RESEARCH ARTICLE OPEN ACCESS

A Review: Welding Of Dissimilar Metal Alloys by Laser Beam Welding & Friction Stir Welding Techniques

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

ABSTRACT
Welding of dissimilar metals has attracted attention of the researchers worldwide, owing to its many advantages and challenges. There is no denial in the fact that dissimilar welded joints offer more flexibility in the design and production of the commercial and industrial components. Many welding techniques have been analyzed to join dissimilar metal combinations. The objective of this paper is to review two such techniques – Laser welding and Friction stir welding. 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 summarizes the trends and advances of these two welding processes in the field of dissimilar welding. Future aspects of the study are also discussed.
Keywords – dissimilar, friction stir welding, laser welding, microstructure, tensile test

I. INTRODUCTION

Engineers today are facing the challenge to join dissimilar materials as they are seeking to create new structures or machine parts in various industries. Joining of dissimilar materials is very attractive for many applications as we can use the more costly one only where necessary. In fact, dissimilar joining could be frequently faced in many scenarios including automotive, aerospace, electronics and shipbuilding industries. [1] The demand for producing joints of dissimilar materials which can provide appropriate mechanical properties and good cost reduction is continuously increasing due to their advantages. [2]

Problems including porosity formation, solidification cracking, and chemical reaction may arise during fusion welding of dissimilar materials although sound welds may be obtained in some limited cases with special attentions to the joint design and preparation, process parameters and filler metals.[1] The problems arising in realizing welded joints from sheets of different materials that are difficult to obtain by employing commonly used technologies, have lead to a widespread use of new techniques of welding. [2] Two such techniques which are being adopted for joining of unlike metal pairs are Laser Beam Welding (LBW) and Friction Stir Welding (FSW).

II. OVERVIEW OF THE PROCESSES

This section gives an overview about the two aforementioned welding processes.

2.1 Friction Stir Welding Process

Friction stir welding (FSW) is a solid state welding technique used for joining successfully aluminum alloys. A friction stir butt weld is produced by plunging a rotating tool into the facing surfaces of two plates. The tool consists of a shoulder and a profiled pin emerging from it. As the rotating pin moves along the weld line, the material is heated up by the friction generated by the shoulder and stirred by the rotating pin in a process similar to an extrusion. [3] The schematic of its working is shown in the Fig. 1.

Due to the absence of parent metal melting, the new FSW process is observed to offer several advantages over fusion welding. The benefits that stand out most are welding of difficult to weld alloys, better retention of baseline material properties, fewer weld defects, low residual stresses, and better dimensional stability of the welded structure. Above all, FSW is an environmentally cleaner process, due to the absence of a need for the various gases that normally accompany fusion welding. [4]

FSW process produces no smoke, fumes, arc glare and it is an eco-friendly process. Further, no consumable filler material or profiled edge preparation is normally necessary. [4]

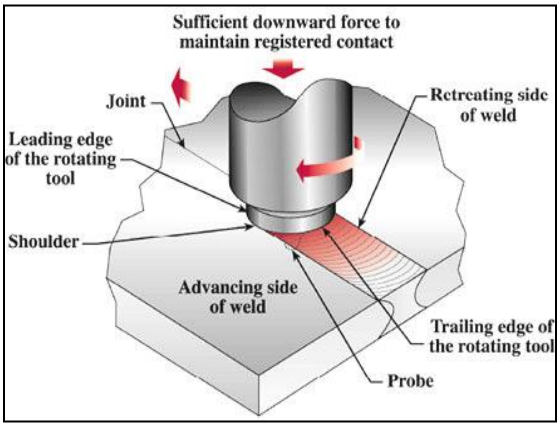

Fig. 1 Schematic Representation of FSW principle [4]

2.2 Laser Beam Welding

Laser beam welding (LBW) processes is a unique welding technique used to join multiple pieces of metal through the heating effect of a concentrated beam of coherent monochromatic light known as LASER. It is a high-energy-density welding process and well known for its deep penetration, high speed, small heat-affected zone, fine welding seam quality, low heat input per unit volume, and fiber optic beam delivery. [5]

The principle of operation as shown in Fig. 2 is that the laser beam is pointed on to a joint and the beam is moved along the joint. The process will melt the metals in to a liquid, fuse them together and then make them solid again thereby joining the two pieces. [5]

Laser processing is free of electromagnetic fields and is, thus, suitable for welding dissimilar couples. With flexibility in the power intensity, power distribution, and scanning velocity, laser welding is emerging as a major joining process. [6] The research on laser beam welding of dissimilar materials in the area of macro-materials processing primarily focuses on potential applications in the automotive and aerospace industry for thin sheet applications.

