INFLUENCE OF SURFACE CONDITION ON LASER BRAZING OF ALUMINUM TO STEEL

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Abstract

Traditional fusion joining of aluminum to steel is often complex due to high heat input which promotes excessive formation of thick intermetallics at the interface of the joint that leads to low strength and premature failure. Brazing would be a probable solution which utilizes a filler material and eliminates melting of the base metal and can potentially avoid intermetallics formation but requires careful selection of the filler metal. Laser brazing would be a potent tool for joining of aluminum alloy to galvanized steel.

In this work, laser weld-brazing was carried out using Al-Si eutectic filler wire for joining of AA 6082 T6 with galvanized steel and AA 6082 T6 with galvannealed steel in lap configuration. The microstructural characteristics of the laser brazed joints were studied under SEM, and it revealed cast structure in the brazed zone and mild intermetallics formation at the steel interface under both surface conditions. Interface layer was indexed as binary Al-Fe Intermetallics, and its thickness varied along the interface. The average shear strength of AA6082 T6 with galvannealed steel joint was only 210 N/mm with typical interfacial failure due to mechanical osculation, while that of AA6082 with galvanized steel was 290 N/mm and it failed at the HAZ of AA6082.

Keywords: AA6082, Galvanized steel, Galvannealed steel, Laser brazing.

1. Introduction

Joining of aluminum to steel has potential application in the transport industry. Aluminum and its alloys reduce the weight of the structure, while steel provides required strength, corrosion resistance, and low fabrication cost. However, successful fusion joining of steel to aluminum alloy is challenging due to wide variation in thermo-physical characteristics. Major problem is formation of brittle intermetallics (IMC) at the steel interface, which subsequently, reduces the joint efficiency [1-2].

To have more reliable joints, in recent studies, friction stir welding [3], diffusion bonding [4], ultrasonic welding [5], were explored to join aluminum to steel. The results show that thickness and distribution of the intermetallic compound layer can be controlled to some extent, but it has limitation in joint design and configuration.

Laser brazing would be an alternative joining technique for dissimilar metals (Aluminum to steel) because of its low heat input nature, smooth bead surfaces and flexibility over other welding technique [6]. It is very usual as chance of Al/Fe intermetallics formation at the joint interface is low with low heat input process. In previous studies, diode laser was used to braze-weld aluminum with different coated steel using eutectic filler wires. This coated steel helps in wetting and improves joint efficiency. Currently, researchers focus on (a) reducing intermetallic thickness at the interface by using surface modification techniques (b) nucleation and growth study of the intermetallics which includes the diffusion of elements at the IMC layer [7].

Dong et al. [8] and Laukant et al. [9] have suggested that joint efficiency can be increased, provided intermetallic compound layer thickness is limited to 10 microns. Jacome et al. [10] reported that increasing silicon content (3 to 5 %) in the aluminum filler wire has significantly reduced the growth of intermetallics thickness by 40%. Whereas addition of 1 % Mn to the filler wire did not show any change in intermetallics growth. However, marginal improved joint strength. Yagati et al. and other researchers [11-12] found that increase in Si (5 to 12%) would limit the growth of the IMC layer and improves the joint efficiency. Watanabe et al. [13] reported that introduction of A1050 interlayer during ultrasonic welding of A5052 to SS400 reduces the growth of Fe_2Al_5 intermetallics.

In the present study, laser brazing was carried out with 4047 filler wire for joining of AA 6082 T6 with galvanized steel and AA 6082-T6 with galvannealed steel in lap configuration. The influence of surface condition of the steel on the macrostructure and microstructures along with mechanical properties of the joints were investigated.

2. Experimental Procedure

For the present study, 2 mm thick AA6082-T6, Galvanized steel (GI), and galvannealed steel (GA) were laser brazed with 4047 (Al-12Si) filler wire. Base material and filer wire chemical compositions are shown in table 1.

