International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 1, January-2014, pp: (508-515), Available online at: **www.erpublications.com**

Literature review of advancement in hybrid joining techniques

Amit Kumar

Department of Mechanical & Industrial Engineering, Indian Institute of Technology,
Roorkee Uttarakhand-247667, India

Abstract

Industries like space and airplanes have shown remarkable interest in the hybrid welding process due to its great advantages as compared with the fundamental processes of welding. The hybrid welding process used vast potential of different fields like laser, plasma, arc, and adhesives. It provides significant improvements in weld quality and efficiency of processes. This study describes the principles, means and applications of hybrid welding processes. The objective of this study is to introduce the different hybrid processes and to discuss how the technology may be adopted in industrial applications. Profound understanding of the advanced technology of hybrid joining will improve the productivity of welding in various industrial applications. Based on large literature review, important areas for further research have been identified.

---

1. INTRODUCTION

Hybridization of welding processes is usually done to develop a hybrid process that combines the best characteristics of parent welding process, with a hope for some synergistic benefit additionally. In hybrid joining, two fundamentally different processes are combined to create a process with extended capability [1-4]. Hybrid process sometimes may result unique benefits due to synergy between the two basic processes. In the hybrid welding processes we get a lot of advantages like high welding speed, low thermal load, high depth penetration and less demanding on joint preparation or fit-up [2-3]. Improvement of productivity results due to thicker welded materials, joint and fit-up allowance, better stability of molten pool, and improvement of joint metallurgical quality [5].

In hybrid joining process we couple different joining processes to improve the joint and process efficiency. For an efficient use of hybridization, it is necessary to understand the complex physical phenomena precisely that govern the welding technique. Coupling of various joining processes provides a large range of hybrid joining [4, 6]. Mechanical joining, chemical joining or adhesive bonding and welding, including brazing and soldering, represent the majority of all joining methods. These processes certainly represent all of the fundamental approaches of joining. We categorize the hybrid joining in the following ways:

Mechanical hybrid joining: Hybrid of mechanical fastening (riveting and bolting) with structural adhesive bonding.

Welding hybrid joining: Hybrid of welding and structural adhesive bonding; Hybrid of two different welding processes; Hybrid of two welding processes with an intermediate layer.
Detailed mechanical and micro structural characterization and hardness testing of the weld specimen revealed that the hardness values in the fusion zone are good irrespective of the parameters [1-8]. Transverse tensile testing showed that the joint efficiency is higher than that of basic welding processes [4-10]. In some of the hybrid welding process impact energy values of the welds can be found higher than the base material if all parameters are proper.

2. OBJECTIVE OF THE STUDY

The literature review is a usual method to study thoroughly different approaches of the topic to be studied. The study was carried out based on databases from which different approaches of hybridization of joining methods were identified. After identifying and analyzing those approaches, a classification framework was developed. Also, we present the classification of the literature. The variations were then separated (for more objective analysis) and are presented in the paper. Lastly, an analysis of the review is performed in order to provide a wider knowledge of the searched topic.

To accomplish this study aims; this research is based on the examination of various journals, all of which are related to welding areas. We use journals because we also believe that journals are the resources that are most commonly used to acquire information and Study new findings.

3. LITERATURE REVIEW

3.1. Laser Hybrid Welding

The availability of efficient and robust laser beam sources allows the laser to extend its scope of application for welding technology. In laser hybrid welding laser is coupled with some other welding process. From the survey we found that laser can be used with different king of welding processes. For the study, synchronous information including spectral signal, high-speed photography and electrical signal are used to explore the physical interaction between the laser and other coupled process and effect of the combined heat source on the welding process are analyzed.

High productivity and quality issues for welding processes supported Laser Beam Welding (LBW) process to become increasingly important for joining metallic parts in recent years []. The advantages of this welding process are in addition to high speed welding a small heat affected zone and low thermal distortion of the work piece. The main disadvantage of the LBW is the small gap bridging ability, so LBM is coupled with other welding processes to compensate these drawbacks []. Here we have different possible combinations of laser.