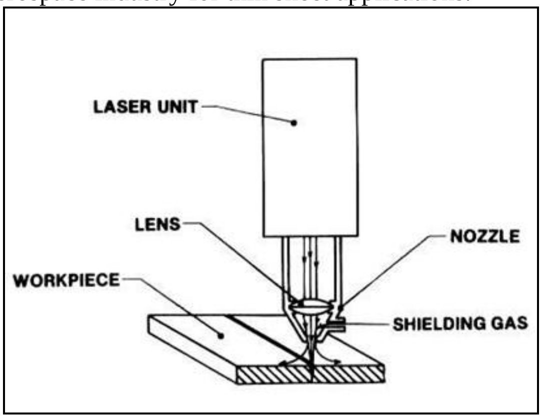

Fig. 2 Principle of Laser welding [5]

A high potential for application of laser beam welding is shown, for example, for the material combinations steel-aluminum and aluminum-titanium. With appropriate process control and the typical laser deep welding effect, it is possible to form only a minimum intermetallic phase hem and thus achieve good mechanical properties of the joint. [7]

III. LITERATURE SURVEY

Some notable research papers regarding the dissimilar welding of metals using Laser and Friction Stir technique are being summarized below. Also, some papers are being discussed which spread light on the comparative studies of various welding processes including either LBW or FSW.

Sadeesh P et al. [8] studied the influence of rotation speed and traverse speed over the microstructural and tensile properties of the welded joints of dissimilar alloys of aluminium by adopting Friction Stir Welding. The materials were 5mm thick plate of AA 2024-T4 (Al-Cu alloy) and AA 6061-T4 (Al-Mg-Si alloy). Optimum process parameters were obtained for joints using statistical approach. The welded samples measured 100 × 50 mm and the welding tool used was AISI H13 tool steel. Thereafter, optical microscope, scanning electron microscope (SEM) and energy dispersive spectroscope (EDS) were used to evaluate the metallurgical characterization. Vickers hardness tests were conducted across the various regions of the weld spacing of (0.25mm). Tensile tests were also conducted.

From microstructural analysis it was evident that the material placed on the advancing side dominates the nugget region. The Fig. 3 shows the photographs after the tensile tests of the plates welded by cylindrical tool and squared tool. The hardness in the HAZ of 6061 was found to be minimum, where the welded joints failed during the tensile studies.

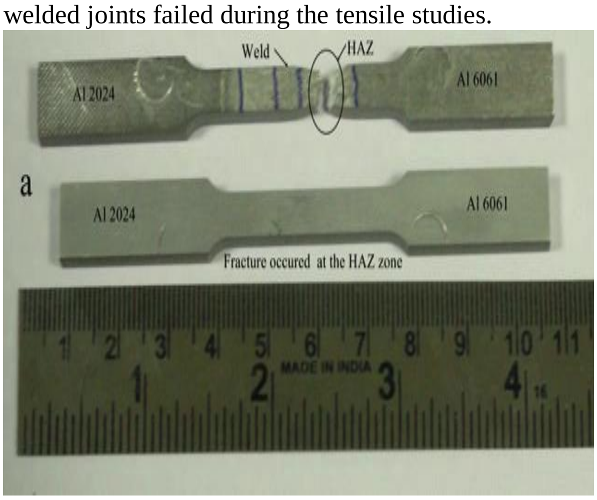

Fig. 3(a) Tensile test - cylindrical threaded pin [8]

