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Research paper

Effect of filler wire composition on performance of Al/Galvanized steel joints by twin spot laser welding-brazing method

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ABSTRACT

A twin-spot laser welding-brazing (LWB) process to join aluminum alloy 6022 and hot-dip galvanized steel in coach peel configuration was reported. A maximum surface roughness and sufficient mechanical strength are the important criteria which are affected by the process parameters during welding to judge the weld quality for some applications, such as the automotive industry. Thus, the influences of the main laser welding-brazing process parameters (laser power, wire feed rate, and scanning speed) on the mechanical strength and surface roughness of welds were studied and analytical models relating the output properties of interest to process parameters were also developed. The response surface methodology (RSM) and desirability function were utilized for optimizing the multi-response LWB process. Finally, validation experiments were conducted on an optimized process condition which exhibited good agreement between the predicted and experimental results. Four different filler wire materials were employed (AlSi12, AlSi5, AlSi3Mn1, and ZnAl15). The effects of the wire alloying elements on the microstructure of the weld, weld surface quality, and mechanical resistance were investigated. The measured intermetallic compound, IMC, layer at the Fe/Al interface of joints revealed that AlSi12 filler wire resulted in the thinnest IMC layer at less than 2 μm; in contrast, this value increased to 7 μm for joints with ZnAl15 wire. In terms of surface roughness, the lowest (Ra = 0.917 μm) and highest (Ra = 2.83 μm) values were achieved by using AlSi3Mn1 and ZnAl15 wires, respectively. Although the Zn-based filler wire offered the maximum tensile resistance around 180N/mm, joints with AlSi12 wire had mechanical resistance of 120 N/mm and lower values of IMC layer thickness and surface roughness. Therefore, AlSi12 filler material is recommended as the laser brazing filler material for joining dissimilar aluminum-galvanized steel coach peel panels in automotive body-in-white (BIW) fabrication applications.

1. Introduction

Government legislation regarding fuel efficiency and environmental issues has aroused the interest of the automotive industry to create new technological solutions. Beside the development of new powertrain solutions, mass reduction of the vehicle body is another effective approach. Lightweight structures currently are seen as a composite of structural materials such as steel, aluminum, and magnesium. From both a mechanical and economical perspective, hybrid structures have been introduced as an efficient way to satisfy these conditions [1]. In recent years, this approach has opened up an attractive field of research for joining aluminum and steel alloys together. The existence of a significant difference between Al and steel in terms of thermal and physical properties and almost zero solid solubility of Al in Fe, and vice versa, made the formation of intermetallic an inevitable result [2]. The generation of brittle intermetallic compounds (IMCs) with hardness around 1000 Vickers originated from the diffusion of iron into molten aluminum material. L. Agudo [3] pointed out that the formation of Fe_xAl_y from the Fe/Al intermetallic family was vital to have an effectual joining between the Al and steel. Lin et al. [4] showed that the mechanical performance of aluminum and steel joints were linked to the thickness of Fe and Al rich intermetallic layers where thicker ones lead to brittle fracture of joints. They stated that to avoid brittle fracture the thickness of IMC layer should be less than 10 μm. The correlation between the growth of the IMC layer and thermal cycle at the Fe/Al interface was developed experimentally and numerically by Mathieu et al. [5]. They showed that the thickness of the intermetallic layer was affected by the process temperature, process duration, and time of interaction at high temperature. Therefore, the growth

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of IMC layer thickness could be controlled by modifying the process speed and heat input. Laser-based joining technologies could be a suitable candidate for joining dissimilar materials because of a concentrated energy density on a small area, ease of automation, and ability to reach a high scanning speed [6]. Several researches have been conducted on laser welding-brazing (LWB) of steel to aluminum in different joint configurations wherein a fusion welding joint was generated on the aluminum side and a brazing joint was formed on the steel side of the weld. Saida et al. [7] used LWB for an Al-steel lap joint configuration with AlSi12 filler. They fabricated joints at a laser power level of 1300 W resulting in a maximum strength of approximately 80% of the Al5052 base material and an IMC layer thickness less than 2 μm. Filliard et al. [8] investigated LWB of steel to Al in an angled configuration by means of a single laser beam with spot diameter of 3 mm, laser power of 6 kW, and welding speed of 4–6 m/min. They succeeded in obtaining joints with mechanical strength of 101% of mechanical properties of filler material and IMC layers with thickness less than 2 μm. Shabadi et al. [9] conducted experiments to join the low carbon galvanized steel to aluminum sheet by means of Al-Zn filler wire with a laser power of 1.5 kW and scanning speed of 2 m/min. The generated intermetallic layer had thickness less than 10 μm, and the dominant fracture mode occurred in the heat affected zone of the Al panel.