3.1.1. Laser- Plasma hybrid welding

In order to fulfill demands for quality and efficiency in the field of welding engineering, numerous works in research on the optimization of the welding processes are in progress. Aims of the research are increasing the welding speed, stabilizing the welding processes, decreasing the reject rate and reducing the pre and post welding machining. We are now studying the development of a new plasma-laser hybrid welding method in order to increase the productivity of the existing technologies of plasma arc welding and laser beam welding and to compensate their disadvantages, by using common machinery. Experimental results of some researchers in this field are shown in the table 3.1 [1, 2].

Plasma Arc Welding (PAW) process was created as the enhancement of the TIG welding process, and achieves intensities close to laser beam welding process. PAW combines the advantages of LBW, like high intensity, and Metal Arc Welding, like gap bridging. But the main disadvantage of PAW is the process instability. In order to compensate the respective disadvantages of different welding processes hybrid welding processes have been developed. The main feature of those processes is the combination of existing processes to unify the advantages and compensate the disadvantages.

3.1.2. Laser-SAW hybrid welding

The laser beam-submerged arc hybrid welding method originates from the knowledge that, with increasing penetration depth, the laser beam process has a tendency to pore formation in the lower weld regions. The coupling with the energy-efficient submerged-arc process improves degassing and reduces the tendency to pore formation. The high deposition rate of the Submerged Arc process in combination with the laser beam process offers, providing the appropriate choice of weld preparation, the possibility of welding plates with a thickness larger than 20 mm in a single pass, and also of welding thicker plates with the double-sided single pass technique. Table 3.2 depicts some experimental results of hybridization [3].

3.1.3 Laser-Arc hybrid welding

Arc welding is the most widely used technology in joining applications because the machines are inexpensive and easy to operate, and the outcomes of the welding processes are successful. Drawbacks are shallow penetration and humping of weld beads in high-speed welding. An arc can be unstable because it can deviate unpredictably between the work piece and the electrode tip, resulting in an irregular weld. Under normal circumstances, the arc selects the route between the electrode and the work piece which has the smallest electrical resistance. For instance, welding of titanium by the MIG process is difficult because the arc cathode is not stable and drifts around on the weld bead, producing spatter. In the hybrid laser-arc welding process, a laser beam and an electric arc are coupled in order to combine the advantages of both processes as shown in the table 3.3 [5-8]. Once the mutual interaction between the two energy sources is optimized, the combination of the two processes opens large areas of applications and increases its capabilities.