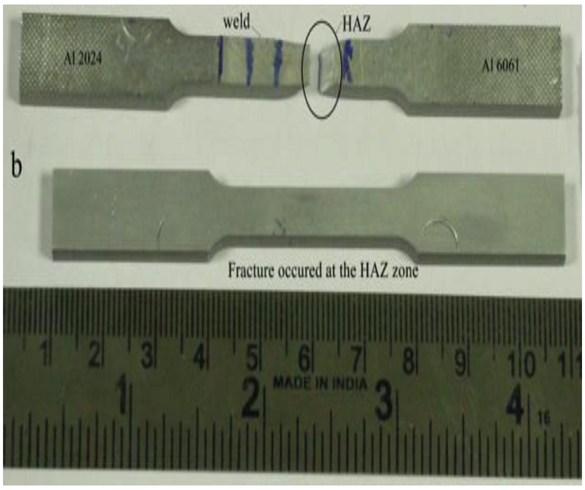

Fig. 3(b)Tensile test – squared pin [8]

Yahya Bozkurt et al. [2] optimized Friction Stir Spot Welding Process (FSSW) to weld dissimilar AA2024-T3 and AA5754-H22 aluminum alloys using Taguchi approach. The plates had thickness of 1.6 mm and 1.5 mm respectively. 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. analysis of variance (ANOVA) test was performed to identify the welding parameters that are statistically significant. MINITAB 15, statistical software, was used to explain the welding parameter effect. The experimental results showed that the positioning of the plates played an important role on the strength of the joints. Finally, the results were confirmed by further experiments.

Table 1 Experimental layout using an L9 orthogonal array [2]

Exp No.	FSSW Process Parameters				Error E
	A Tool rotation speed (rpm)	B Tilt angle (°)	C Tool plunge depth (mm)	D Dwell time (s)	
1	1500	0	2.45	2	
2	1500	2	2.55	5	
3	1500	3	2.65	10	
4	2100	0	2.45	2	
5	2100	2	2.55	5	
6	2100	3	2.65	10	
7	3000	0	2.45	2	
8	3000	2	2.55	56	
9	3000	3	2.65	10	

M. Schimek et al. [9] have explored the welding of dissimilar aluminium and steel employing 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 feed rate was varied from 3.75 m/min to 5 m/min. The experimental set up for this study is shown in Fig. 4.

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. Tensile tests were performed to determine the maximum tensile shear strength. The aluminum alloy EN AW-5182 was found unsuitable for welding due to the high magnesium content, which led to high weld spatter. The highest potential for a possible practical application was found for the mixed combination of steel H360LA and aluminum alloy EN AW-6016.

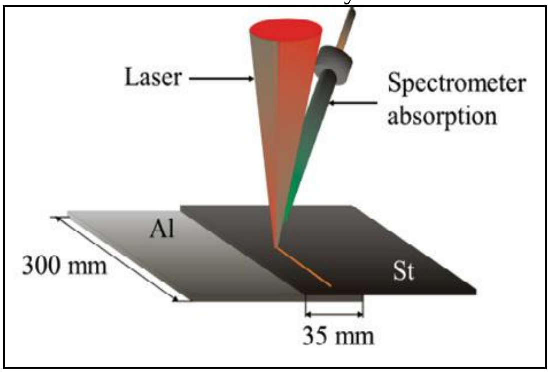

Fig. 4 Experimental setup for welding [9]

K. Kimapong and T. Watanabe [10] were successful in butt-joint welding of plates of Aluminum alloy A5083 (Al-0.5 Mg-0.5 Mn wt-%) to SS400 mild steel by Friction stir welding process. They investigated the effects of pin rotation speed, position of the pin axis, and pin diameter on the tensile strength and microstructure of the joint. The plates had dimensions of 140×40×2 mm. The rotating tool used was made of high-speed tool steel (SKH57), having 15-mm-diameter shoulder and an unthreaded pin 2 mm in diameter and 1.9 mm long. Welds were made with the pin rotating clockwise at speeds of 100 to 1250 rpm. The pin transverse speed, that is, welding speed, was 25 mm/min.

After welding, tensile test was undertaken along with X-ray energy-dispersive spectroscopy (EDS). Tensile test suggested that fracture and cracking tends to occur at the interface of the joint (as shown in Fig. 5). The results also showed that a small amount of intermetallic compounds was formed at the upper part of the steel/aluminum interface, while no intermetallic compounds were observed in the middle and bottom regions of the interface. Pins that were too small in diameter, i.e., 1 mm diameter, could not produce a weld. Pin diameters from 2 to 4 mm showed similar joint tensile strength.

