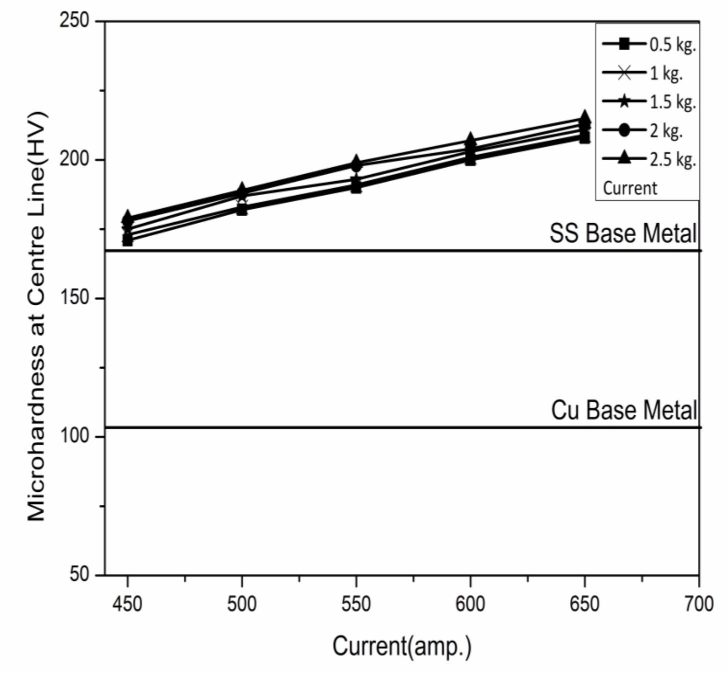



Fig.7: Microhardness versus current for different load setting.

The graph between microhardness versus currents with varying load is shown in Fig.7. It is observed from the Fig.7. that the microhardness value for 2.5 kg. at Centre line is higher than the other loads and it is gradually decreased with the reduction in load values.

**EFFECT OF CURRENT ON THE TENSILE STRENGTH**

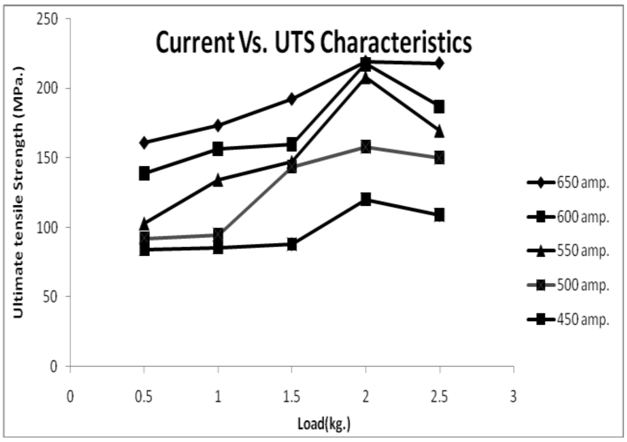



Fig.8: The behavior of UTS of induction welded specimen Cu and SS(AISI304L) for different current settings and loads.

The measured tensile strength value of the welded specimen Cu-SS for different currents from 450A to 650A was plotted for the different loads from 0.5kg. to 2.5kg. and shown in the Fig.8. Experimentally it has been observed that the value of UTS of the welded specimen increases with the increase of current for a particular load because as the current increases. Originally stainless steel has better UTS as compared to copper. During induction heating, stainless steel and copper both melted at the interface zone and because of this material is diffused in both sides. More amount of stainless steel would be diffused in copper side due to gravitational effect since stainless steel is kept above the copper. So as the temperature increased, more stainless steel would be diffused in the copper side. Consequently, the UTS value of welded specimen Cu-SS improved. It is observed from the Fig.8. that the UTS value in welded specimen Cu-SS for the current 650A is higher than the other current values and it is gradually decreased with the reduction in current values. It is also observed from the Fig.8. that the UTS value in welded specimen Cu-SS increased gradually from the load 0.5kg. to 2kg. and then it decreased. The UTS value is higher at 2kg. load as compared to another load so 2kg. load is found to be the optimum load in 0.5kg. to 2.5 kg. loads range.

## VII. CONCLUSION

In this study, Induction welding was conducted for stainless steel-copper varying current setting and load to investigate the micro-hardness, microstructure as well as the tensile strength of the welded joints. As a result of test conducted, the following conclusions were made. From the residence time measured during the Induction welding process, it was found that the time required for welding of stainless steel- copper was decreased with the increase in current setting.

From the micro-hardness examination of welded joints average micro-hardness of stainless-steel to copper welded samples with different current settings.it has been observed that the maximum micro-hardness in the stainless-steel side and minimum micro-hardness in copper side but in the joining line it is varying with the different current setting. The minimum microhardness at 450A and maximum at 650A.

From the microstructural examination of the welded joints, it was found good crack free bonding between the materials. There was a solid-state diffusion bonding taken place between the metals. Moreover, a little evidence of Heat Effected Zone found in the vicinity of the joint. From the Tensile Strength analysis of the welded joints, it was found that the Ultimate Tensile Strength of the stainless Steel to copper joints changes with varying current setting. The Ultimate Tensile Strength of joints were increased with increasing in current setting. The Ultimate Tensile Strength of stainless Steel to Copper joints were the highest at 650A and lowest at 450A because heat generation was less in this setting so bond formation between Stainless steel and copper was not good.

It is also observed that 2 kg. load in all these current settings have found to be optimum load so the maximum UTS value is observed at 2 kg. load at 650 amp. current.

From comparative study, it was found that a similar pattern was formed between the micro-hardness, microstructure and ultimate tensile strength. In case of microhardness in joining line is maximum at 650A as well as minimum at 450A current setting. In microstructure good diffusion was found between copper and stainless steel in joining zone at 650A current setting in case of ultimate tensile test highest tensile strength at 650A and lowest at 450A current setting.

## VIII. SCOPE FOR FUTURE WORK

Induction welding has already proven to be a worthwhile technology for joining of metals. The past two decades have seen the emergence of induction welding as a suitable and effective technology for welding of similar-to-similar and similar-to-dissimilar metals. The simplicity of the physical process and the extensive research into numerical modelling of the heating process has allowed for the development of the induction welding process. The test carried out in this thesis work includes variable parameter such as current setting, load and Residence time. There are still some more areas like measurement of fatigue strength and impact strength, in which further investigation could lead to a greater understanding of the effect of some other parameters on the welded joints. The experimentation was carried out using round bars of Stainless Steel and Copper. Some other dissimilar materials which are electrically conductive can also be used for the purpose. Microstructural studies at higher magnification, which can be done by using equipment such as XRD and SEM, can provide better understanding of the properties and composition of the material.

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