Microstructure Evolution and Bonding Strength of Brazed Joint of Stainless Steel and Copper

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ABSTRACT

The joining behaviour between stainless steel and copper has an importance in scientific and engineering applications such as high energy ring vacuum chambers and International Thermonuclear Fusion Experiment Reactor (ITER). In this research, the rapidly solidified foils of nominal composition 50Cu-40Mn-10Ni (C50) are used as a filler alloy for brazing between stainless steel (304 SS) and copper (Cu) plates. It is examined that C50 foil makes a good contact joint between two dissimilar metal plates of different thermal conductivities. The brazed region is mostly free from any porosities and intermetallic compounds, emphasizing on the distribution of solid solution phases. It causes high bonding strength of 304 SS-Cu butt joint at low brazing temperature (B_T=920°C) with a fracture at the joint area. On the other hand, the fracture occurs at Cu base metal for B_T = 980°C. The fractography also shows the presence of several dimples at Cu substrate and severely deformed region at stainless steel substrate, representing a good quality bonding between 304SS and Cu plates.

Keywords: Brazing, Diffusion, Electron Microscopy, Solid solution phases, Bonding Strength.

1.0 INTRODUCTION

The joining behavior between stainless steel (SS) and copper (Cu) joint has an importance not only in high energy ring vacuum chambers but also in the International Thermonuclear Fusion Experiment Reactor (ITER) [1]. The multiple assemblies of SS to Cu can be joined by internal bonding, explosive bonding, or furnace brazing [2, 3]. The TIG brazing using Ag-Cu fillet alloy is also a promising technique making the joint between SS and Cu flange [1]. However, TIG method causes a considerable amount of softening and oxidation of Cu away from the joint. There is also a problem for large sections of beam chamber due to poor thermal diffusivity between SS and Cu, preventing the fast attainment of brazing temperature. It can be avoided by a local heating like laser beam at the adjoining area. Gopinathan et al. has investigated the CO_2 laser welding of stainless steel to OFC copper at the University of Tennessee Space Institute [4]. In this case, 98% of radiation reflects from Cu surface, therefore, it is required to focus the beam at the joint or stainless steel. Another approach is the electron beam welding which is regularly used to the join 304 SS to OFC Cu for invasive probes into H_2-fueled NASA engines [5]. It results in the sound joint with no evidence of cracking; however, it shows the inhomogeneous structure at the joint area. On the other hand, the brazing is one of the most efficient and good method for joining between two dissimilar metals. However, a limited research works have been found for brazing between 304 SS and Cu. Chen et al. studied the microstructural evolution at the joining of Cu-Be alloy and 304 SS by active brazing [6]. They have found several intermetallic phases at the brazing zone, which might decrease the strength of the joint. Stainless steel can be diffusion bonded with Cu alloy by inserting a gold foil at the joint interface [7]. This bonding enhances the strength properties of the joint, however, the processing cost increases due to the use of gold foil. Therefore, aim of this work is to develop a strong joint between 304SS and Cu plates in a simple and economical way.

2.0 MATERIALS AND METHODS

The brazing foil (C50) with a nominal composition of 50Cu-40Mn-10 Ni (wt %) was melt spun through a single roller melt spinning technique. The developed foils were measured with a width of 10 mm and a thickness of 40 µm. The foil showed solidus and liquidus temperatures at 900 and 945°C, respectively [8]. The brazing foil was kept as a filler alloy between two dissimilar metal plates of 304 SS and Cu. The joining surfaces of 304 SS and Cu substrates were ground by SiC papers, were cleaned ultrasonically in acetone prior to brazing. It is followed by the insertion of brazing foil between two substrates and proper fixing inside a specially designed brazing jig (**Fig. 1**). Subsequently, the whole brazement assembly was kept inside a resistance heating furnace and the brazing operation was carried out at three different temperatures 920, 940 and 980°C for 5 minutes with a heating rate of 10°C/min under an inert atmosphere. The microstructural characterization of the brazed joints was carried out by a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) for quantitative analysis. The tensile testing was carried out using a universal tensile testing machine of Instron a crosshead speed of 0.01mm/min.