Di Zuo et al. [11] 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.

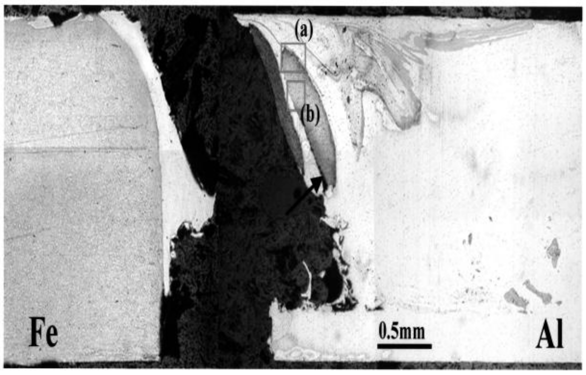

Fig. 5 Cross sectional view of the fracture along the interface between the steel fragment and the aluminium matrix [10]

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_9A_{l4}) and a hypoeutectic structure. Gray relational theory was used to define the relationship between the thicknesses of different zones and the mechanical properties. Even though the intermetallic compound formation was reduced, the joints failed at the intermetallic layer in the shear–tensile test. Hence, it was concluded that the specific layers in which the Cu/Al joints fractured can be positioned accurately.

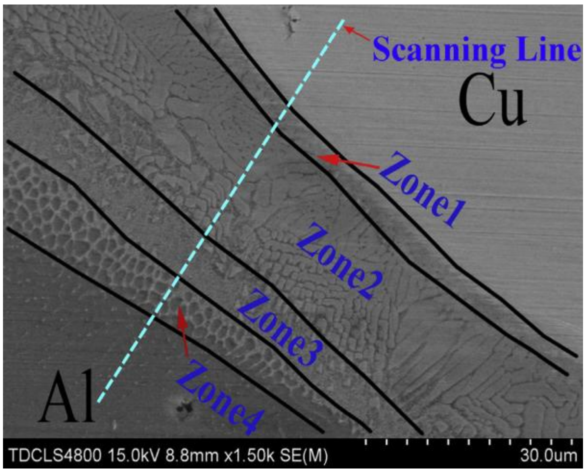

Fig. 6 Morphology of four zones in intermediate layer [11]

S. Malarvizhi and V. Balasubramanian [12] investigated the effect of three welding processes – Gas tungsten arc welding (GTAW), Electron beam welding (EBM) and Friction stir welding (FSW) on the fatigue crack growth behavior of welded joints of AA2219 aluminium alloy. Square butt joints were fabricated from the rolled Al plates having dimensions 300 mm ×150 mm ×5 mm. Transverse tensile properties of the welded joints were evaluated. Of the three joints, the joints fabricated by FSW process exhibited higher fatigue crack growth resistance compared to GTAW and EBW joints. The superior tensile properties (higher yield strength and elongation) and preferable microstructures (very fine, dynamically recrystallised grain size along with fine and uniformly distributed strengthening precipitates) and favorable residual stress field (higher magnitude of compressive stress field) in the weld region are the reasons for superior fatigue performance of the FSW joints.

Moneer Hammed Tolephih et al. [13] carried out a practical comparative study of the mechanical properties of a butt-welded joint of Aluminium alloy AA7020-T6 (Al-Mg-Zn), adopting Friction Stir Welding (FSW) and Metal Inert Gas (MIG) welding techniques. The plates had dimensions 200 mm length, 100 mm width and 5 mm thickness. FSW joints were carried out using a High Speed Steel tool with 15 mm shoulder diameter and the insert pin diameter and height were 5 mm and 4.85 mm, respectively, with cone angle 2.5°. FSW employed different tool rotations - 450, 560, 710 and 900 rpm and at different transverse speed of 16, 25 and 40 mm/min by vertical milling machine.