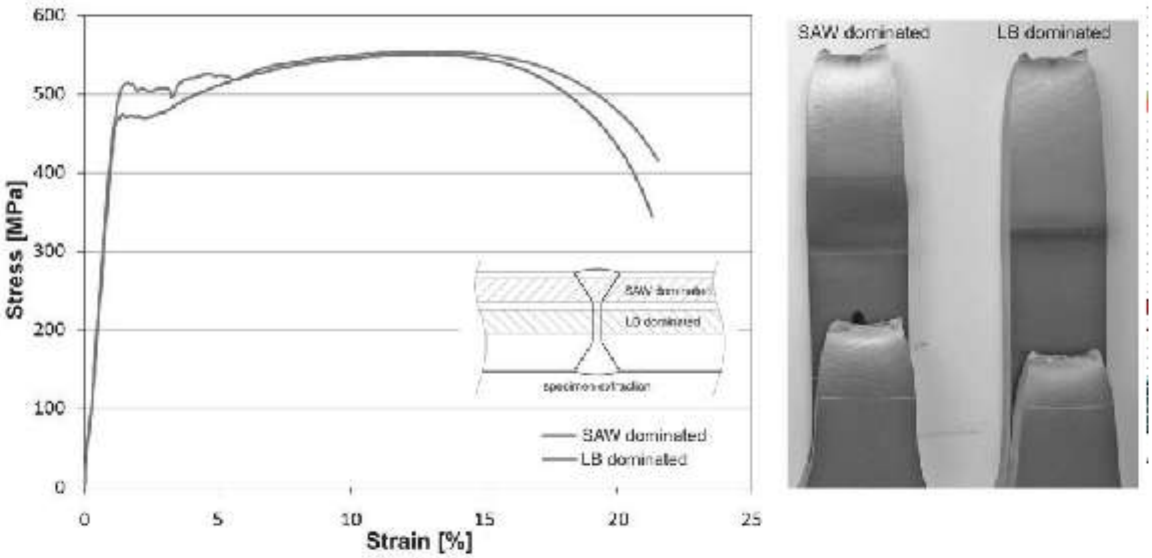

Figure 1. Tensile strength test and specimen [3].

3.1.4 Laser- FSW hybrid welding

When the FSW was applied to thicker plates or higher melting point alloys, such as steels, and Ti or Ni alloys, a much higher heat input is required to soften the materials so that the plastic stirring can proceed. The main consequence of an insufficient heat input is the formation of groove-like defects in the stir zone, which will decrease the weld quality. The rotating tools also face a risk of being broken because a much higher resisting force is imposed on the rotating tools.

Table 3.1 Hybrid laser- plasma welding process papers

Sr. no	Author	Metal system/ filler metal	Parameters	Results
1.	Claus E. et al. [1]	Al	LP= 550 W; WS=30-150 cm/min; GFR= 0-15 l/ min;	Best combination of parameters is as: I-150; WS- 50cm/min; GFR- 4 l/ min;
2.	F. Moller et al. [2]	Al alloys	LP=1-4 KW; I=30-110 A;	Laser causes reduction of plasma voltage and the effect decreases with increase in plasma current; Plasma Voltage effect is more in case of DCEN.

Table 3.2 Hybrid laser- SAW welding process papers

Sr. no	Author	Metal/ Filler metal	Parameters	Results
1.	Uwe Reisgen et al. [3]	X65 Steel	LP- 20 KW; ED- 3 mm; OP 122 basic flux; WS- 1 m/min	Hardness- 275 HV1(LD), 225 HV1(SD); Avg Impact Energy- 200J(LD), 95J(SD)
2.	Uwe Reisgen et al. [4]	S235	LP- 20 KW; WS- 1 m/min	Hardness- 240 HV1(LD), 196 HV1(SD); Avg Impact Energy- 220J(LD), 95J(SD)

Table 3.3 Hybrid laser- arc welding process papers

Sr. no	Author	Metal/ Filler metal	Parameters	Results
1.	Gang Songa et al. [5]	Mg alloy AZ31B	LP=400W; I=300A; WS=80mm/min; AL=3mm; ED=3.2mm	Tensile shear is 80% comparable to those of base metal; Parameters D and DLA have key effect weld bead shape; Corrosion resistance of FZ is equivalent to that of base metal.
2.	A. Fortunato et al. [6]	304 SS / 308L wire	TI=65; GFR=20l/min; WS=1m/min; LP=3KW	The two sources involved must be at a 2–3mm mutual distance; Laser focus depends on the GMAW metal transfer mode; Pulsed/spray-arc should be preferred to short/globular-arc.
3.	Xiaoyan Gu et al. [7]	Q235A steel/ H08Mn2Si	GFR=20l/min; WS=5mm/s; LP=.5-1.5KW; I=70-100A	Laser influences the arc shape, slows down droplet transfer, reduces resistivity and stabilizes arcs; Electron temperature is from 7000 K to 17000 K and increases with the increasing laser power and decreasing defocusing distance.
4.	Hongyang Wang et al. [8]	AZ31 Mg 6061 + Al alloys	0.08 mm-thick Ni interlayer; 0.1 mm-thick Adhesive	Adhesive changes the surface state of the Al alloy and the welding mode in Al alloy is in a conductive mode; Adhesive and Ni interlayer restrain the reaction between Mg and Al.