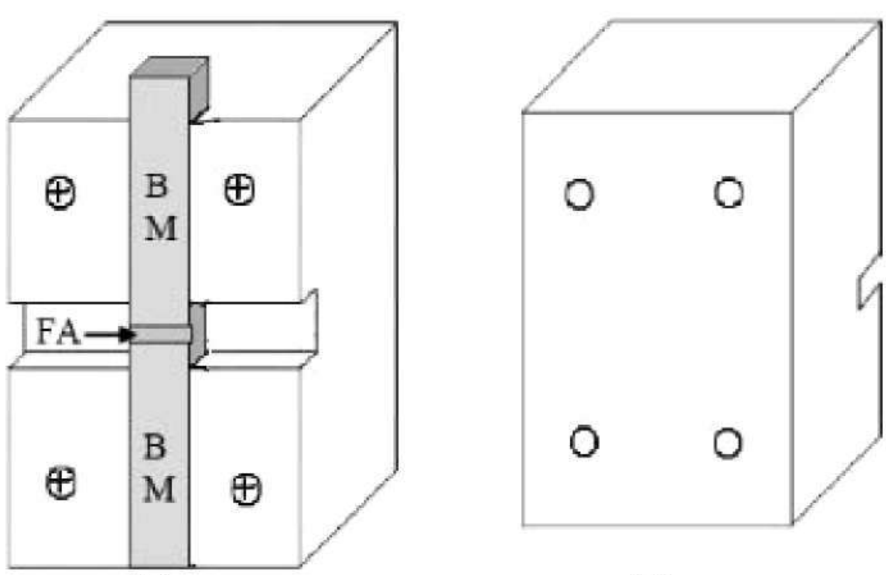
3. RESULTS AND DISCUSSION

3.1 Developed Brazing Foil and Brazed Joint

The developed brazing foils are quite ductile by showing 180° folding (**Fig. 2a**). Due to uniform thickness and porosity free nature, the foils make a successful joint between two dissimilar metal plates of 304 SS and Cu (**Fig. 2b**). The joint between two dissimilar metals such as stainless steel and copper becomes always difficult owing to different thermal conductivities of two metals. However, the developed brazing foil C50 makes a good contact joint owing to its homogeneous microstructure, melting point lower than Cu melting point and narrow melting zone [8]. Moreover, the common Cu matrix for the filler alloy and one of the base metals also causes a good bonding between two different metal plates.

3.2 Microstructural Evolution at the Joint Region

Fig. 3 shows a typical SEM backscattered image of 304SS-Cu brazed joint with C50 foil. The joint is free of porosities and any major particles at the interface. It is mainly divided in three regions, base metal (BM), interfacial region (IR) and filler alloy (FA) (**Fig. 3a**). The filler alloy (FA) region of BSE image is not distinguished from the base metal (Cu) due to the presence of same major element Cu in the matrix of FA and one of the base



(a) (b)

Fig. 1 : Schematic diagram of brazement assembly showing (a) Bottom part and (b) Top part of brazing jigs (BM: Base metal and FA: Filler alloy)

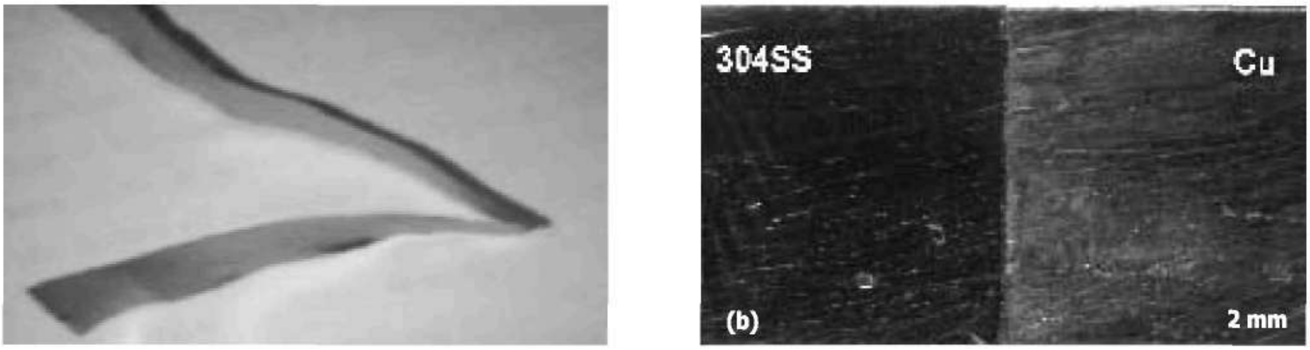


Fig. 2 : Developed brazing foil shows (a)180° folding and (b) successful joint between 304SS and Cu

