RESEARCH PAPER | Engineering | Volume - 5 | Issue - 1 | Jan Special Issue - 2015 | ISSN - 2249-555X

Laser Welding and Friction Stir Welding of Dissimilar Materials: A Review

KEYWORDS friction stir welding, laser welding, dissimilar metals, microhardness, tensile strength

Ms. Deepika Harwani	Mr. Kapil Banker
PG Student, Department of Mechanical, SVBIT, Gujarat Technological University	Asst. Professor, Department of Mechanical, SVBIT, Gujarat Technological University

ABSTRACT The ability to manufacture a product using different combinations of metals and alloys increases the flexibility in design and production. Joining of dissimilar metals, however, seems to be a challenging task owing to the large differences in physical and chemical properties of the base metals. There has been continuous research on parametric optimization and effects of process parameters on the properties of the welded joint by various processes for joining dissimilar materials. Laser Beam Welding, a high power density and low energy-input process, employs a laser beam to produce welds of dissimilar materials. Friction Stir Welding, a solid-state joining process, is also successfully used in dissimilar welding applications like aerospace and ship building industries. This paper attempts to review the published literature of both Laser welding and Friction Stir welding of dissimilar metal pairs.

I. INTRODUCTION

Friction Stir Welding (FSW) process is a solid-state joining process which employs a non-consumable rotating tool to join two facing surfaces. Friction between the rotating tool and the workpieces generates heat, and the high normal pressure under the tool causes a plasticised zone of material to form around the probe. As the tool is traversed along the joint line, the workpiece material is heated, plasticised, and extruded around the tool probe. The extruded material forms a solid-phase joint behind the tool as it passes. Its principle is shown in Fig 1. FSW finds applications in shipbuilding, automotive and aerospace sector, general fabrication, robotics and computers.

Laser Beam Welding (LBW) is a welding technique which uses a laser beam to join pieces of metal. When the laser beam is focused onto the workpieces, it provides a concentrated heat source, allowing for narrow, deep welds and high welding rates (as shown in Fig. 2). It is a versatile process, capable of welding carbon steels, stainless steels, aluminium and titanium, including dissimilar combinations.

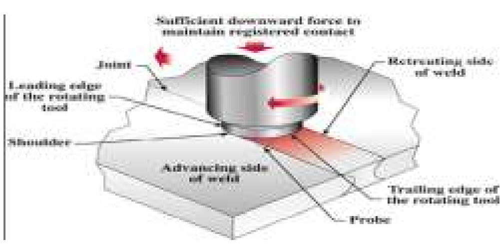

Fig. 1 Principle of Friction Stir Welding [10]

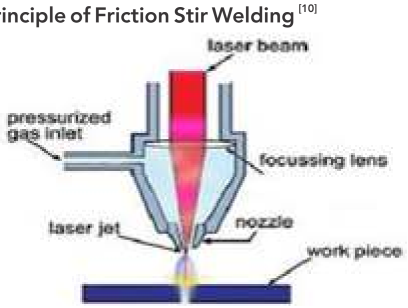

Fig. 2 Principle of Laser Beam Welding

I.LITERATURE REVIEW

Di Zuo et al. [1] investigated the influence of various process parameters on the intermediate layer formed between the welded joint of copper and aluminium, by employing laser welding. A continuous Nd:YAG laser source was used for welding 1060 aluminium alloy and T2 copper alloy, both having dimensions (100 × 20 × 0.3 mm). During welding, the welding speed was varied from 95 mm/s, 105 mm/s, 115 mm/s, 125 mm/s, 135 mm/s, and 145 mm/s to 155 mm/s in order to obtain different welding energy inputs per unit length while the laser power was fixed at 1650 W. Microstructures of the welded joints were observed by metallographic microscopy and scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS) for chemical constitution analysis. It was found that the intermediate layer was made up of four zones, which could be distinguished by their morphology and colors. On the Al-rich side, the zones mainly consisted of dendrites (α-Al) and a lamellar eutectic structure (α -Al + θ-$CuAl_2$). On the Cu-rich side, zones mainly consisted of columnar grains (γ_2-Cu_9Al_4) and a hypoeutectic structure. Gray relational theory was used to define the relationship between the thicknesses of different zones and the mechanical properties.