Table 3.4 Hybrid laser- FSW process papers

Sr. no	Author	Metal/ Filler metal	Parameters	Results
1.	Woong-Seong Chang et al. [9]	AA6061-T6 Al Alloy+AZ31 Mg Alloy	LP- 2KW; TS- 800 r/min; WS-35 mm/min.; Plunge depth-3.9 mm; Pin length- 3.8 mm	Max tensile strength- 95 MPa, 169 MPa (with Ni foil); there is reduction in formation of inter-metallic brittle material at interface with use of Ni foil.
2.	Y.F. Sun et al. [10]	Carbon steel S45C plates	LP- 2kw; TI – 45; TD- 15mm; Shielding gas- Ar	Max welding speed-800 mm/min when laser beam was focused 10 mm ahead of the rotating tool; Formation of the brittle martensite and bainite is prevented by the laser preheating

LD- laser dominated; SD- SAW dominated; WS= welding speed; LP=laser power; I= current; GFR= gas flow rate; ED= electrode diameter; D= defocus distance; DLA= distance of laser to arc; TD= tool diameter; TS= tool speed; TI= torch inclination

3.2 Friction Stir Hybrid Welding

Friction Stir Welding (FSW), developed and patented by The Welding Institute (TWI) in 1991, is a solid-state joining process [11]. In this process a rotating tool consisting of a probe and shoulder plunges into the work piece, generating heat through both friction and plastic deformation, and traverses the joint line. Its original purpose was to weld aluminum and aluminum alloys.

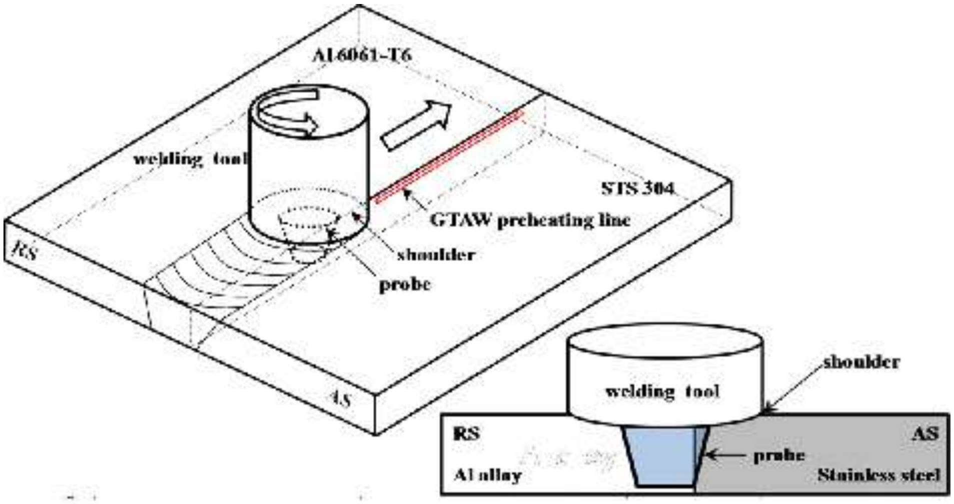

Figure 2. Hybrid FSW schematic [13].

The temperatures during the FSW are below the melting temperature due to which the problems associated with fusion welding, such as the evaporation of some constitutive elements, formation of second phases, porosity, embrittlement cracking, fumes, arc flash, spatter, and pollution can be eliminated. Other advantages of the FSW over fusion welding include the prevention of inclusions and impurities, low distortion, lower residual stresses, excellent mechanical properties, low shrinkage, energy efficiency etc. FSW requires no filler material and, in most cases, does not require the use of a shielding gas [12].

3.2.1 GTAW assisted FSSW

Use of materials like Al and Mg alloys is increasing as structural materials due to their light weight. Therefore, in order to incorporate Al alloy–steel hybrid structures, adequate joining process for dissimilar material combinations is required. It is difficult to obtain sound dissimilar material welds of these different materials by conventional fusion welding techniques because of the formation of inter metallic compounds, which cause to decrease the mechanical properties of the weld [13].

