Laser Beam Welding of Ti/Al Dissimilar Thin Sheets - A Literature Review

K. Kalaiselvan, A. Elango, N.M. Nagarajan, N. Mathiazhagan

***Abstract*—**Dissimilar joining of Titanium and Aluminum thin sheets has potential applications in aerospace and automobile industry which can reduce weight and cost and improve strength, corrosion resistance and high temperature properties. However successful welding of Titanium/Aluminium sheets is of challenge due to differences in physical, chemical and metallurgical properties between the two. This paper describes research results of Laser Beam Welding (LBW) of Ti/Al thin sheets in which many researchers have recently performed and critically reviewed from different perspectives. Also some of notable works in the field of laser welding with changes in mechanical properties, crack propagation, diffusion behavior, chemical potential, interfacial reaction and the microstructure are reported.

***Keywords*—**Laser Beam Welding (LBW), Mechanical properties, Titanium and Aluminium thin sheets.

I. Introduction

BOTH technical and economic reasons suggest joining dissimilar thin sheets benefiting from the specific properties of each material in order to perform flexible design. Adhesive bonding and mechanical joining have been traditionally used although adhesives fail to be effective in high-temperature environments and mechanical joining are not adequate for leak-tight joints. Friction stir welding is a valid alternative even being difficult to perform for specific joint geometries and thin plates. Hence the attention has therefore been shifted to laser welding. Interest has been shown in welding Ti/Al especially in the aviation industry in order to benefit from corrosive resistance, strength properties, low weight and cost. Titanium alloy Ti-6Al-4V and aluminum alloy sheets are considered in this review being the most common ones in aerospace and automotive industries. Laser welding is thought to be particularly useful in reducing the heat affected zones and providing deep penetrative beads. Nevertheless many challenges arise in welding dissimilar metals and are further complicated considering the specific features of the thin sheets.

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II. Working principle of LBM

The schematic diagram of Laser Beam Welding [1] setup is shown in Fig. 1. The laser source is used to deliver laser beam with a capacity of 4 kW in multimode condition. The plane polarized laser beam comes out of the laser source. The beam delivery system consists of phase retarder which converts laser beam from plane polarized to circularly polarized form. The mirror acts as a beam bender and focusing lens are used to focus laser beam on the work piece. A separate nozzle is used for deliver the argon gas to prevent work piece from oxidation and heat dissipation. The CNC part program co-ordinates both table movements and laser power delivery control.

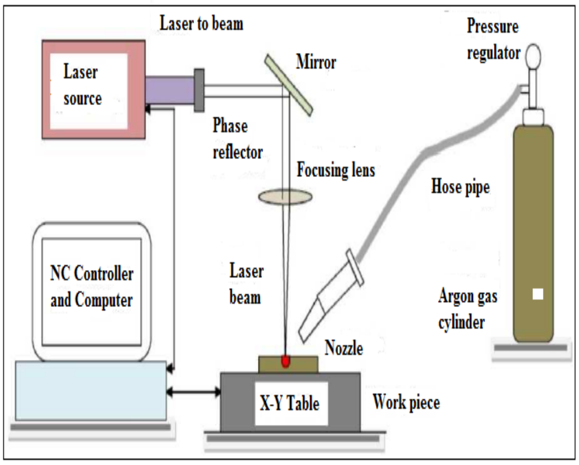

Fig. 1 Working Principle of Laser Beam Welding

The laser welding is carried out by placing the specimen on machine bed and held firmly using permanent magnets on either side of the plates. The specimen mounting arrangement is used for creating bead on plate during the welding process. The process parameters and thermo mechanical properties are investigated subsequently.

III. Literature Review

Zhihua Song et al. [2] have studied on interfacial microstructure and mechanical property of Ti6Al4V/A6061 dissimilar joint by direct laser brazing without filler metal and groove. In that study similar alloys with 2 mm thickness by laser beam without filler metal can produce sound brazing joints with good appearance under welding conditions of 4 kW laser power, 4 m/min welding speed and 0.8–1.0 mm laser offset at aluminum alloy side. They concentrated laser offset distance which has a great influence on the thickness of interfacial IMC layer and the mechanical property of joint. With increasing laser offset, the thickness of interfacial IMC layer decreases and the tensile strength of joint increases. When the laser offset is1.0mm, thickness of interfacial IMC layer is about 0.26 mm and the average tensile strength of joint is about 64%of the aluminum alloy base metal. The interfacial intermetallic phase is TiAl3. They have used the joining mechanism of Ti6Al4V/A6061 dissimilar alloys by laser brazing is the formation of intermetallic phase TiAl3 at the interface which metallurgically connects Ti6Al4V and A6061 plates together. They have concluded that the thickness of interfacial IMC layer is decreased by increasing the laser offset and dissimilar joints tend to fracture in the fusion zone of aluminum alloy and the tensile strength of joint increases.