Table 2 Welding conditions and process parameters [12]

Parameter (Unit)	GTAW	EBW	FSW
Current (mA)	150	0.051	
Voltage (kV)	0.03	50	
Speed (mm/s)	3	16	
Polarity	AC	DC	-
Vacuum (bar)	-	10^{-4}	
Shielding gas	99.99% pure Argon	-	-
Gas flow rate (lt/min)	14	-	-
Tool rotational speed (rpm)			1400
Welding Speed (mm/s)			1.5
Axial force (kN)			12
FSW Tool details			Threaded pin with 6 mm diameter and 4.8 mm length made of high carbon steel

For the purpose of comparison, three points bending tests and microhardness tests were performed on the welded coupons. It was concluded that the increase of the ultimate tensile strength for FSW was 340 MPa while it was 232 MPa for MIG welding, where it was for base metal 400 MPa. The minimum microhardness value for FSW was recorded at HAZ and it was 133 HV0.05 while it was 70 HV0.05 for MIG weld at the welding metal. The FSW produced 2470 N higher than MIG welding in the bending test and a decrease in the localized grain size for FSW in the stirred zone 12 µm and it was 37 µm for MIG while it was 32 µm for the base metal.

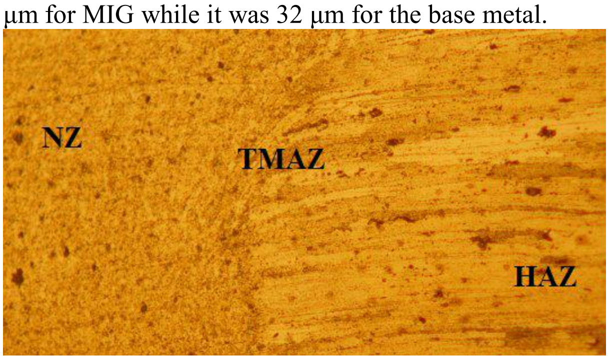

Fig. 7 (a) Microstructure of FSW zone [13]

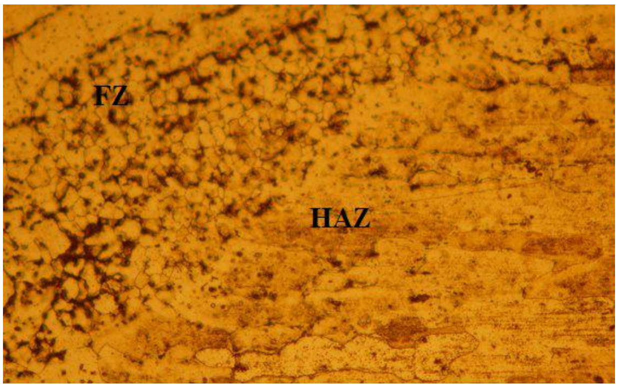

Fig. 7 (b) Microstructure of MIG welded zone [13]

L. Reis et al. [14] presented the comparative characterization of fatigue behavior of Aluminium AA6082-T6 lap joints, produced by two different techniques – Laser welding and Friction Stir welding. This study was conducted within the LighTRAIN project, involving two universities (IST-Portugal, FEUP-Portugal), two industrial companies (ALSTOM-Portugal, QUANTAL-Portugal) and one research centre (ISQ-Portugal), that aims to improve the life cycle costs of the aluminum underframe of a passenger railway car, with a novel light-weighted solution. The material chosen was of 2 mm thickness which was welded by a conical pin and a spiral shoulder by FSW. To characterize the welded lap joints, several mechanical tests were performed: non-destructive tests through microstructure examination and hardness measurements; tensile, bending and fatigue tests using a servo-hydraulic test machine, with 100 kN load capacity. Fatigue results of lap joints of Al alloy loaded perpendicular to the weld line showed that the LBW joints have higher fatigue strength in comparison with the FSW joints.

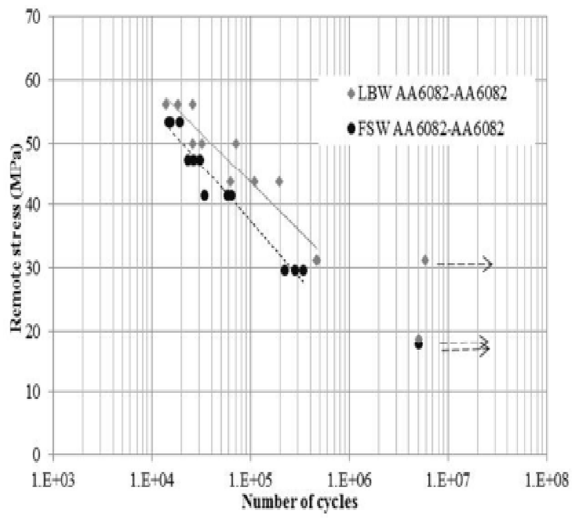

Fig. 8 S-N fatigue data of LBW and FSW specimens (R=0.1) [14]