Most studies of the laser welding-brazing process have been carried out by using a single laser beam, but several multi-beam laser heads have been developed for this process. The main purpose behind this innovation is enhancing the quality and mechanical properties of joints by preheating the joining partners and deeper filling of the gaps [10]. Yang et al. [11,12] comprehensively investigated the effect of laser beam arrangement on welding of similar and dissimilar materials in the coach peel configuration. Based upon the comparative results in terms of the mechanical properties, surface roughness, microstructural evolution, and finite element thermal analysis, the cross-beam laser mode was recommended as the best choice to join the aluminum panels. Frank S. [13] reported that a combination of continuous and pulsed laser beams in a circular and line-shaped mode perpendicular to the weld provided good wetting where the pulsed laser removed the aluminum's oxide layer, while the continuous beam melted the filler material. At a welding speed of 3.6 m/min, they could limit the IMC layer thickness to less than the critical value of 10 μm. Mohammadpour et al. [14] demonstrated that the resultant joints of LWB of aluminum to steel coach peel panels by means of dual cross-beam mode exhibited better performance than joints from dual in-line laser beam mode. Based upon numerical simulation results, at the welding speed of 3.6m/min, the critical temperature range (700 °C–900 °C) for the duration of less than 1 s at the Fe/Al interface generated a thickness of the IMC layer of less than 3 μm.

The LWB joints are typically on the visible exterior of a car body for applications such as a deck lid or roof. The resultant joints require not only adequate strength to pass dynamic testing, but the welded joints should also be defect free with sufficiently low surface roughness to avoid post-weld processing. There is no doubt that these required qualities of the LWB joint are directly influenced by the input process parameters. Consequently, laser welding-brazing can be considered as a multi-input multi-output process. This point of view can enable utilization of the design of experiments (DOE) method to build up mathematical relationships between the LWB process input parameters and output variables. However, there are no available studies in the literature on the multi-response optimization of laser welding-brazing of steel to Al and the interaction of process parameters by using a statistical approach. There is limited work on the laser brazing of Al to Al and steel to steel coach peel panels which investigated a single response either on geometry of the weld bead or on surface roughness. Zhou et al. [15] conducted a hybrid optimization methodology to address the effects of process parameters on the bead profile of laser brazed steel panels. They combined a genetic algorithm (GA) and ensemble of metamodels (EMs) to establish the relationships between process parameters and bead geometries measured from experimental data. Rong et al. [16] optimized the seam shape in the laser brazing process by using the method of back propagation neural network (BPNN) and genetic algorithm (GA). They introduced welding speed, wire speed rate, and gap as the input parameters and discussed their effects on the sum values of bead geometry. Yang et al. [17] conducted experiments based on Taguchi L9 orthogonal array to optimize the shielding gas parameters (tube angle, gas flow rate, and distance between the center of nozzle and laser beam) to enhance the surface quality and mitigate the weld surface defects. The experimental results showed that the surface roughness of the bead was less than 1 μm when a circular gas nozzle was positioned at 5 mm behind the laser beam, and the flow rate of shielding gas (pure argon) was adjusted at 30 Standard Cubic Feet per Hour (SCFH) with an inclination angle of 45° to the horizontal plane.

In this study laser welding-brazing process was utilized to join aluminum to steel panels by four commonly used filler wires at a high scanning speed. First, the influence of process parameters on desired responses was investigated by means of Response Surface Methodology (RSM) in order to clarify the effects of input parameters on the final results. Then a multi-objective optimization approach was implemented to find the optimal processing condition based on defined responses (maximum mechanical strength and minimum surface roughness). Finally, the effect of filler wires (AlSi12, AlSi5, AlSi3Mn1, and ZnAl15) and distribution of alloying elements in the weld were investigated with respect to the mechanical strength, surface roughness, and microstructure.

2. Experimental work

2.1. Material and methods

The materials used for dissimilar LWB in this study were aluminum 6022 and Hot Dip Galvanized (HDG) low carbon steel (GMW2M-ST-S-CR4) with chemical compositions as presented in Table 1. The thickness of coach peel panels were 1.2 mm and 0.65 mm for Al and HDG, respectively. The coach peel configuration in this study corresponds to the simplified geometry of an industrially relevant automotive application in the joining of roof to body side outer (see Fig. 1).

The average zinc coating thickness of steel panels was approximately 10 μm with a typical cross section of coating is presented in Fig. 2. It should be noted that the coating thickness was not uni-

Table 1
Chemical composition of substrate materials.

Substrates	Alloying elements							
	Si	Fe	Mn	Mg	Zn	Ti	Cr	Al
Al6022	1.00	0.15	0.07	0.56	0.01	0.02	0.02	Bal.
Hot dip Galvanized steel (HDG)	C	Al	Mn	P	Si	S	Fe	
	0.003	0.034	0.11	0.01	0.005	0.008	Bal.	