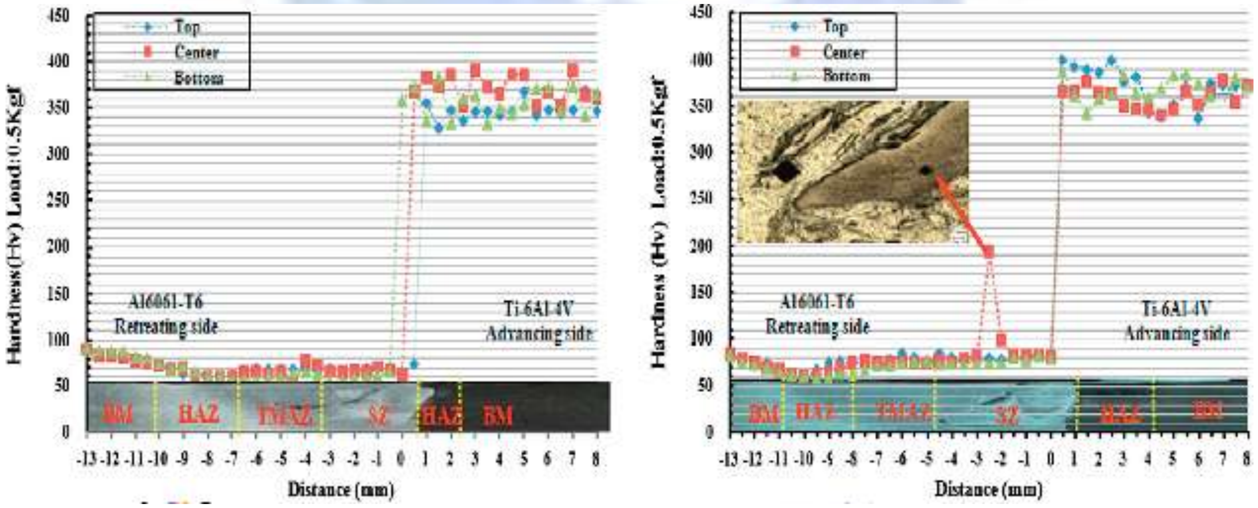

Figure 3. Hardness profile of FSW and hybrid FSW [13].

FSW is solid state welding process that enhances weldability in joining light material of Al and Mg alloys and reduces formation of inter metallic phases in dissimilar materials. However, when FSW is used to join dissimilar materials such as Al/Fe alloy, Al/Ti and Al/Cu alloy, it is difficult to produce sound joints due to the difference in material properties. So we use secondary heat source in the form of GTA for equal heat distribution in hybrid FSSW [13].

3.2.2 FSS adhesive hybrid welding

Friction stir spot adhesive welding is an innovative derivative to FSSW and adhesive bonding. It can be used for assembly of dissimilar Al to Mg alloys which are used in automobile, aerospace industries due to their ultra-lightweight, high strength-to-weight ratio and superior damping capacity. Adhesives provide excellent uniform stress distribution over a large bonding area and the weld itself improves the peel resistance of the adhesive joints. S.H.Chowdhury et al. [14] investigated application of adhesive (Terokal5089 adhesive) with FSSW process. They found that with the use of adhesive, in addition to FSSW, for joining of Al-Mg metal system failure energy was 26.5 J. Also, hardness in the stir zone was uniform with the application of adhesive.

