Journal of Manufacturing Processes 25 (2017) 126–133

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

The study of mechanical strength for fusion-brazed butt joint between aluminum alloy and galvanized steel by arc-assisted laser welding

Jiankang Huang, Jing He, Xiaoquan Yu, Chunling Li, Ding Fan*

State Key Laboratory of Advanced Processing and Recycling of Non-ferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China

ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form
19 November 2016
Accepted 28 November 2016

Keywords:
Arc-assisted laser welding
Aluminum alloy
Steel
Tensile strength

ABSTRACT

By the method of arc-assisted laser brazing with preset filler powder, the dissimilar metals butt welding experiment between 5A06 aluminum alloy and galvanized steel was conducted. The intermetallic compounds (IMCs) thickness was observed by scanning electron microscope (SEM), the spreading width was measured by micrometer and the tensile strength (TS) was tested by the tensile test machine. The effects of laser power, arc current, welding speed and the distance of heat sources on TS were investigated. The results show that the IMCs thickness increases with the increase of laser power, arc current, welding speed and the decrease of the distance of two heat sources. The assisted arc can improve spreading width with a low heat input. The TS is not only related to the IMCs thickness, but also related to the spreading width, the TS can be enhanced by improving the spreading width of aluminum liquid on steel side based on the IMCs thickness is less than 10 μm. The solder joint with good mechanical property can be obtained, and it's IMCs thickness can be controlled in the range of 10 μm by using the optimum laser power, arc current, welding speed and the distance of heat sources that is 1.2 kW, 15 A, 10 mm/s, 15 mm, respectively. The maximum TS of joint is up to 163 MPa and the IMCs thickness of which is 8.7 μm.

1. Introduction

Global warming has become the topic of public concern, and reducing the emissions of carbon dioxide is attracting attention. Hence automotive lightening has been the focus of the study in all automobile industries [1]. Depending on its low density and excellent mechanical properties, the aluminum alloy becomes the optimum material for lighter cars [2,3]. But it is quite expensive for the body structure with only aluminum alloy and the automobile industries are unwilling to undertake this exorbitant cost, so we have to only replace parts of car's steel body by aluminum alloy [4]. Accordingly, it is of great significance for the study of joining aluminum to steel.

The major problem of joining aluminum–steel dissimilar metals is the different properties of materials and the occurrence of IMCs [5]. These compounds have a serious impact on weld quality and mechanical properties of the joints due to their high hardness and brittleness [6–8]. The key to improve the mechanical properties of the joints is to control the formation of IMCs and limit IMCs thickness within 10 μm based on the growth mechanism of IMCs [9–12]. Nowadays many measures have been proposed to control the IMCs thickness such as resistance spot welding [13,14], diffusion bonding [15], penetration welding [16], friction welding [17–19], brazing [20], explosive welding [21,22], welding–brazing and other methods [23–26]. Welding–brazing has become the focus of many academics among these welding methods because it can effectively limit the formation of IMCs. The key of welding–brazing is the heat source that determined the heat input energy, accordingly to control the heat input of welding–brazing. Studies have shown that heat sources has a great relationship with the formation of IMCs [12]. Cao et al. [27] obtained aluminum–steel joint with the cold metal transfer (CMT) welding–brazing technology, the IMCs thickness of which was controlled in 5–10 μm, and found the TS depend on the IMCs thickness and softening in the heat shadow region. Song et al. [28] got the joint of 5A06 aluminum alloy and SUS321 stainless steel by TIG welding–brazing with 4047 Al–Si eutectic filler metal and modified non-corrosive flux, and discovered the failure generally located in the IMCs layer when its thickness exceeded 10 μm. Sierra et al. [29] achieved the joint between steel and 6016-T4 Al alloy by laser braze welding using 4047 filler wire and brazing flux. They detected that the IMCs thickness was less than 2 μm and the cracks derived from the reaction layer of steel/bead interface. Zhang and Liu [30] obtained joints of aluminum alloy 2B50 and stainless steel 1Cr18Ni9Ti by MIG

* Corresponding author.
E-mail address: fand@lut.cn (D. Fan).