M. Dehghani et al. [15] investigated the effects of various parameters of FSW on intermetallic and defect formation in joining Aluminium alloy (Al 5186) to Mild Steel. The thickness of MS and aluminium sheet was 3 mm. The tool rotation speed for all samples was fixed at 355 rpm. The welding speed, pin size, tool plunge depth, tool tilt angle and pin geometry were changed to find the optimum welding condition in which the tunnel defects were prevented and formation of IMCs (Intermetallic Compounds) was restricted. The tool shoulder diameter was 18 mm. The pin diameter and pro- file were: (a) 4 mm, non-threaded cylindrical, (b) 3 mm, non- threaded cylindrical and (c) standard M3 threaded pin. After welding, tensile tests were conducted at a constant crosshead speed of 1 mm/min.

Metallographic studies were conducted by utilization of optical microscopy (OM) and electron scanning microscopy (SEM). It was found that in dissimilar FSW of aluminum to steel for preventing tunnel formation the pin diameter was more important than its threaded profile. As the welding speed increased, the IMCs decreased and the joint exhibited higher tensile strength. The tunnel defect could not be avoided by using cylindrical 4 mm and 3 mm pin diameter. By using a standard threaded M3 tool pin, tensile strength of the joint increased to 90% of aluminum base alloy strength. At higher welding speed and lower tool plunge depth, the joint strength decreased due to lack of bonding between aluminum and steel.

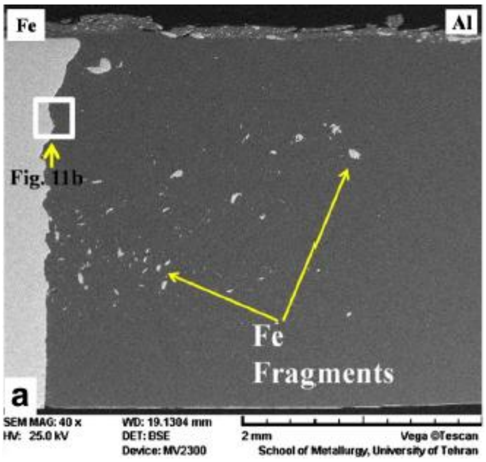

Fig. 9 (a) SEM micrographs showing no IMC region in the weld nugget [15]

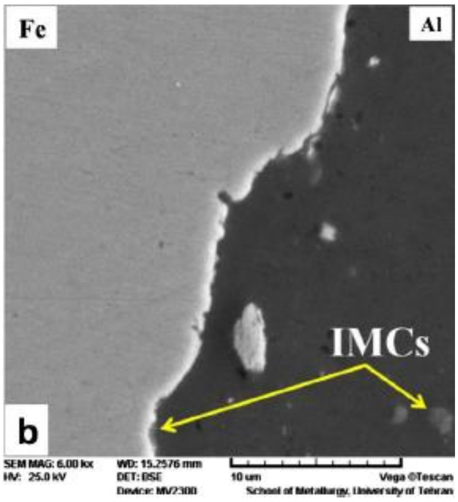

Fig. 9 (b) SEM micrographs showing thin IMC layer at the Al/Fe interface [15]

IV. CONCLUSION

From the above literature, following points can be summarized.

- Friction Stir welding and Laser beam welding processes are widely used for the welding of dissimilar metals and alloys.
- Significant parameters in LBW are power of the laser source, welding/scanning speed, beam spot diameter and the focal length from the wprkpiece. The clamping of the workpieces is also considered important.
- Significant parameters in FSW are rotational speed of the welding tool, welding speed/traverse speed and position of the plates to be welded.
- Important properties which are studied by the researchers in both LBW and FSW techniques when joining dissimilar metal pairs are tensile strength, shear strength, microstructure and hardness.
- Optimization techniques like Taguchi approach, are adopted to minimize the experimental runs during the welding of dissimilar metals.
- Various analysis methods like ANOVA and Grey relational approach are also used while investigating the relations between the parameters and their influence on the properties of the welded joints.
- The butt welds are the most common ones in the fabrication and construction of many structures.
- Aluminium alloys are being utilized in the welding of automotive industry as it enhances the weight saving owing to its light weight.
- Since reducing the weight of vehicles is one of the efficient measures nowadays, the use of the combination of steel and aluminum alloy has been increasing in fabricating vehicles.