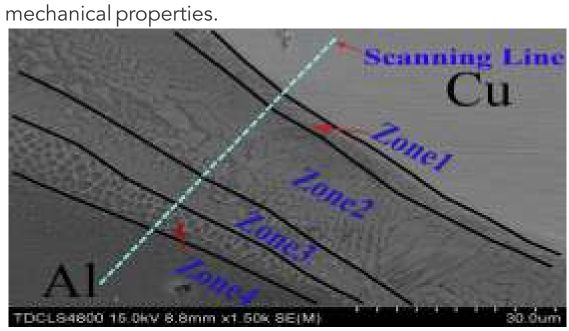

Fig. 3 Morphology of four zones in intermediate layer [1]

J.F. Guo et al. [2] have friction stir welded dissimilar alloys of Aluminium AA6061 and AA7075 with a variety of different process parameters. The alloys were taken in the form of rolled plates both having length of 300mm, width 50mm (in rolling direction) and 6.3mm thickness. Butt joints were then produced using a friction stir robot at a constant tool rotation speed of 1200 rpm. The temperature history profiles in the HAZ and at zones close to TMAZ (thermo-mechanically affected zones) were also measured using K-type thermocouples having diameter of 0.25 mm and simulated using a three-dimensional computational model. These thermocouples were fixed into the holes with short bars of 1.6 mm diameter 5356 Al filler wire. The filler wires were then mechanically punched to improve the contact between the thermocouples and the workpiece.

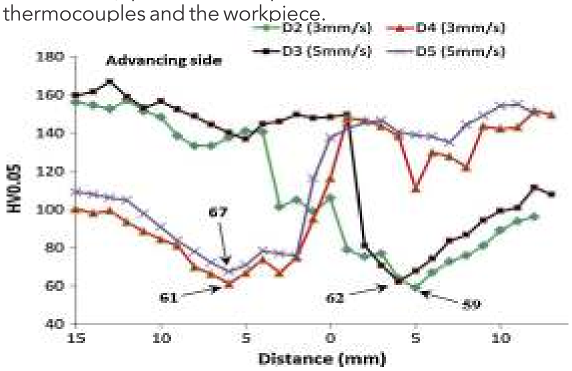

Fig. 4 Vicker's microhardness profiles of the cross-section of dissimilar joints [2]

P. Woizeschke et al. [3] have highlighted some new developments in laser welding of CFRP – Aluminium structures. A combined welding-brazing process was applied to join aluminum and titanium structures. The aluminum and titanium structures are fixed onto a clamping device with the aluminum part on top. A laser beam is split in two beams to enable a simultaneous double sided joining process. The authors have spread light on the 'wire concept' which represents a parallel arrangement of miniaturized loop connections and the 'foil concept' is which based on titanium laminates. This concept is characterized by joining a Ti-CFRP laminate to an aluminum sheet. Aluminum alloy EN AW-6082 was used for the experiments in this paper. Slots of 1 mm and 2 mm width and 2 mm and 6 mm depth were milled into the aluminum sheets having a thickness of 4 mm to insert the titanium transition structures. The titanium foils of the transition laminate had a thickness of 0.6 mm each.

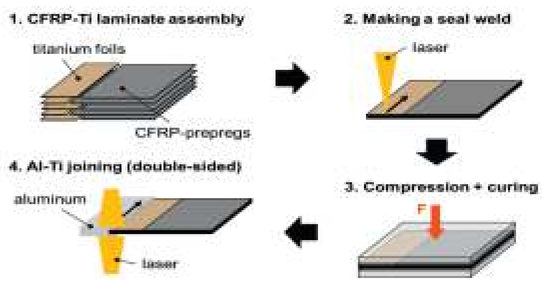

Fig. 5 Procedure of the foil concept to join CFRP and aluminum structures by laser beam processes [3]

RajKumar.V et al. [4] studied the effect of tool design and other welding parameters like feed rate on friction stir welded dissimilar aluminium alloys AA 5052 – AA 6061. Two samples were welded – Sample 'A' welded at 710 rpm and 28 mm/min feed and Sample 'B' welded at 710 rpm and 20 mm/min feed. The coupons, having dimensions 100mm x 50 mm, were butt welded using a standard milling machine having a special clamping arrangement. AA 5052 was kept at the advancing side and AA6061in the retreating side. AISI H13 tool steel was used as the tool material. The shoulder diameter was 16mm and pin diameter being kept 6mm. After welding, optical microscopic studies were carried out along with the tensile tests. The hardness profile was monitored using Matsuzawa MMT-X Vickers hardness tester. It was inferred after the practical study that cylindrical threaded pin rendered excellent bondage between both the alloys.

Fig. 6 Snapshot of the cylindrical threaded tool after welding [4]

Yahya Bozkurt et al. [5] applied Taguchi approach to optimize the Friction Stir Spot Welding Process (FSSW) (as shown in Table 1 below) to weld dissimilar AA2024-T3 and AA5754-H22 aluminum alloys having the thicknesses of 1.6 and 1.5 mm, respectively. Four process parameters were selected: the tool rotation speed, dwell time, tool plunge depth, and tilt angle. The dimensions of all spot welded test specimens were 25_100 mm with a 25_25 mm overlap area. The FSSW tool was made of hot work tool steel (i.e., AISI H13) coated with Aluminum Titanium Nitride (AlTiN) and had a hardness of 56 HRC. The shoulder diameter, pin diameter, and pin length of FSSW tool were 10 mm, 4 mm, and 2.35 mm, respectively. Two case test specimens produced regarding the position of Al sheets. The experimental results showed that the positioning of the plates played an important role on the strength of the joints. The analysis of variance (ANOVA) test was performed to identify the welding parameters that are statistically significant. a MINITAB 15 statistical software was used to explain the welding parameter effect.

