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A study on induction welding of mild steel and copper with flux under applied load condition

R.K. Bhogendro Meitei[a], Pabitra Maji[a], Ashutosh Samadhiya[b], Subrata Kumar Ghosh[a,*], Barnik Saha Roy[a], Alok Kumar Das[c], Subhash Chandra Saha[a]

[a] Department of Mechanical Engineering, NIT Agartala, Tripura, 799046, India
[b] Department of Mechanical Engineering, Rama University, Kanpur, U.P., 209217, India
[c] Department of Mechanical Engineering, IIT (ISM) Dhanbad, Jharkhand, 826004, India

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ABSTRACT

In the present study, Induction welding was carried out to achieve the joining between dissimilar metals such as mild steel (AISI 1015) and copper (Cu) in open atmosphere with different loads and different current settings. Microstructural evaluation of the welded joints was done by optical microscope and scanning electron microscope (SEM). The study showed that Cu was well bonded with mild steel (MS) without any crack near diffusion line. The X-Ray Diffraction (XRD) analysis was carried out and it revealed the presence of $FeCu_4$ and $Cu(Fe_2O_4)$ along with Cu and Fe. Joint quality was examined by measuring ultimate tensile strength (UTS) and microhardness. The UTS of the welded specimens was found to be increasing with the increase of load and current. The maximum UTS was obtained for specimen welded at 650 A with 2.5 kg load applied during welding. Microhardness distribution of the welded specimens showed that microhardness at interface line was more than that of copper and less than that of mild steel. The maximum microhardness on the copper side was at the interface line and attained base metal microhardness 1 mm onward from the interface. However the microhardness on mild steel side increased nearly upto 6 mm from the interface line.

1. Introduction

The application of bi-metallic system increases with the need of material optimisation, weight reduction, and sustained product operation under extreme service conditions. Copper-steel combination is being used widely in power generation industries, nuclear industries due to their high electrical and thermal conductivity and stiffness [1]. The difference in chemical and thermomechanical properties between copper and mild steel makes it very hard to achieve a defect free welded joint between them.

Velu et al. [2] have studied the effect of nickel and bronze based filler materials to get a copper-steel welded joint by Shielded Metal Arc Welding (SMAW). The outcomes of their investigation showed that nickel based filer material in copper-steel joining caused better welding quality than the bronze based filler material. However crack generation due to residual stress at weld interface is very difficult to avoid by conventional welding techniques. Many solid state welding processes such as explosive welding, diffusion bonding, friction welding and ballistic impact welding were investigated for dissimilar material welding [3–6]. Though the mechanical properties of the joint were enhanced by these processes, but the joint configuration is restricted. Electron beam welding (EBW) was a very common technique adopted for joining copper and steel in past decades due to high heat intensity available in the process [7,8]. However the influence of vacuum environment in EBW process limits its application areas. Laser welding is mostly used from past few years for copper-steel welding. Mai et al. [9] proposed a model for welding copper and steel by laser welding such that most of the energy could be absorbed by steel. But complete metallurgical bonding was not achieved. Yao et al. [10] used scarf geometry to improve the high temperature gradients through the thickness direction during welding of copper-steel by CO_2 laser, but an intermixing zone was formed in weld pool adjacent to the copper side. Chen et al. [11] welded copper and stainless steel by an oblique CO_2 laser and found grain growth in copper side. The mechanical strength of the joint was dependent on amount of copper melting. Zhang et al. [12] used a hybrid welding technique to obtain a crack free join between copper and steel.

Induction welding is one type of resistance welding process where joining is done by resistive surface heating by electromagnetic induction and pressure application. The process can easily be adopted to

* Corresponding author.
E-mail address: subratagh82@gmail.com (S.K. Ghosh).

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manufacture pipes with high production rate, and does not require welding consumables [13]. Induction brazing and welding techniques have been adopted for joining various dissimilar materials and steel pipes in recent years [14–19].

The thermal conductivity of copper is much higher than mild steel but the electrical resistivity and specific heat of mild steel are higher than those of copper. This may results in mismatch of strain generated during solidification. Therefore a modified method for heating is required for mild steel and copper welding.

In the present investigation an attempt has been made to perform a butt joint of copper and mild steel (AISI 1015) rods by high frequency induction welding process. The microstructure of the welded specimens was studied. The effect of load and current on tensile strength and microhardness of the welded specimens were also examined.

2. Experimental details

2.1. Materials

Experiments were carried out on AISI 1015 mild steel and commercial copper (99.9% pure copper) rods of 60 mm length, which were machined in Lathe to make a specific shape according to ASTM E8-04 standard, as shown in Fig. 1. The chemical compositions of mild steel have been presented in Table 1.