Table 1. Chemical composition of the base material

Material	C	Mn	P	S	Ti	Fe	Si	Cu	Cr	Zn	Mg	Al
Steel (IF steel)	0.002	0.25	0.020	0.020	0.30	Rest	-	-	-	-	-	-
AA6082	-	0.40 - 1.00	-	-	-	0.50	0.7-1.3	0.10 max	0.25 max	0.20	0.06 - 1.20	Rest
Filler (4047)$AlSi_{12}$	-	0.55 max	-	-	-	0.6	10.5 - 13.5	-	-	-	0.15 max	Rest

For laser brazing experiments, specimens of 150 mm x100 mm size were used in lap configuration (aluminum is placed over steel). Before experiment, Aluminum samples were wire brushed to remove any oxide layer over the surface of and cleaned with acetone, were as steel pieces were degreased with acetone. Brazing experiments were carried out using a laser head (Scansonic Al_2O_3 DYD2W-1.7) integrated to 6 kW Diode laser. Laser brazing experiments parameters were tabulated in table 2.

Table 2. Parameters for laser brazing of lap joints

Sample Id	Laser power (kW)	Speed (m/min)	Wire Feed Rate(m/min)
AA6082/GA	4	2	2.5
AA6082/GI	4	2	2.5

Laser brazing experiments were performed with a spot size of 1.7 mm. The shielding gas is fed through of a 5 mm diameter nozzle in a reverse configuration with a gauge pressure of 1 bar and a nozzle spacing distance of 3 mm. The metallographic samples of laser brazed joints were prepared for macro and microscopic observation. The samples were etched with Keller reagent, then examined with an optical microscope (Carl Zeiss) and SEM (JEOL JSM-6084LV) for microstructural analysis. Shear Tensile tests of the welds were carried using 100 kN servo-hydraulic universal testing machine (model: BISS, India) at a constant crosshead speed of 0.5 mm/min.

3. Results and Discussions

3.1 Macrostructures

Figure 1 shows the cross-section of laser brazed AA6082/GI and AA6082/GA lap joints. Joints exhibit typical welding characteristics at the aluminum side; whereas at steel side, brazing is the sole mechanism. Macrostructure has revealed little discernable porosity which can be attributed to hydrogen entrapment during the process.

Figure 1a shows the lap joints prepared with galvannealed steel. The joint exhibits convex shape with the higher wetting angle and reduced wetting length. Reduction in wetting length could be attributed to heat dissipation into the base material, and same results were also reported by Frank et al. [14].

The presence of zinc on the galvanized steel helps to improve the wetting and spreading, of molten filler wire by consuming addition heat at the material interface. The joint exhibits less convex curvature shape with the increased wetting length (figure 1b). According to Gatzen et al. [15], wetting is also based on varity of factors such as surface roughness, heterogeneity of the surface, physical characteristics of liquid and atmospheric conditions.

