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Studies on Ti/Al Sheet Joint Using Laser Beam Welding – A Review

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***Abstract*—**Laser beam welding has wide acceptability due to least welding distortion, low labour costs and convenient operation. However, laser welding for dissimilar titanium and aluminium alloys is a new area which is having wider applications in aerospace, aircraft, automotive, electronics and other industries. The present study is concerned with welding parameters namely laser power, welding speed, focusing distance and type of shielding gas and thereby evaluate welding performance of titanium and aluminium alloy thin sheets. This paper reviews the basic concepts associated with different parameters of Ti/Al sheet joint using Laser beam welding.

***Keywords*—**Laser Beam Welding (LBW), Dissimilar joining Titanium and Aluminum sheets.

I. Introduction

SUCESSFUL Welding of Titanium and Aluminum alloy is of challenge due to the differences in physical, chemical and metallurgical properties between the two alloys. In recent years, brazing, diffusion bonding, friction stir welding and laser welding have been attempted to join Ti/Al dissimilar metals. Laser Beam Welding (LBW) is more flexible compared with other welding techniques and attracts more attention from scientists and engineers. Advantages of LBW in comparison to Electron Beam Welding (EBW) are the laser beam can be transmitted through air rather than vacuum and the process is easily automated with robotic machinery. Recently demand for dissimilar metal joints of titanium to aluminium alloy has risen in industry, especially in transportation vehicle industry. However it is well known that fusion welding of titanium to aluminium alloy is difficult because of brittle intermetallic compound that is generated at the joint interface. The most important is the thermo-physical properties of the corresponding metals. Some properties are temperature dependent for assessing weldability for deriving welding strategy by Zhihua Song et al [1].

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II. Literature Discussions of Titanium/Aluminium Alloys

The laser power and welding speed determine the pre test results Zhihua Song et al [1]. Test result show that 4kW and 4m/min are the optimum parameters for the conventional welding of Ti and Al alloy plates with thickness of 2mm. Before welding, the plates are cut and machined into rectangular welding samples. The surfaces of the welding samples are to be ground with grit paper to remove the oxide film and then cleaned by ethanol before welding. During welding the focus position is kept on the top surface of aluminum alloys as shown in Fig. 1.

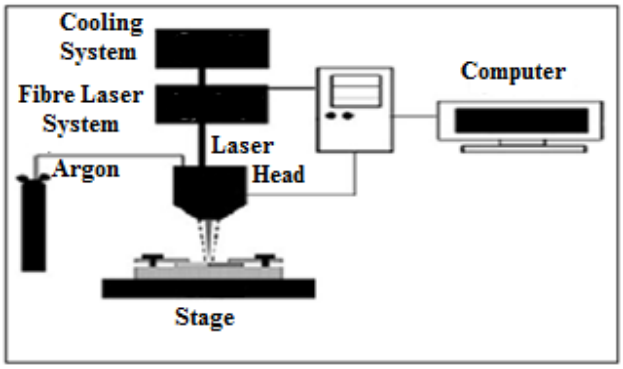


Fig. 1 Laser welding of dissimilar materials process full set up diagram

Parameters and welding speeds were adjusted to produce welds with consistent top bead and under bead, minimal spatter and undercut Hui-Chi et al [2]. Gas shielding for the weld top bead was supplied via a 10mm diameter pipe shown in Fig. 2. In all cases argon 10 lit/min was used for shielding.

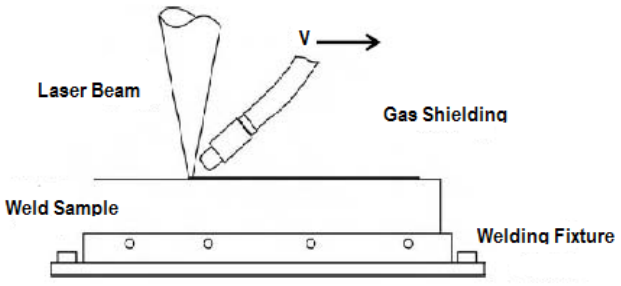


Fig. 2 Gas shielding arrangement

A. Laser Power, P (KW)

The laser power is a critical parameter to obtain a full penetration depth and to control the weld bead profile. High

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power density at the work piece is crucial to achieve keyhole welding and to control the formation of welds. Studies realized in this domain showed this effect of laser power in conventional laser beam welding on the penetration depth and weld width. The increasing beam power led to deeper and wider beads. The penetration depth and weld width increased with increasing laser power due to higher power density Afia et al [3]. The weld width becomes larger with increasing laser power. For example the threshold power to achieve full penetration is 2.5 kW for 2 mm aluminium plates welded at a speed of 4 m/min and a focused diameter of 0.25 mm. when laser power was too low, lack of penetration was observed whereas high laser power produced laser cutting.