2.2. Experimental setup

The experiment was performed on induction heating machine (make- Ambrell Inc. maximum power 10 kW) in atmospheric condition. A cooling unit (make- Werner Finley Pvt. Ltd.) was attached with the induction heating machine to draw out the heat generated in the coil. A fixture was made to hold the specimens and for applying load by dead weight. An insulated brick with a supporting pin and a vertically movable loading shaft were the main components of the fixture. The specimens were fixed inside the induction coil with the help of the supporting centre and the loading shaft (Fig. 2). Load was applied as per experimental requirements.

2.3. Selection of process parameters

Frequency cannot be controlled for the particular machine and it was nearly around 300 kHz for all the experiments. Load and input current were chosen to be varied in present study. Some trial experiments were conducted to determine the operational span of these parameters. It was found that the joining between copper and mild steel was not feasible for input current below 450 A. The maximum input current available was 650 A. Load was taken to be varied from 0.5 kg to 2.5 kg as 3 kg load caused too much bulging in the joint. The experiments were carried out according to the parameters listed in Table 2.

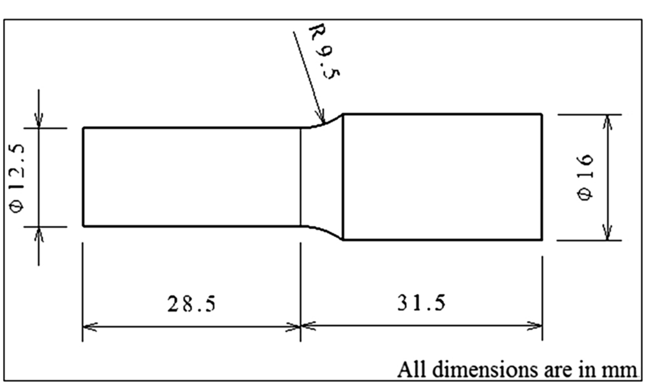

Fig. 1. Schematic diagram of specimen.

Table 1
Chemical compositions (wt%) of mild steel (AISI 1015).

Fe	C	Mn	S	P
≤99.5	≤0.18	≤0.6	≤0.05	≤0.04

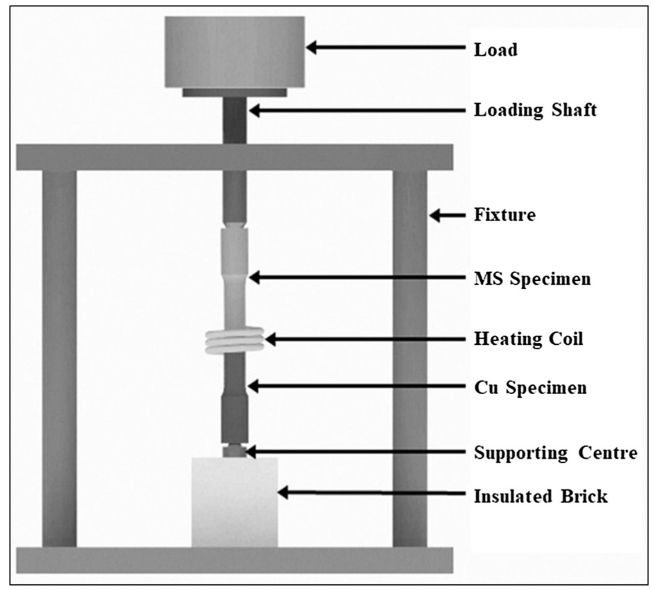

Fig. 2. Induction Welding setup.

Table 2
Parameter settings.

Sample no.	Current (A)	Load (kg)
1	450	0.5
2	450	1.0
3	450	1.5
4	450	2.0
5	450	2.5
6	500	0.5
7	500	1.0
8	500	1.5
9	500	2.0
10	500	2.5
11	550	0.5
12	550	1.0
13	550	1.5
14	550	2.0
15	550	2.5
16	600	0.5
17	600	1.0
18	600	1.5
19	600	2.0
20	600	2.5
21	650	0.5
22	650	1.0
23	650	1.5
24	650	2.0
25	650	2.5

2.4. Welding procedure

The surfaces of the specimens to be welded were polished up to 1500 μm grit finish by emery paper, followed by surface cleaning in acetone bath. A thin layer of silver brazing white flux was applied on the surfaces to be welded of both mild steel and copper to prevent oxidation. Copper specimens were fixed on the insulator brick and the mild steel specimens were placed over copper. Then the load was applied by the loading shaft. The axis of the load was kept in line with the