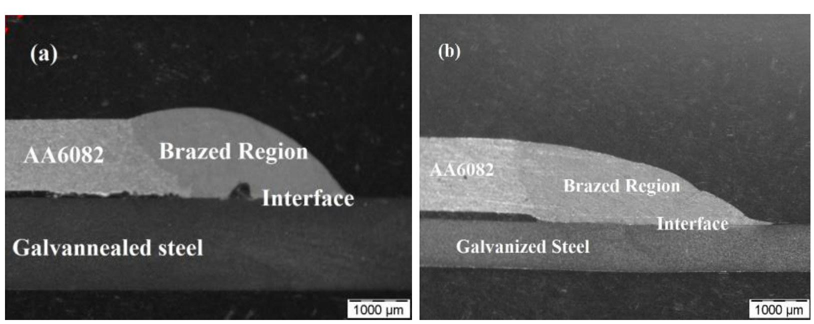

Figure 1 macrostructure of laser brazed (a) galvannealed (b) galvanized sample

3.2 Microstructure

The SEM micrographs of all laser brazed samples (steel interface) are displayed in figure 2. The brazed joint comprises of different regions (a) solidifying filler metal (b) aluminum steel interface (c) heat affected zone at the aluminum side. In the figure, only first two zones were displayed. In brazed zone microstructure both the joints show a α-Al dendritic structure with aluminum-silicon in the interdendritic region. Figure 2 depicts the different region in laser brazed joints in both (galvanized and galvannealed steel) the conditions. From Figure 2, it can be seen that the thickness and distribution of intermetallics are uneven in all conditions (galvanized and galvanized steel) because of the difference in temperature throughout the joint.

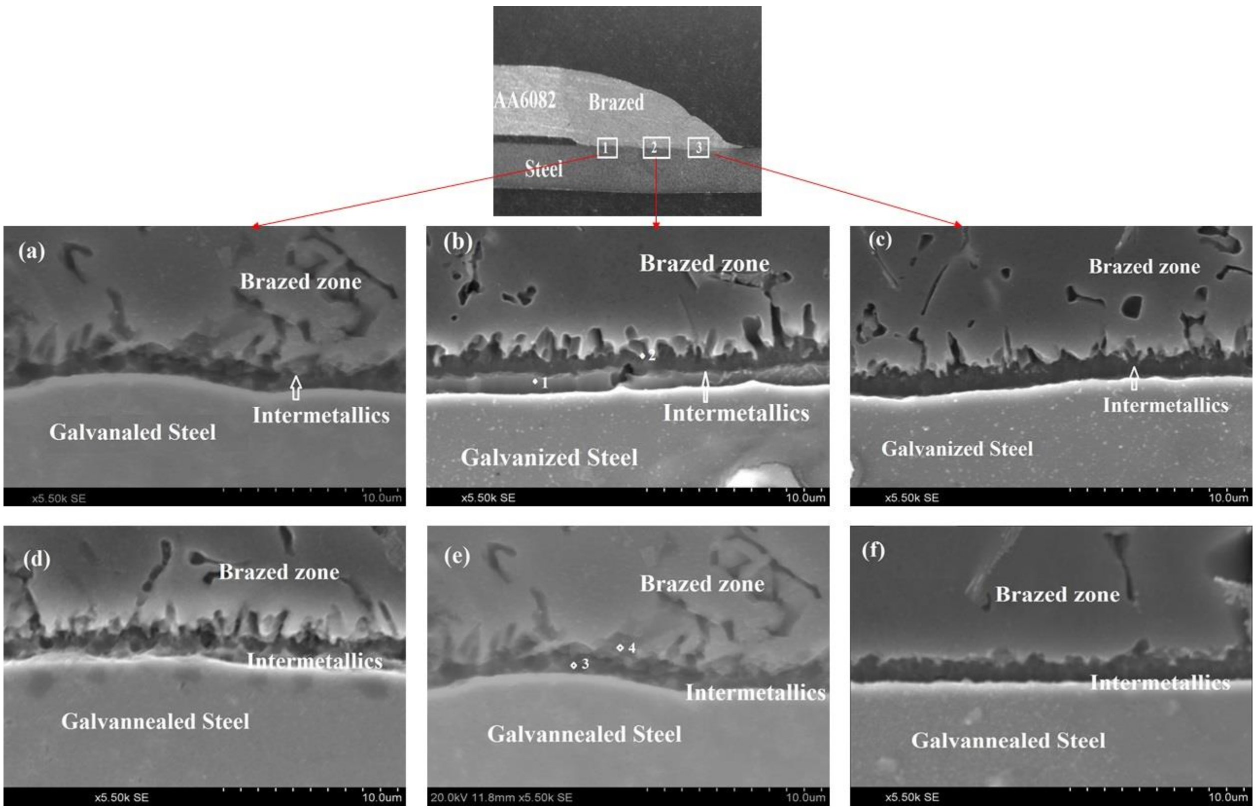

Figure 2: microstructures of laser brazed joint with different surface conditions (galvanized and galvannealed steels)