metals. The IR between 304SS and FA seems like a grain boundary. The fine thickness and homogeneous microstructure of rapidly solidified C50 filler alloy results in a uniform segregation and porosity free brazed microstructures [8].

Several phases of Fe, Cu, Ni, Cr and Mn have been formed at the joint area, examined by energy dispersive spectroscopy (EDS) chemical analysis at different points (**Table 1** and **Fig. 3b**). The points of 1-4 are observed as the composition of SS with a presence of Mn content diffused from FA region, leading to the formation of Fe-Mn phases. It is possible due to complete solubility of Mn in Fe. On the other hand, the maximum solubility of Cu in γ-Fe is about 13 wt% [11, 15]. Therefore, Mn solubility in Fe is better than that of Cu in Fe. The IR zone (point 5) corresponds to Fe-rich phases formed to be combining with Mn/ Cu / Cr /Ni. Points 6-9 correspond to FA zone, showing chemical composition with varying concentration of Fe, Cu, Mn, Ni and Cr. Due to high diffusion of Mn in Fe and poor solubility of Fe in Cu, the relative concentration of Cu is higher than the FA composition. According to Cu-Ni phase diagram, Ni is completely soluble in Cu [16], resulting in the formation of (Cu,Ni) solid solution phases, and there is no tendency of the formation of intermetallic compounds.

The brazing operation of 304SS-Cu joint starts from the melting of Cu-based FA owing to its low melting point than the base metals, and it is followed by a liquid metal zone at the surfaces of 304SS and Cu. Subsequently, the migration of small amount of FA to BM and the dissolution of large amount BM at brazed region, leading to a relation between solid metal dissolution and liquid metal migration. The reactions between FA and BM are governed by the volume diffusion and the grain boundary diffusion, acting adjacent to IR and beyond IR at the BM region, respectively [9, 10, 11]. Therefore, the brazed joint micro-structure is the combined effect of these two diffusion mechanisms, affecting the diffusion rate of constituent elements, leading to the formation of different solid solution phases [12].

3.3 Bond Strength

Bond strength of the brazed joint was derived by the tensile testing. **Fig. 4** shows the stress-displacement curves of SS-Cu