Laser power was varied between 12 joules to 16 joules and the specimens were passed through tensile and hardness test Ashitosg et al [4]. Laser power was controlled by the machine directly. Laser power can be varied as per requirement. The welding speed was kept 2 mm/min in this set of experiments while laser beam diameter was at kept 1.8mm with welding frequency 12Hz. In thick sheet partial penetration welding maximum power is directly related to penetration depth. When the thickness of the work piece is large enough, most of the energy will be conducted away and allowing the weld to form with a nice conical, high aspect ratios shape Mohammed Naeem et al. [9]-[11]. However when the thickness of the work piece is on the order of the maximum penetration depth for the corresponding maximum powers the bulk is not large enough to conduct away significant amount of laser energy resulting in a larger molten pool. For full penetration welding if the molten pool grows too large to be held in position by the surface tension drop out defect will occur in which case the molten pool is forced through the bottom surface due to gravity and shielding gas pressure Ashitosg et al [4], Tu et al [5]. Aluminum is especially susceptible to drop out because it has low viscosity at high temperatures.

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

The penetration depth and weld width both increase linearly with decreasing welding speed and decrease with increasing welding speed. The penetration depth and weld width both decrease linearly with increasing welding speed Afia et al. [3], Tu et al. [5], Mehmelti et al. [12]. Moreover the speed lead too either to improve or to decrease the weld quality in particular by the formation of the defects such as cracking or the pores formation. Indeed at low speeds the interaction time between molten metal and surrounding air is large enough to allow pores to nucleate in large quantity grow and escape from the molten pool as a result of buoyancy and convection flow. Moreover when the welding speed is too slow the bead produced by the superfluous heat exchange will extend to the side and the heat influenced area will become too heat and extended. The seam metallographic structure crystal becomes thick sometimes the cracking will appear which will seriously influence the welding quality. When the welding speed achieves the lower limitation the superfluous power absorption also will induce local evaporation loss and hollows Mohammed Naeem et al. [9]-[11]. Moreover using lower welding speeds induced no real change will be expected in the penetration depth but wider the weld width and especially the heat affected zone (HAZ).

For thick sheet partial penetration welding is shown in Fig. 3 reducing the speed increases the penetration until the process becomes unstable. However, when welding thin sheets the absence of surrounding material can lead to a significant increase in molten pool size.

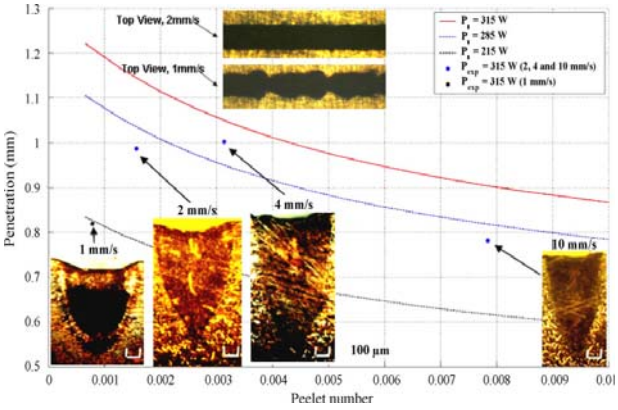


Fig. 3 Data comparison at low speed welding

Again this is undesirable due to the drop out effect as well as the thermal distortion due to the increased heat input. Therefore the speed should be chosen to be high enough that the drop out and distortion are not significant but low enough to maintain a consistent weld by avoiding the high accelerations and decelerations needed to trace the crack at high speeds Tu et al [5].

C. LBW Density (W/cm2)

The power density is one of most pivotal parameters in laser weld. When the laser power density is lower than 106 W/cm², the laser weld belongs to category of heat exchange weld. When the laser power density achieves only 106 W/cm², the deep penetration weld can be formed and “keyhole effects” appears. The ‘keyhole effects’ is closely correlative to the laser power density which is more low, the ‘keyhole effects’ is more unstable even cannot be formed and the melting pool is also small Theron et al. [6]. The melting depth of laser weld is directly correlative to the laser output power density and which is the function of incidence beam power and beam diameter. Therefore to enhance the power density we can enhance laser power or decrease the laser speed. A good balance has to be found to avoid laser cutting when the power density is too high and lack of penetration when the power density is too low. Concerning LBW, increasing the laser power (P) and decreasing the welding speed (V) result in an increase of the power density. It is evident that the tensile shear strength of the Ti/Al joints is dependent on the penetration characteristics of the welds Theron et al [6]. This can be attributed the fracture path of the samples along the fusion line. General insufficient clamping resulting in small contacting areas leads to some poor joints being obtained which might have otherwise resulted in good joints. Linear

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relationships exist between power and travel speed required for welding of dissimilar metal combinations.

D. Beam Diameter

Beam diameter is the key factor for laser weld. But for the laser beam with high power it is difficult to measure and 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. We can adopt two methods to enhance the power density, one is to enhance the laser power and the other one is to reduce the diameter of the beam. The power density has linear relation with the laser power and square ratio relation with beam diameter. So the effect of reducing beam diameter is better. Lasers beam mode comes in two flavors 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. This high intensity small spot is ideally suited for laser cutting applications, but generally not great for welding, as weld widths are too narrow to accommodate most production fit-up tolerances.