Table 3.5 Hybrid GTAW- FSW process papers

Sr. no	Author	Metal	Parameters	Results
1.	HanSur Bang et al. [12]	Al alloy (Al6061-T6)+ SS(STS304) (3 mm)	Shoulder dia-18 mm; probe dia-6 mm; pin length 2.7 mm; GTAW - 2mm from weld center	Maxi tensile strength- 290 MPa(at 300 rpm); slightly finer recrystallized grains are in the SZ of HFSW than that of FSW
2.	HanSur Bang et al. [13]	Al6061-T6 Al alloy + 6%Al–4%V Ti alloy (3.5 mm)	Shoulder dia-18 mm; probe dia-5 mm and length-3.3 mm; tool speeds- 300–450 rpm;	Max tensile strength-300 MPa; elongation to fracture- 2.8%; microstructure of the HAZ in the Al alloy is very similar to Al alloy base metal

3.3 Plasma-GMAW hybrid welding

In GMAW, a welding arc is established between the continuously fed filler wire and the base material. The filler wire is melted by the welding arc plasma and droplets of the melted alloy travel across the welding arc and fall into the weld pool. From the research it was found that the droplets are overheated by the surrounding welding arc and their temperature is higher than the melting temperature of the filler metal. Overheating of the droplets increased with the increment in welding current. In plasma-GMA hybrid welding, a gas metal arc is coaxially positioned inside a plasma arc established between a plasma nozzle and the base material. Heating from the surrounding plasma arc stabilize the droplet transfer in GMA welding, even for low welding currents.

C.H. Kim et al. [15] in their study used Al 5083 plate with a thickness of 25 mm and an Al 5183 wire as the base and filler material. A 50% Ar and 50% He mixture was supplied as the shielding gas at a flow rate of 40 l/min. The diameters of the filler wires used were 1.2 mm, 1.6 mm, and 2.4 mm, and a DC pulse current was applied. In plasma-GMA hybrid welding, Ar was used to serve three purposes- the shielding, plasma, and GMA gas. Flow rates for the shielding, plasma, and GMA gas are 5 l/min, 15 l/min, and 10 l/min, respectively. A continuous-wave current was applied to obtain a plasma arc and a DC pulse current was applied for GMA. It was found that in plasma- MA hybrid welding, the surrounding plasma arc could supply additional heat and stabilized the transfer of droplets for GMA welding and for a 1.6mm diameter wire and the melting rate afforded by plasma-GMA hybrid welding was almost three times that afforded by GMA welding.

3.4 Hybrid Joining by Chemical Bonding and Plastic Deformation

For thin metallic and continuous carbon fiber reinforced thermosetting plastic sheets we use this type of hybrid welding. As in case of rivet joining with an adhesive, it does not require any additional components so eliminates holes and ultimately avoids stress concentration.

Zhequn Huanga et al. [16] performed the experiment with CFRP sheets (.6 mm) and Al alloy sheet (.5mm) with elastic epoxy adhesive in the working temperature range of −40◦C to 120◦C. During the experiment some parameters were kept constant. Embossing temperature was 100◦C, punch load was fixed at 5 ton and time duration for embossing was 10 s. Diameter of punch and die were 8mm and 12mm respectively. From the experiment they found that placement of the specimen also has effect on the strength of the joint. Optimized placement (from top to bottom) is as follows: A2017Psheet, adhesive layer, CFRP sheet and dummy sheet. The mechanical anchor effect of the embossed pit, the expansion of the adhesive area, the concentration of adhesive at the edge of the pit and the heating procedure are the main reasons for the improved joining quality. Shear load and static absorption energy of joint increases.