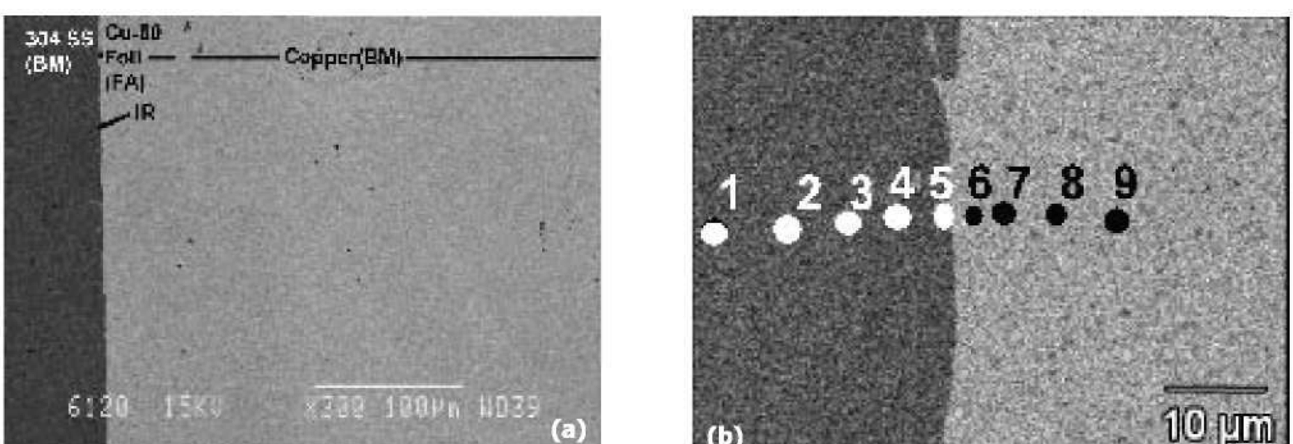


Fig. 3 : SEM-BSE image of 304 SS-Cu brazed joint showing (a) Porosities free joint area (b) EDS elemental analysis at different points

Table 1 : EDS Analysis at Dirrerent Points of Fig. 3b

Elements (wt%)	Cr	Mn	Fe	Ni	Cu
Point 1	19.12	2.02	69.56	9.30	0.00
Point 2	19.08	2.65	67.80	10.47	0.00
Point 3	18.61	2.25	66.34	12.81	0.00
Point 4	19.19	1.46	69.65	9.71	0.00
Point 5	17.01	3.99	59.58	13.11	6.30
Point 6	0.77	8.65	2.30	3.41	84.87
Point 7	0.00	8.38	2.29	4.30	85.03
Point 8	0.69	6.77	1.88	3.41	87.25
Point 9	0.48	9.65	0.66	4.59	84.63

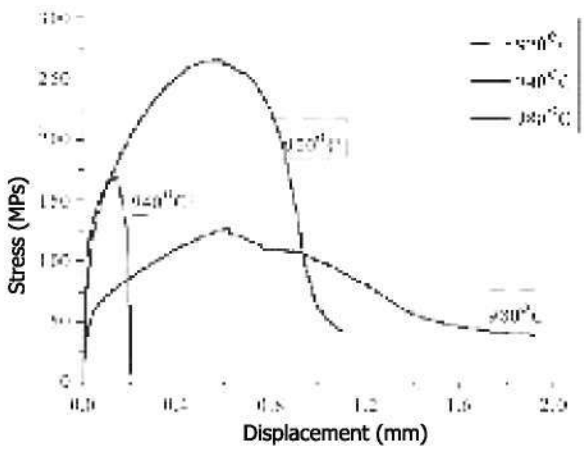


Fig. 4 : Stress- displacement curve SS-Cu butt joint brazed with Cu-50 filler alloy.

brazed joints by rapidly solidified C50 filler alloy. The curves show the ultimate tensile strength (UTS) value of 260, 175 and 126 MPa at the brazing temperatures of 920, 940 and 980°C, respectively. The UTS values of annealed 304 SS and pure Cu are 660 and 350 MPa, respectively [13, 14]. It means the maximum bond strength achieved at 920°C is 75% of base metal strength of Cu. The reason is the strong bonding between SS and Cu plates, depending upon the formation of phases at the joint area. The intermetallic compounds formation results in brittle failure, while the solid solution phases leads to ductile fracture. Therefore, the high bonding strength of 304SS-Cu joint is possibly related to solid solution phase formation at joint area, observed by EDS results described earlier.

3.4 Fractography Study

The photographs of fractured regions of SS and Cu plates are shown in **Fig. 5.** The nature of fracture area varies with bonding temperatures. The fracture takes place at the joint area when brazing temperature (BT) is 920°C, however, it occurs at BM of Cu near joint for BT = 980°C. Due to the softening of Cu, the early fracture occurs at the base metal (Cu) region for high BT. Therefore, the low brazing temperature is always preferable for better bonding between 304SS and Cu plates. The bonding behaviour at low brazing temperature is examined by fractography of two different fractured substrates. The severe deformation at some regions of 304SS substrate explains not only strong bonding (**Fig. 6a**), but also several dimples at Cu substrate (**Fig. 6b**) express good ductility in 304SS-Cu joint.