Multi mode lasers by contrast utilize core diameters between 50 to 300 microns resulting in lower intensity, more uniform, 'flat top' beams which promote an enlarged melt zone more in line with welding requirements. The Fig. 4. shows a schematic of the laser exiting and the cross section of power intensity through the beam diameter for the two modes.

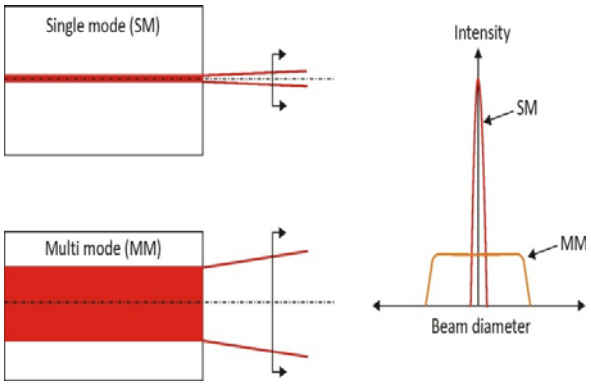


Fig. 4 Laser power intensity of beam diameter for two modes.

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 and if the intensity is too high Mohammed Naeem et al [9]. The multimode laser beam more equally distributes its intensity across the weld resulting in more stable welding conditions. It is less sensitive to gaps between welding surfaces and its larger flat top intensity profile melts more base material volume effectively bridging gaps as needed.

E. LBW Focal Distance, (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 Theron et al. [6], Leong et al. [7]. 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 onto 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 to form plasma, influence on mechanical properties and shielding effect Leong et al. [13]. To reduce the plasma effect use inert gases such as helium or argon can be used as welding gas, there is no reaction on the weld metal and do not affect weld metallurgy. This plasma effect can be reduced as a result of the higher ionization potential of helium and then the weld profile can be improved Shidid et al. [8].

G. Shielding Gas Pressure

Shielding gas is usually used off-axially to avoid disturbing the welding pool. However, due to the design of the laser head used in this study, the assist gas is injected coaxially to create a nitrogen atmosphere to prevent oxygen or hydrogen from reacting with the molten aluminum. In order to prevent significant amount of molten metal from being ejected by the co-axial assist gas, the flow rate of the gas needs to be reduced or the distance between the nozzle and the top of the work piece be increased. This will reduce the pressure exerted on the molten pool, while maintaining an atmosphere that shields from oxygen or hydrogen. In full penetration welding this effect could become even more critical because of the lack of support for the molten aluminum at the bottom surface. This process can very easily become laser cutting if the shielding gas pressure is too high. A shielding gas pressure between 30 and 40 psi was found to be satisfactory.

III. Comparison with Other Welding Technologies

A number of benefits are provided by laser welding in comparison with conventional technologies. For instance the process can be performed in remote locations or inside three dimensional components from single side access where the introduction of electrodes would be impossible. Furthermore new opportunities are offered in autogenously joining difficult materials including but not limited to titanium and aluminum alloys without the need for filler metal, no pre heating and neither mechanical finishing are required. Increased processing speed is achieved and as a consequence productivity improves.

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Advantages come from the primary feature of narrowly focusing the heat source to a very small area in the order of few tenths of millimeters local laser welding 5 precision treatment and extremely high cooling rates are benefited in the order of 104°C/s whilst a rate of 102°C/s results in tungsten inert gas welding. Compared with slower processes grounds are then given to further advantages in dissimilar welding which traditionally is only feasible for certain combinations of the base elements. Indeed irrespective of the alloys being joined the properties of different materials are generally difficult to be matched and the formation of brittle intermetallics occurs.

IV. Conclusion

The welding parameters and properties of engineering materials continue to be a topic of considerable interest and relevance in the manufacturing community. The current study reveals the significance of the following laser welding parameters of Ti/Al dissimilar thin sheet joint.

1. The penetration depth and weld width increased with increasing laser power due to higher power density.
2. The penetration depth and weld width both increase linearly with decreasing welding speed.
3. The melting depth of laser weld is directly correlative to the laser output power density and which is the function of incidence beam power and beam diameter.
4. When the focus distance reduces to a certain value, the melting depth will suddenly change, which will establish necessary conditions for producing penetration pores.
5. Plasma effect can be reduced as a result of the higher ionization potential of helium and thus the weld profile can be improved.
6. Even the Titanium to Aluminium weld which was sound in the aluminium rich region contained a few small micro cracks in the small root area where high dilution with titanium had created brittle intermetallic phases.

V. Future Study

LBW results in high quality welds. The identification of developing new optimum parameters for different size and different materials of dissimilar sheet metals are in scope of future study.

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