V. FUTURE ASPECTS

Based on the above literature survey, we can infer that very limited amount of work has been done in the area of integrated or comparative analysis of LBW and FSW procedures for welding of dissimilar metals. This opens a new horizon for future researches, in the field of aforementioned two welding processes for dissimilar welding.

REFERENCES

[1] 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*" - *Materials and Design 56 (2014) 185–192, Elsevier Ltd.,*

[2] 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*" - *Materials and Design 51 (2013) 513–521, Elsevier Ltd., 2013*

[3] Moneer Hammed Tolephih, Kadhim M. Mashloosh, Zainab Waheed, "*Comparative Study of the Mechanical Properties of (FS) and MIG Welded Joint in (AA7020-T6) Aluminum Alloy*" - *Al-Khwarizmi Engineering Journal, Vol. 7, No. 2, PP 22 – 35 (2011)*

[4] V. Balasubramanian, "*Friction Stir Welding: An Environmentally Cleaner Welding Process" - Department of Manufacturing Engineering, Annamalai University*

[5] G Harinath Gowd, E Venugopal Goud, "*Analysis of Performance Characteristics of Laser BeamWelding*" - *International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462, Vol. 4 No.05, pg. 1925, May 2012*

[6] Gandham Phanikumar, Sambandam Manjini, Pradip Dutta, Jyotirmoy Mazumder, and Kamanio Chattopadhyay, "*Characterization of a Continuous CO2 Laser–Welded Fe-Cu Dissimilar Couple*" - *Metallurgical And Materials Transactions A, Volume 36A, pg. 2137, August 2005*

[7] 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" - Physics Procedia 12 (2011) pg. 142–149, Elsevier Ltd.,*

[8] Sadeesh P, Venkatesh Kannan M, Rajkumar V, Avinash P, Arivazhagan N, Devendranath Ramkumar K, Narayanan S, "*Studies on friction stir welding of AA 2024 and AA 6061 dissimilar metals" – Procedia Engineering 75 (2014) pg.145 – 149, Elsevier Ltd.*

[9] M. Schimek , A. Springer, S. Kaierle, D. Kracht, V. Wesling, "*Laser-welded dissimilar steel-aluminum seams for automotive lightweight construction*" - *Physics Procedia 39 (2012), pg. 43 – 50, Elsevier Ltd.*

[10] K. Kimapong and T. Watanabe, "*Friction Stir Welding of Aluminum Alloy to Steel*" – *Welding Journal, pg. 277 – 282, October 2004*

[11] Di Zuo, Shengsun Hu, Junqi Shen , Zhiqing Xue, "*Intermediate layer characterization and fracture behavior of laser-welded copper/aluminum metal joints*" - *Materials and Design 58 (2014), pg. 357–362, Elsevier Ltd.*

[12] S. Malarvizhi and V. Balasubramanian, "*Fatigue crack growth resistance of gas tungsten arc, electron beam and friction stir welded joints of AA2219 aluminium alloy*" - *Materials and Design 32 (2011), pg. 1205–1214, Elsevier Ltd.*

[13] Moneer Hammed Tolephih, Kadhim M. Mashloosh, Zainab Waheed, "*Comparative Study of the Mechanical Properties of (FS) and MIG Welded Joint in (AA7020-T6) Aluminum Alloy*" - *Al-Khwarizmi Engineering Journal, Vol. 7, No. 2, PP 22 – 35 (2011)*

[14] 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), pg. 350–357, Elsevier Ltd.*

[15] L. Reis, V. Infante, M. de Freitas, F.F. Duarte, P.M.G. Moreira, P.M.S.T. de Castro, "*Fatigue Behavior of Aluminium Lap Joints Produced by Laser Beam and Friction Stir Welding*" - *Procedia Engineering 74 (2014), pg. 293 – 296, Elsevier Ltd.*