M. Schimek et al. [6] have investigated the welding of Aluminium and Steel using an Nd:YAG laser with a maximum output power of 4 kW with two focus diameters of 600 and 1200 µm. Two aluminum alloys EN AW-5128 with a thickness of 1.4 mm and EN AW-6016 with a thickness of 2.0 mm, and two steels H360LA in 1.0 mm thickness and 22MnB5 with an aluminum-silicon coating and without coating in 1.7 mm thickness were used as test materials. The weld seams were made with a focus diameter of 600 µm and a laser power of 3 kW. The obvious reason for this is the high radiation intensity in the focus of the laser beam. The feed rate was varied from 3.75 m/min to 5 m/min. To reach more investigation results about the welding depth and joining width, a laser power of 4 kW and a focus diameter of 1200 µm with feed rates from 1.75 m/min to 2.88 m/min were used. In addition to the welding tests, an "online" spectral analysis was performed. For this purpose, the process illumination was coupled to a spectrometer via an optical waveguide. A serial interface for data transmission and accompanying software was used.

Y.F. Sun et al. [7] carried out flat spot friction stir welding of 6061-T6 Al alloy and mild steel plate with a thickness of 1 mm. This technique included two steps. In the first step, a specially designed back plate with a round dent on the plate surface was used and thus a protuberance was formed on the bottom side of the welds due to the material flow into the dent.

Fig. 7 Break of the welding seam within the steel sheet [6]

Volume - 5 | Issue - 1 | Jan Special Issue - 2015 | ISSN - 2249-555X

In the second step, a probe-less rotating tool was used to remove the protuberance as well as the keyhole. In the first step, the welding processes were carried out with same welding parameters but with the rotating tools having different probe length – 1.0, 1.3 and 1.5 mm respectively. In order to study the effect of the probe length on the final properties of the welds after the second step, an optimal welding parameter of 500 kg applied load, 700 rpm rotation speed and 2 s dwell time was used for the first welding process. After welding, optical microscopy (OM) and electron backscattered diffraction (EBSD) were used to characterize the microstructure of the joints. Hardness was also measured along both the central-line on the cross-section of the upper Al plate and the lower steel plate. Shear tensile tests were also carried out. It was found that No obvious intermetallic compound layer was observed along the Al/Fe interface after the first and second welding steps

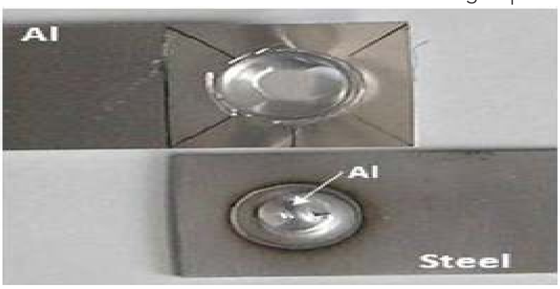

Fig. 8 A photo of fractured specimen [7]

Vicente Afonso Ventrellaa et al. [8] have studied about the welding of Ni-alloy Hastelloy C-276 foils by employing a pulsed Nd:YAG laser. The foils had 100 microns thickness. Pulse energy was varied from 1.0 to 2.25 J at small increments of 0.25 J with a 4 ms pulse duration. To evaluate the influence of the pulse energy, welding was performed using specimens positioned as lap joints, in an argon atmosphere at a flow rate (Fr) of 10 l/min. The macro and microstructures of the welds were analyzed by optical and electronic microscopy, tensile shear test and Vickers microhardness test. No welding cracks were found in any of the welds and no discontinuities were observed in the fusion metal of the beads, which demonstrates the efficiency of the shielding gas in preventing oxidation, large porosities and gas inclusions, which cause poor weld quality. It was also inferred that the ultimate tensile strength (UTS) tends to increase at first and then decrease as the pulse energy (Ep) increases.