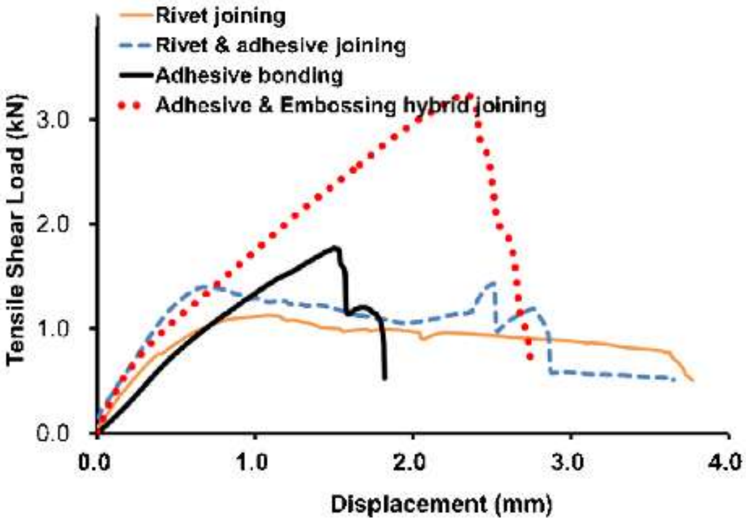

Figure 4. Force – displacement curve for different kind of joints [16].

4. FUTURE SCOPE BASED VARIOUS FINDINGS

This study includes the various research journals on hybrid welding processes of different kinds. In this field a lot of research has been done in past and its applications are increasing rapidly in automobile and aerospace industries where weight reduction with improvement in efficiency is very must. This field has wide and bright scope for further research in future. Joining of materials with different metallurgical properties is possible with hybrid welding without any compromise on material properties and weld strength. Also, hybridization of processes improves the weld qualities with slight increase in cost and it gives synergetic result in some cases. To get the fruitful results without loss of resources from a specific combination of different processes for hybridization there must be synchronization among the processes i.e. every combination doesn't make hybrid process.

Laser-plasma hybrid process has been developed to produce the keyhole-effect, which requires high power laser. The mechanisms of interaction between laser and plasma arc are identified by varying main parameters like laser power, plasma current, and plasma polarity. In case of LBW without the possibility to degas through keyhole that is open to the bottom of the weld seam the keyhole dissociates metal vapor pores into the liquid weld metal at the lower end of the keyhole due to hydrostatic pressure that keeps the keyhole open. The typically deep and narrow weld geometry and the small liquidity interval prevent these pores from degassing to the top of the weld. Thus the metal vapor is enclosed in the solidifying weld metal and forms a more or less distinct band of pores. The initial idea of the laser beam submerged arc hybrid welding process originates from the above mentioned mechanism of pore formation. The arc welding process, characterized by relatively lower power density and wider process zone, gives a wide bead, thus enhancing the joint's root bridging ability. The laser beam process, characterized by higher localized power density, leads to a deeper penetration. Thus in hybrid Gas Metal Arc- laser beam welding, a wide and deep bead is achieved with higher welding speeds compared with the GMAW process.

To extend the tool life and improve the welding efficiency, several preheating methods or hybrid FSW technique have been used to introduce more total heat input during the FSW process of high melting point metallic materials. For example, the preheating sources can be the laser beam, micro- plasma arc, electric resistance heat, high frequency induction or electromagnetic radiation and thus we obtain a hybrid welding technique for better results. Joining of dissimilar metals is difficult with friction stir welding process but this problem can be solved by hybrid friction stir welding technique, in which material flow is enhanced and the load between tool and material is reduced by the use of additional heat source as like GTAW process.

CONCLUSIONS

The analysis carried out in earlier sections indicates both the efficiencies and inefficiencies of the hybridization of joining techniques. On one hand, this approach has many desirable characteristics, but on the other hand, it indicates that it is not always beneficial to combine two or more welding processes. Therefore, adequacy to reality is based on the compatibility of the combining techniques. The main objective of this study was to conduct a literature review to identify, classify, and analyze the hybridization of joining techniques proposed by several researchers. Most of the combinations proposed are fundamentally concerned with metal systems to be joined and synchronization of basic welding methods. How to determine the feasible combination of joining techniques becomes one of the most important topics of theoretical studies. Previous studies have dealt with this matter, but further modifications and new areas of hybridization are also possible. Firstly, detailed comparative studies of the various possible combinations of joining techniques can be carried out. Adhesive bonding can also be a useful tool to improve the strength of weldments. This is an open area for future research. This study also deals with the difficulties of adapting the adhesive bonding with fusion welding processes and highlights the limitations of such combinations. The practical application of the hybridization of joining techniques that were developed theoretically deserves further research.