Figure 2(a-c) shows there is a noticeable difference in the morphology of intermetallic layers at the steel interface obtained from the location (1-3, marked in the schematic view). The Location 2 shows needle-shaped structures protruding in the bead, while location 1 and 3 showed only plate-like structure with needles above it. These needles in the location 1 and 3 are finer than the needles in the location 2. In case of Figure 2 (d-f), the undulation at the interface is prominent, due to high temperatures experienced and it may also be the reason for the growth of thicker intermetallic layer. Galvannealed steel exhibits increased IMC layer thickness compare to galvanized steel. It was reported that Zn absorbs most of the energy, lesser energy are available for formation of intermetallics at the steel interface [15]. Energy Dispersive Spectroscopy (EDS) analysis was performed on different location on the interface and results are shown in table 3. Phases identified in case of galvanized steel are Al_2FeSi, Fe_2Al_5 and same can be observed in the figure 2b (demarcated as 1 and 2). In case of galvannealed steel, identified intermetallics are Al_3FeSi_2, $AlFe_3$ can be seen in figure 2e (demarcated as 3 and 4).

Table 3: ED's analysis at intermetallics

PT. No	At. %				possible Intermetallic
	Al	Si	Fe	Zn	
1	50.62	23.37	26.01	-	Al_2FeSi
2	65.58	7.90	25.94	0.58	Fe_2Al_5
3	3.87	-	86.13	-	$AlFe_3$
4	51.95	16.15	31.90	-	Al_3FeSi_2

3.3 Tensile Properties

Lap shear test were conducted under tension on laser brazed samples prepared with similar heat input conditions. From the results, it is noticed that higher strength was achieved with galvanized sample (approximately 290 N/mm), whereas, galvannealed sample has shown 210 N/mm.

Figure 3 represents the failure locations of the joints as obtained by shear testing. It can be seen from figure 3 that in case of galvanized steel, the failure was in the heat affected zone; while, galvannealed sample failed in the brazed region. Form the fracture location results; it can be concluded that high wetting angle is the reason for lower joint strength for the galvannealed sample.

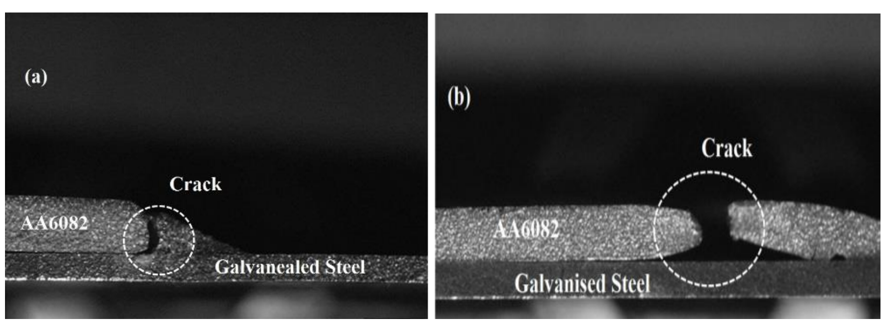

Figure 3 fracture location (a) galvannealed (b) galvanized samples

4. Conclusions

In this paper, laser brazing was performed with AA6082/Galvanized steel, and AA6082/Galvannealed steel in lap configuration and their characterizations revealed the following conclusions:

1. Due to difference in surface condition, wetting of molten Aluminum over the steel surface and the morphology of IMC layer were found to be different.
2. Brazing with galvanized steel has revealed Aluminum rich intermetallics; whereas, galvannealed steel has shown iron-rich intermetallics.

3. The maximum tensile strength of joints was up to 290 N/mm when was brazed with galvanized steel and it failed in the HAZ of Aluminum. The tensile strength of Galvannealed steel decreased due to bead characteristics.

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