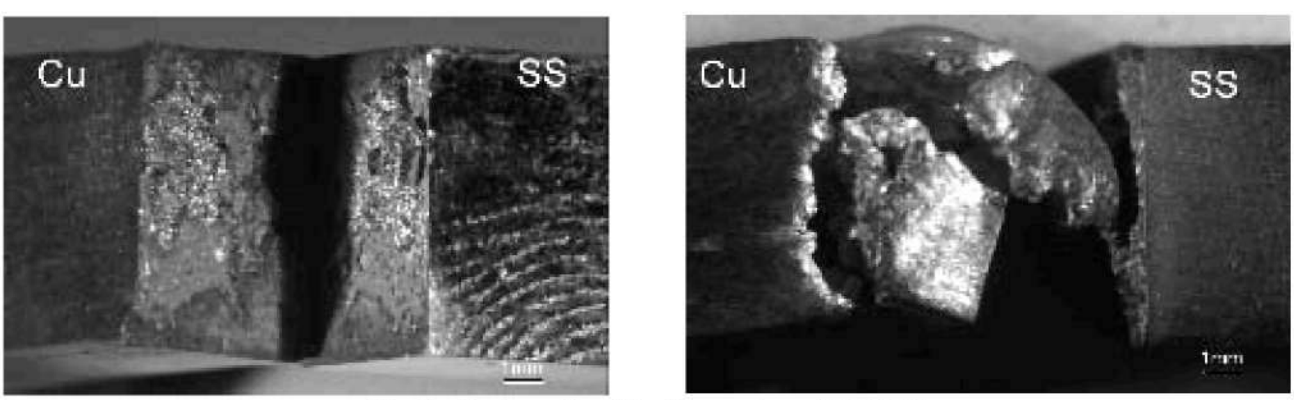


Fig. 5 : Photographs of fracture surface of 304SS-Cu joint brazed by C50 alloy (a) at 920°C, (b) at 980°C

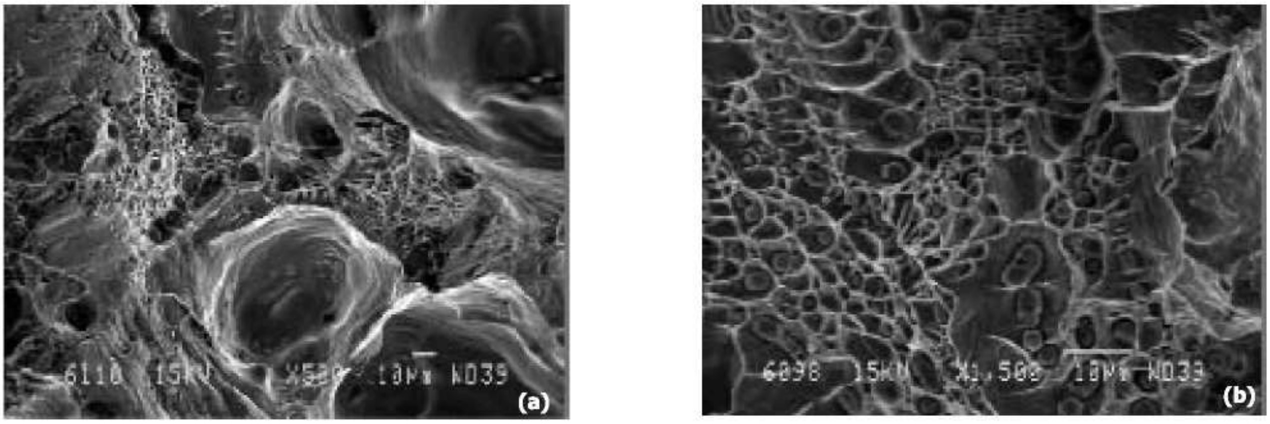


Fig. 6 : Fractographs of the butt joint at (a) SS substrate, (b) Cu substrate

4.0 CONCLUSIONS

Following conclusion can be drawn from the present work on brazing of 304 stainless steel to copper:

i. The developed 50Cu-40Mn-10Ni (C50) brazing filler is successful in making a joint between 304SS and Cu plates.

ii. The joint region is free from intermetallic compounds and porosities, resulting in a strong bonding between two dissimilar metals.

iii. The brazing at 920°C shows highest strength, which is approximately 75% of annealed Cu strength.

iv. The fractured areas of high bond strength joint are the combinations of severely deformed regions and several dimples.

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