REFERENCES

[1]. Claus Emmelmann, Marc Kirchhoff, Nikolai Petri; Development of Plasma-Laser-Hybrid Welding Process; Physics Procedia 12 (2011) 194–200.
[2]. F. Moller, C. Thomy; Interaction effects between laser beam and plasma arc in hybrid welding of aluminum; Physics Procedia 41 (2013) 81 – 89.
[3]. Uwe Reisgen, Stefan Jakobs, Markus Schleser, Oleg Mokrov, Eduardo Rossiter; Laser Beam Submerged Arc Hybrid Welding; Physics Procedia 39 (2012) 75 – 83.
[4]. Uwe Reisgen, Simon Olschok, Michael Mavany, Stefan Jakobs; Laser Beam Submerged Arc Hybrid Welding; Physics Procedia 12 (2011) 179–187.
[5]. Gang Song, Liming Liu, Peichong Wang; Overlap welding of magnesium AZ31B sheets using laser-arc hybrid process; Materials Science and Engineering A 429 (2006) 312–319.
[6]. A. Fortunato, A. Ascari, G. Tani, L. Tomesani; The influence of arc transfer mode in hybrid laser-mig welding; Journal of Materials Processing Technology 191 (2007) 111–113.
[7]. Xiaoyan Gu, HuanLi, LijunYang, YingGao; Coupling mechanism of laser and arcs of laser-twin-arc hybrid welding and its effect on welding process; Optics & Laser Technology 48 (2013) 246–253.
[8]. Hongyang Wang, Liming Liu, Fei Liu; The characterization of laser-arc-adhesive hybrid welding of Mg to Al joint using Ni interlayer; Materials and Design 50 (2013) 463–466.
[9]. Woong Seong Chang, S.R. Rajesh, Chang-Keun Chun, Heung-Ju Kim; Microstructure and Mechanical Properties of Hybrid Laser-Friction Stir Welding between AA6061-T6 Al Alloy and AZ31 Mg Alloy; J. Mater. Sci. Technol., 2011, 27(3), 199-204.
[10]. Y.F. Sun, Y. Konishi, M. Kamai, H. Fujii; Microstructure of S45C steel prepared by laser-assisted friction stir welding; Materials and Design 47 (2013) 842–849.
[11]. Don-Hyun Choi, Chang-Yong Lee, Byung-Wook Ahn; Hybrid Friction Stir Welding of High-carbon Steel; J. Mater. Sci. Technol., 2011, 27(2), 127-130.
[12]. HanSur Bang, HeeSeon Bang, GeunHong Jeon; Gas tungsten arc welding assisted hybrid friction stir welding of dissimilar materials Al6061-T6 aluminum alloy and STS304 stainless steel; Materials and Design 37 (2012) 48–55.
[13]. HanSur Bang, HeeSeon Bang, HyunJong Song, SungMin Joo; Joint properties of dissimilar Al6061-T6 aluminum alloy/Ti–6%Al–4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding; Materials and Design 51 (2013) 544–551.
[14]. S.H. Chowdhury, D.L.Chen; Lap shear strength and fatigue behavior of friction stir spot welded dissimilar magnesium-to-aluminum joints with adhesive; Materials Science & Engineering A 562 (2013) 53–60.
[15]. C.-H. Kim, Y.N. Ahn, K.B. Lee; Droplet transfer during conventional gas metal arc and plasma-gas metal arc hybrid welding with Al 5183 filler metal; Current Applied Physics 12 (2012) S178- S183.
[16]. Zhequn Huanga, Sumio Sugiyamab, Jun Yanagimoto; Hybrid joining process for carbon fiber reinforced thermosetting plastic andmetallic thin sheets by chemical bonding and plastic deformation; Journal of Materials Processing Technology 213 (2013) 1864– 1874.