http://dx.doi.org/10.1016/j.jmapro.2016.11.014

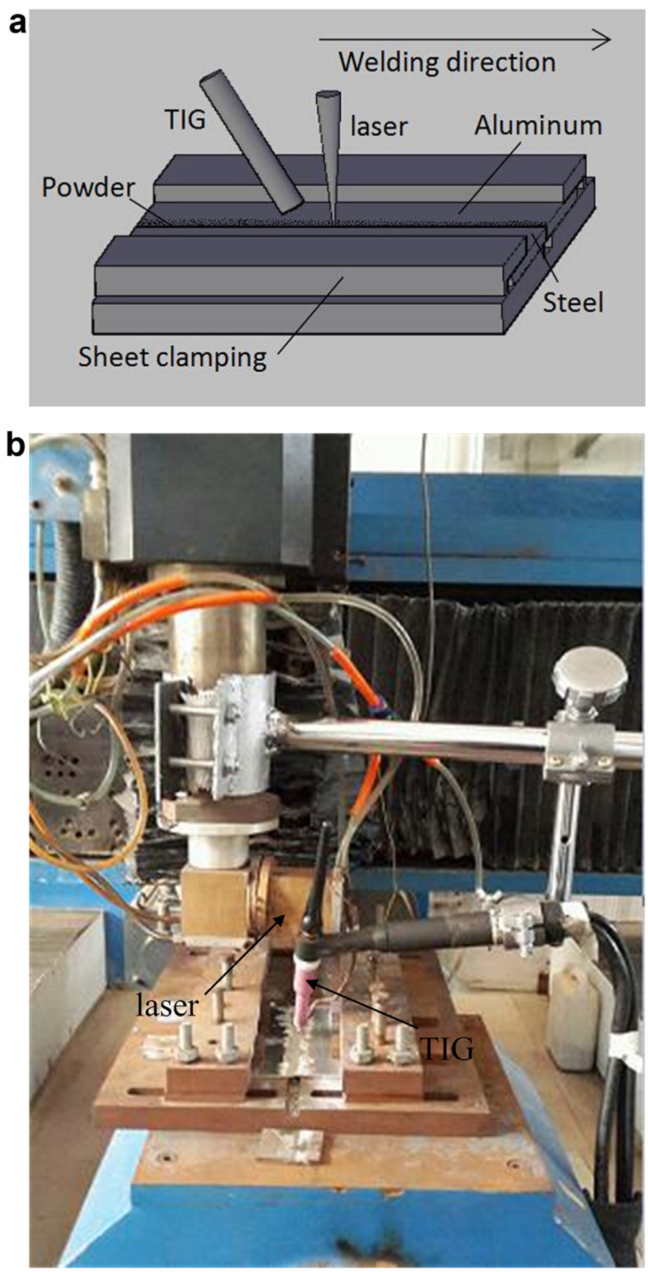

Fig. 1. Principle of arc-assisted laser brazing with preset filler powder welding process. (a) Elevation view. (b) Side view.

welding–brazing method with 4043 Al–Si filler metal and found out that the strength of the joints was increased linearly with the reaction layer width. Borrisutthekul et al. [31] achieved the joint between steel and aluminum by laser welding and found that the joint strength increased with the decrease of intermetallic reaction layer thickness.

According to the research mentioned above, a conclusion seems justified that the TS of joint is related not only with the IMCs thickness, but also with the spreading width. Recently, Fan et al. [32] found a new method called arc-assisted laser brazing with preset filler powder, which can improve the spreading width of aluminum liquid to steel, and inferred that the increasing spreading width can enhance TS. It is known that the welding parameter has a substantial effect on TS. However, in the arc-assisted laser brazing with preset filler powder, the influence of welding parameters on the increase of TS has not been investigated.

The aim of the present work is to obtain a butt joint between 5A06 aluminum and galvanized steel with good mechanical properties by arc-assisted laser brazing with preset filler powder and study the influence of welding parameter on TS. We chose different parameters to do the welding experiments. After welding, the IMCs thickness was observed by SEM, the spreading width was measured by micrometer, and the TS of specimens were tested by tensile test machine. Then, the optimum welding parameters were obtained and the effect of laser power, arc current, welding speed and the distance of heat sources on the IMCs thickness and the spreading width were investigated. Finally, the relationship between TS and both spreading width and IMCs thickness was deduced from the dates obtained from the experiments.

2. Experimental procedure

2.1. Arc-assisted laser welding

The arrangement of arc-assisted laser welding is shown in Fig. 1. The TIG torch is fastened behind the laser beam to ensure synchronous motion and the distance between the centers of the TIG torch and laser beam was D_{LA}, and the angle of the TIG torch to the vertical direction was 60°. The arrangement of arc-assisted laser welding is similar to laser–TIG hybrid welding, but unlike laser–TIG hybrid welding, the arc current of arc-assisted laser welding is small and has little effect on the heat input of base material, and the distance of the two heat sources is long resulting in no interaction of laser beam and TIG arc which is the symbol of laser–TIG hybrid welding. Through the arc-assisted laser welding process, the main heat input is from laser beam, and the function of arc is to improve the spreading width. The principle of the arc to improve spreading width in arc-assisted laser welding is that the arc force can shock the surface of molten pool, promoting the molten pool spreading laterally.

2.2. Materials

The materials used in the study included 2 mm thick 5A06 aluminum alloy, 1 mm thick ST04Z galvanized steel and preset filler powder. The specimens size of both 5A06 aluminum alloy and the galvanized steel is 150 mm (length) × 50 mm (width). The chemical compositions of aluminum alloy, galvanized steel and preset filler powder are listed in Table 1.

2.3. Welding procedures

The welding equipments used were GS-TFL-10KCO_2 High Power Crosscurrent CO_2 laser and TSP300 TIG welder. Before welding, the oxide films on the surface of aluminum alloy were wiped off with sandpaper, and the specimens of aluminum alloy and galvanized steel were cleaned to remove oil and grease with acetone. Then the cleaned specimens were arranged with butt joint and the pre-welding gap is 0.4 mm. And coating the CJ401 fluxes (the main compositions are KCl, NaCl, LiCl, NaF and so on) and the preset filler powder on the weld bead in turn. The thickness of preset filler powder coating layer is suitable to cover workpiece completely. Afterwards the experiments using different parameters were investigated by arc-assisted laser brazing with preset filler powder. During welding process, the fixed parameters were that laser defocus was 0 mm, arc length was 3 mm and the rich Ar gas as shielding gas, in which the laser shielding gas flow was 15 L/min and the arc shielding gas flow was 10 L/min. The other welding parameters were shown in Table 2.