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Comparative Studies on Dissimilar Metals thin Sheets Using Laser Beam Welding - A Review

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***Abstract*—**Laser beam welding for the dissimilar Titanium and Aluminium thin sheets is an emerging area which is having wider applications in aerospace, aircraft, automotive, electronics and in other industries due to its high speed, non-contact, precision with low heat effects, least welding distortion, low labor costs and convenient operation. Laser beam welding of dissimilar metal combinations are increasingly demanded due to high energy densities with small fusion and heat affected zones. Furthermore, no filler or electrode material is required and contamination of weld is also very small. The present study is to reviews the influence of different parameters like laser power, welding speed, power density, beam diameter, focusing distance and type of shielding gas on the mechanical properties of dissimilar metal combinations like SS/Al, Cu/Al and Ti/Al focusing on aluminum to other materials. Research findings reveal that Ti/Al combination gives better metallurgical and mechanical properties than other combinations such as SS/Al and Cu/Al.

***Keywords*—**Laser Beam Welding, dissimilar metals, SS/Al, Cu/Al and Ti/Al sheets.

I. Introduction

A wide range of materials may be joined by Laser Beam Welding (LBW) using similar metals, dissimilar metals, alloys and non-metals. In the present scenario demand of the joining of dissimilar materials continuously increases due to their advantages, which can provide appropriate mechanical properties and good cost reduction. The weld itself is narrow and volume of intermetallics may be reduced to acceptable limits. It may be possible to offset the beam in one direction or the other allowing control over the composition of the resulting alloy. Also it is feasible to produce sound joints by these methods on a laboratory scale.

Many authors observed SS/Al as the most commonly used and commercially available metal due to its light weight and high strength to weight ratio and the stainless / aluminium combination nowadays also has applications small ship / yacht building. Cu/Al combination finds particular use in electrical and electronic applications. Aluminium has high electrical conductivity, reflectivity and corrosion resistance. Compared to copper slightly smaller thermal and electrical conductivity, but it is a wide range of applications [1], [2]. Many research efforts have been made in the area of laser beam welding of Cu/Al [3]. Furthermore laser beam process can be used for joining of Ti/Al thin sheets. Titanium material offer excellent mechanical properties and corrosion resistance combined with low specific weight [4]. This qualifies titanium for lightweight applications in aviation, automotive and energy engineering [5]. To avoid corrosion from the presence of liquids in the passenger cabin on conventional wide-bodied aircrafts needs to be developed by using titanium and aluminium joints [6].

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II. Discussion on the Effect of Different Parameters on LBW of SS/Al, Cu/Al and Ti/Al Sheets

A. Laser Power, P (kW)

Stainless Steel/Aluminium (SS/Al) the possible power setup ranges between 0.75KW and 1.8kW and with speed 1-7m/min were investigated by Theron et al. [3]. They observed tensile shear strength values were scattered. The highest tensile shear strength is obtained at the lower power densities and higher heat inputs. Large scatter in tensile shear values and similar values are noted for the 0.4 mm and 0.6 mm spot sizes. Little scatter was obtained for 0.3 mm spot which is the optimum for SS / Al welding.

Copper/Aluminium (Cu/Al) alloy the power for the specific set up ranges approximately between 1.2 KW and 3.7 KW at a travel speeds between 2–8 m/min were investigated by Ivanchev et al [3] and reported that the least practical operating window would be for the 0.6 mm spot size. The higher tensile strengths were obtained at lower power levels and travel speeds and the least scatter were present with power densities between 17 and 26 KW/mm². It is evident that the 0.3 mm spot size delivered joints with higher tensile shear values. The 0.4mm spot size had the largest range in laser power variation and second highest tensile shear values. Therefore the 0.4mm spot size is the optimum for Cu/Al welding.

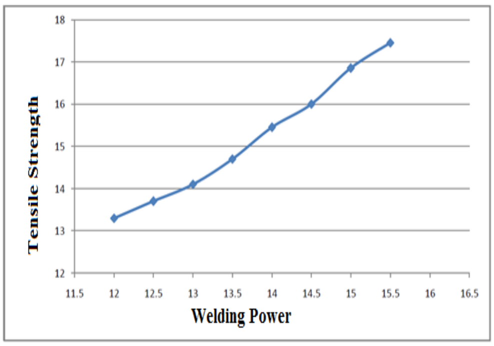

Fig. 1 Graph of tensile strength vs. welding power

Titanium/Aluminium (Ti/Al) the laser power was varied between 12 joules to 16 joules by Ashitosh Pandey et al. [7] and the specimens were passed through tensile test is shown in Fig. 1. Laser power was controlled by the machine directly. The welding speed was kept 2 mm/min in this set of experiments with beam diameter 1.8mm and welding frequency 12Hz.