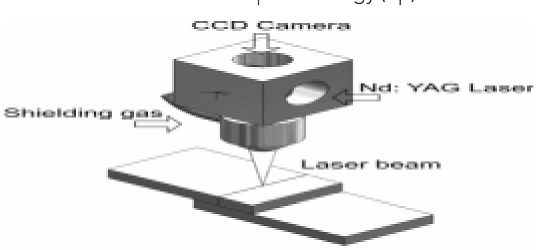

Fig. 9 Experimental set-up of Laser System [8]

Mathias Kraetzsch et al. [9] prepared a prototype for laser welding of dissimilar metal pairs with a fiber laser source having high frequency beam oscillations. A prototype system called "lasertronic®SAO-fast 1.0x (1D)" and corresponding software for controlling the scanner and the power modulation was developed in the first phase of the studies. Using a multi-kW-single-mode-fiber-laser and with respect to a desired image scale of 1:1, collimation and focusing each with a focal length of 200 mm was designed. Furthermore butt joints of Al/Cu have been welded, which were investigated in tensile tests concerning their static strength. The laser power used was 2 kW, welding speed was 4000 mm/min and scan frequency was 2500 Hz. EDX color spectral images were performed in a SEM to visualize the distribution of elements in the melting zone of overlap joints. Tensile tests showed that the laser welded Al-Cu joints failed directly at the fusion zone on the copper side.

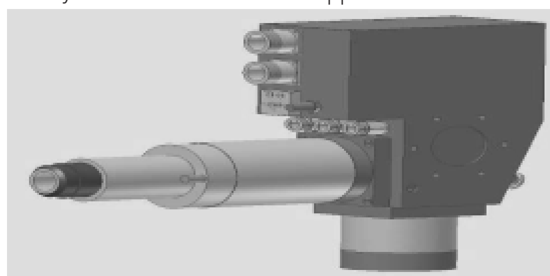

Fig. 10 Prototype system for high-frequency beam oscillation "lasertronic®SAO-fast 1.0x (1D) [9]

I. CONCLUSION

Following points can be summarized from the above literature survey:

- Friction Stir Welding (FSW) process and Laser Beam Welding (LBW) Process are widely used for joining of dissimilar metal combinations for various industrial applications.
- These both welding processes are used for joining of metals to polymers also.
- Important parameters in FSW are rotational speed, welding speed, position of plates and tilt.
- Important parameters in LBW are power of laser source, welding/scanning speed, beam spot diameter and the focal length from the workpiece.
- The properties which seem significant from research point of view are tensile strength, shear strength, microstructure and hardness of the welded joints of dissimilar metal pairs.
- Various optimization techniques are employed while investigating the dissimilar metal joints and some of these include Taguchi approach, ANOVA analysis and Grey relational analysis.

REFERENCE [1] Di Zuo, Shengsun Hu, Junqi Shen , Zhiqing Xue, "Intermediate layer characterization and fracture behavior of laser-welded copper/aluminum metal joints" - Tianjin University, China, Elsevier Ltd., 2014 | [2] J.F. Guo, H.C. Chen, C.N. Sun, G. Bi, Z. Sun, J. Wei, "Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters" - Singapore Institute of Manufacturing Technology (SIMTech), Elsevier Ltd., 2013 | [3] P. Woizeschke, V. Wottschel, "Recent developments for laser beam joining of CFRP-aluminum structures" - Materials Science Engineering, Symposium B6 - Hybrid Structures, , Elsevier Ltd., 2013 | [4] RajKumar.V, Venkatesh Kannan.M, Sadeesh.P, Arivazhagan.N, Devendranath Ramkumar.K, "Studies on effect of tool design and welding parameters on the friction stir welding of dissimilar aluminium alloys AA 5052 – AA 6061" - MRS Singapore - ICMAT Symposia Proceedings, Advanced Structural and Functional Materials for Protection, Elsevier Ltd., 2013 | [5] Yahya Bozkurt , Mustafa Kemal Bilici, "Application of Taguchi approach to optimize of FSSW parameters on joint properties of dissimilar AA2024-T3 and AA5754-H22 aluminum alloys" - Marmara University, Istanbul, Turkey, Elsevier Ltd., 2013 | [6] M. Schimek , A. Springer, S. Kaierle, D. Kracht, V. Wesling, "Laser-welded dissimilar steel-aluminum seams for automotive lightweight construction" - Laser Zentrum Hannover, Germany, Elsevier Ltd.,2012 | [7] Y.F. Sun, H. Fujii, N. Takaki, Y. Okitsu, "Microstructure and mechanical properties of dissimilar Al alloy/steel joints prepared by a flat spot friction stir welding technique" - Materials and Design 47 (2013) 350–357, Elsevier Ltd., 2012 | [8] Vicente Afonso Ventrellaa, , José Roberto Berrettab, Wagner de Rossi, "Pulsed Nd:YAG laser welding of Ni-alloy Hastelloy C-276 foils" - Physics Procedia 39 (2012) 569 – 576, Elsevier Ltd., 2012 | [9] Mathias Kraetzsch, Jens Standfuss, Annett Klotzbach, Joerg Kaspar, Berndt Brenner, Eckhard Beyer, "Laser Beam Welding with High-Frequency Beam Oscillation: Welding of Dissimilar Materials with Brilliant Fiber Lasers" - Fraunhofer IWS Dresde, Germany, Elsevier Ltd., 2011