B. LBW Welding Speed, V (mm/min)

For SS/Al the typical welding speeds for SS/Al with a 100W were studied by Mohammed Naeem et al. [8]. Argon shielding gas was used during these experiments. Because high beam quality of the laser the welding speeds are very high while welding thin foils. However as the thickness increases average power is more important than the beam quality because the process needs extra watts to keep the molten pool going. The welding speed for 500µm thick material is 30mm/s of which heat input is 25J/cm [8]. It is also possible to weld thin foils of dissimilar materials and combination of stainless steel and aluminium for electronic connectors.

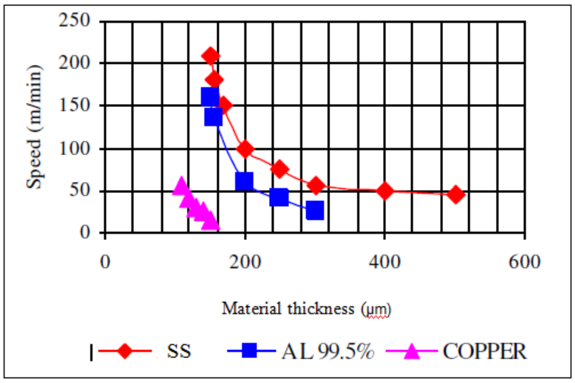

Fig. 2 Material thickness vs. welding speed

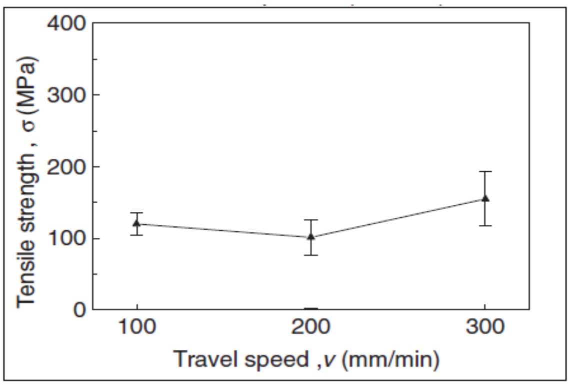

Fig. 3 Speed vs. Tensile strength of Ti and Al alloys joints

For Cu/Al welding experiments were also performed with pulsed parameters like frequency, pulse width and peak power to see if it is possible to weld copper and aluminium [8]. The results show there is not enough peak power to couple into these materials. However with a 200W fiber and hence increased power density it was possible to weld very thin foils of copper and aluminum. Typical welding speeds for these materials and also for stainless steel are highlighted in Fig. 2.

For Ti/Al the average tensile strength of the Ti/Al joint was 311 MPa and travel speed of 300 mm/min were investigated by Masayuki Aonuma et al. [9] is shown in Fig. 3. Increasing travel speed increases the tensile strength of the joints. The average tensile strength of the Ti/Al alloy joints tends to be lower than that of the joints under the base metal conditions. Zhihua Song et al. [10] identified in all Ti alloy and Al alloy joints the fracture occurred near the joint interface is shown in Fig. 4.

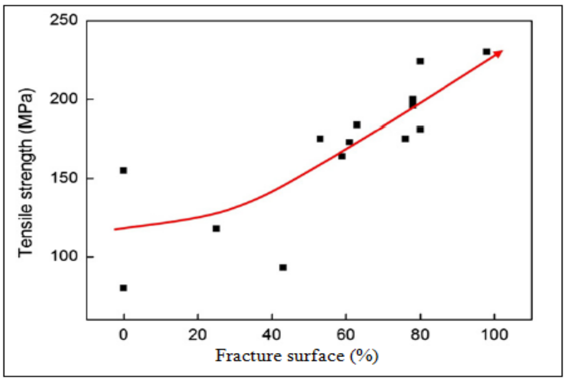

Fig. 4 Fracture surface vs. Tensile strength

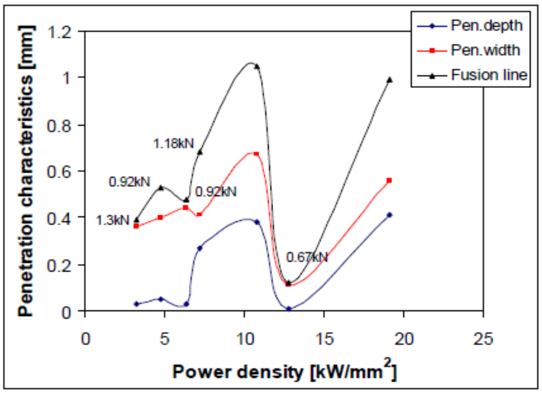

Fig. 5 (a) Power density vs. Penetration characteristics of SS/Al

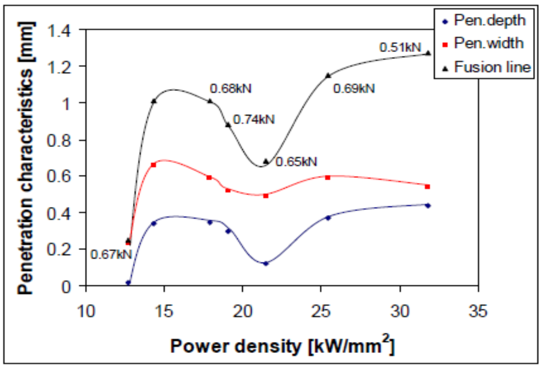

Fig. 5 (b) Power density vs. Penetration characteristics of Cu/Al

The progress of reaction between Ti and Al is such that with the increase in the thickness results in reduction of joint strength. It is also found that fracture surface is higher than 90%; the highest joint strength is just about 72% of the Al alloy base metal [9].

C. LBW Power Density (W/cm²)

The power density is one of most pivotal parameters in laser welding. Increasing the laser power (P) and decreasing the welding speed (V) result in an increase of the power density. Van rooyen et al. [3] found that the tensile shear strength of the joints is depending on the penetration characteristics of the welds and it indicates the power density. From Figs. 5 (a) and (b) indicate the power density of the SS/Al and Cu/Al joints. This can be attributed to the fracture path of all the samples which were along the fusion line.

Tadamalle et al. [11] were discussed on Ti/Al sheet metal and found that energy density is directly proportional to bead width and depth of penetration is shown Fig. 6.

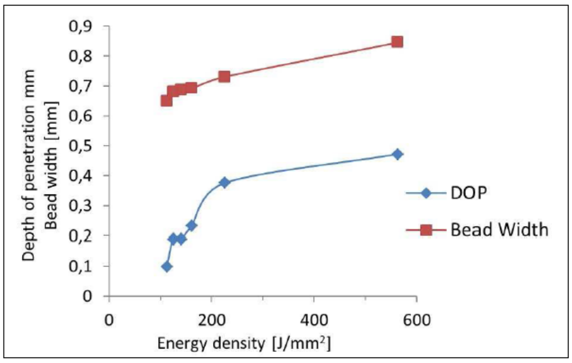

Fig. 6 Energy density vs. Depth of penetration

The full depth of penetration will occur beyond 600J/mm² of energy density. Initially up to 225 J/mm² of energy density the depth of penetration increases drastically from 0.1 mm to 0.375 mm and thereafter the value of depth of penetration increases from 0.375 mm to 0.472 mm for the additional energy input of 337 J/mm² [11]. The laser energy input to the specimen becomes quite larger over a small area which results in increase in the depth of penetration and bead width. This can be reduced to a certain extend by fixing the job tightly.

D. Beam Diameter

Beam diameter is the key factor for laser weld. It is difficult to measure, what is produced by the nature of the beam diameter. For laser weld the condition of high effective deep penetration weld is that the power density on the laser focus must exceed 106 W/cm² by Mohammed Naeem et al. [8] observed the power density has linear relation with the laser power and square ratio relation with beam diameter and hence so the effect of reducing beam diameter is better. Lasers beam like single mode and multi mode. Single mode beam lasers are typically delivered a core diameter of around 9 microns producing a narrow high intensity beam which can be focused down to a spot size as small as 10 microns. Multi mode laser core diameters are between 50 to 300 microns resulting in lower intensity and more uniform. Flat top beams which promote an enlarged melt zone more in line with welding requirements. Fig. 7 shows a schematic of the laser exit and the cross section of power intensity through the beam diameter for the two modes.

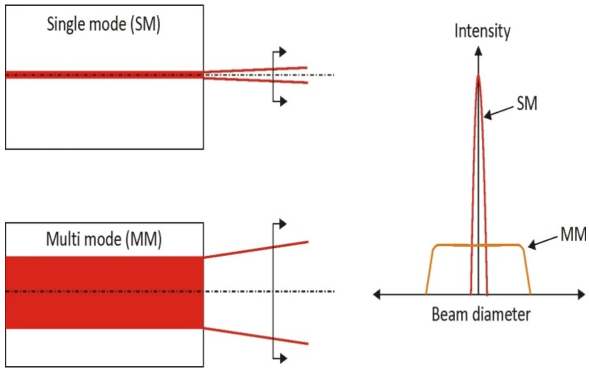

Fig. 7 Laser beam diameter for two modes

In single mode high central intensity which tapers rapidly to the edges concentrates all of its power in a small volume of material. If there is any gap in the joint, the weld will be undercut or under filled due to high intensity [8]. The multimode laser beam more equally distributes its intensity across the weld resulting in more stable welding conditions. Fig. 8 shows cross sections of bead on plate welds for single mode and multimode lasers in 0.06" thickness utilizing (a) Single Mode Laser at 500W and 300 ipm with a 30 micron spot size (b) Multi Mode Laser at 700W and 100ipm with a 150 micron spot size (c) Multi Mode Laser at 1kW and 80 ipm with a 250 micron spot size [8].

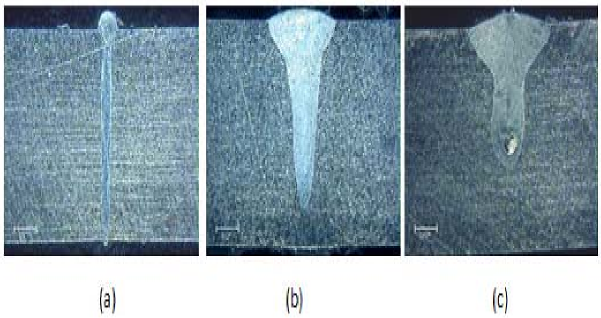

Fig. 8 Cross sections of bead on plate welds for single mode and multimode

There are some cases where single mode lasers can be implemented effectively in welding applications with high speed welding. Very close fitting joints that can be welded with significantly lower laser power but still achieve a certain penetration over multi mode lasers.

E. LBW Focal Distance, f (mm)

The focal distance is defined as the distance between the focal point and the top surface of the sample. The focal plane should be set where the maximum penetration depths or best process tolerances are produced. The laser welding usually needs some focus distance, because too high power density of the beam center at the laser focus is easy to vaporize. When the focus distance reduces to a certain value, the melting depth will suddenly change, which will establish necessary conditions for producing penetration pores [3], [12]. These most results in this domain showed that the focus distance influences not only the laser beam on the weld piece surface, but also the incidence direction of beam. So it has important influences to the melting depth and beam shape.

F. LBW Shielding Gas Flow, V (l/min)

The welding gas is flushed on to the work piece through a nozzle system in order to protect molten and heated metal from the atmosphere. Gases have different chemical reactions and physical properties, which affect their suitability as assist gases for different welding tasks. Three important points must be considered such as plasma its influence on mechanical properties and shielding effect [12]. To reduce the plasma effect, inert gases such as helium or argon can be used and there is no reaction on the weld metal and do not affect weld metallurgy. This plasma effect can be reduced as a result of high ionization potential of helium and hence the weld profile can be improved [13].

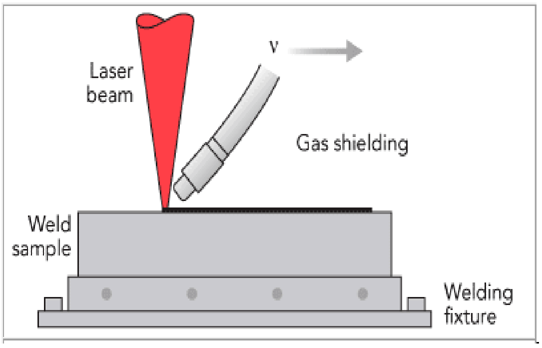

Fig. 9 Gas shielding arrangement

Parameters and welding speeds were adjusted to produce welds with consistent top bead and under bead with minimal spatter and undercut [14]. Gas shielding for the weld top bead was supplied through a 10mm diameter pipe as shown in Fig. 9. In all cases argon with flow rate of 10 litre/minute is used for shielding.

III. Conclusion

1. An overview of laser beam welding of dissimilar materials focusing on aluminum to other materials has been studied.
2. Furthermore, this paper review showed that there is a significant progress in laser welding of dissimilar materials. Most of the cited research studies are focused on understanding the parameters of various welds.
3. There were large differences in melting point between the sheets of Ti and Al welding. There was a region within the lower melting point sheet which had melted but not mixed with the main weld pool.
4. Compare to SS/Al and Cu/Al, Ti/Al gives sound weldment in Aluminium rich region.

IV. Future Scope

1. LBW technology needs to be developed for meeting industrial needs.
2. Full understanding of the dissimilar welding process using LBW is needed to accommodate huge demand in the industries including manufacturing and the aerospace.
3. LBW results in high quality welds. The identification of specific intermetallic phases of dissimilar sheet metals are in scope for future study.

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