Shuhai Chen et al [3] investigated Joining mechanism of Ti/Al dissimilar alloys during laser welding-brazing process. They showed that the fusion welding zones are divided into fusion line (FL), columnar crystal zone (CCZ) and equiaxed crystal zone (ECZ). The microstructures of welding joint consist of Al grains and ternary near eutectic structure including α-Al, Si and Mg2.Si. Fusion line with fine hypoeutectic microstructure was formed by diffusion of element Si from weld pool to semi-molten zone at solid/liquid interface. The columnar crystal was formed due to obvious directionality of heat conduction. Equiaxed crystals were formed in the weld pool due to the stir by filler wire and high degree of super cooling. The microstructures of brazing zone are orderly from Ti alloy to the seam consists of Ti, nano size granular Ti7Al5Si12 and serration shaped TiAl3. Apparent stacking fault structure of intermetallic compound TiAl3 was found. Finally they showed that during the interfacial reaction at solid/liquid interface, the formation of Ti7Al5Si12 depended on the dissolution of Ti alloy and the segregation of Si atoms: Intermetallic phase TiAl3 was formed by the crystallization. Growth of brittle reaction layer could be suppressed because dissolution of Ti alloy was weakened by formation of ternary compound Ti7Al5Si12.

Gerhard LIEDL et al [4] has studied laser assisted joining of dissimilar materials like aluminum alloys to steel, aluminum alloys to titanium and hard metals to steel with high power Nd:YAG and diode lasers. Joining of aluminum alloys from 5XXX and 6XXX groups with AlMg3, AlMgSi1 and titanium or micro alloyed steel H340 galvanized and non-galvanized have been investigated. Additionally butt joints between hard metals K40 86% tungsten carbide, 12% cobalt and 2% titanium and tantalum carbide and carbon steel C75 tensile strength 1450 N/mm2 have been examined. A 1 kW diode laser as well as 3 kW Nd:YAG laser have been used for experiments. Microstructure and mechanical properties of laser welded samples have been investigated by microscopy, SEM and micro hardness analysis. Aluminum to steel samples has been tested by shear strength measurements too. All aluminum samples have been welded in an overlap configuration. Additionally aluminum to steel and hard metal to steel samples has been welded in a butt joint configuration. Mismatch of thermo mechanical properties like thermal expansion coefficient or thermal conductivities of materials selected for welding and the formation of brittle intermetallic phases result in residual stress formation. Line energy, focal position, shielding gas and laser pre- and post-heating have been varied. A precise temperature control with pre heat and post heat treatment has been used to minimize stress and possible weld defects. Results showed that laser welding produces competitive joints without cracks or pores in the weld seam between dissimilar metals.

Vaidya et al [5] have investigated on dissimilar butt welds of Ti6Al4V and AA6056 -T6 by laser beam welding. The initial configuration of a straight interface was modified by chamfering Ti6Al4V. Thus the length of the Al/Ti-interface and the extent of the brittle intermetallic phase TiAl3 were reduced. This configuration has led to the conclusions of grain size in the fusion zone was reduced and the intermetallic phase formed at the interface was thinner. Specimens could be mechanically tested without formation of cracks in the reaction zone and premature pullout or de bonding. The welded coupons were sound in both configurations. Hardness and tensile strength were slightly higher in the modified joint whereby the fracture occurred in the hardness dip on the side of AA6056–T6 and the interface remained intact in both cases. Whereas fracture toughness remained nearly comparable in both cases and the resistance to fatigue crack propagation was improved through the joint modification substantially at least by a factor of two.

During fatigue crack propagation partly intercrystalline fracture occurred in the fusion zone of the unmodified joint specimens. This was absent in the modified joint specimens and completely transcrystalline fracture and striations were observed not only for the interface adhering Al particles but also in the fusion zone. Moreover ductile tearing occurred after a longer crack length. Such fractographic differences clearly show that the improvement brought about by the joint modification is a genuine effect. In addition to the decrease in the interfacial area the modified configuration is inferred to have induced a faster cooling rate. This has most likely decreased the reaction zone, improved the interfacial binding, reduced the grain size in the fusion zone, avoided grain boundary segregation and retained solute for hardening. In turn this microstructure refinement has contributed to improved properties.

Chen Shu-hai et al [6] have worked in laser joining of Al alloy to Ti alloy. Si element diffuses to the interface and enriches there with the mode of Ti dissolution or melting. It is found that Si diffusion behavior plays an important role in forming those interfacial compounds. Chemical potential prediction model of the ternary alloys is established based on MIEDEMA model of solution enthalpy. The influences of Ti molar fraction and temperature on Si chemical potential were analyzed according to calculated results. It was found that the influence of Ti molar fraction is far higher than that of the temperature on Si chemical potential. The minimum value of Si chemical potential is approximate 0.5 of Ti molar fraction which presents a good agreement with experimental data. Further they showed in the case of Ti dissolution mode, the dissolution of Ti alloy in liquid filler induces the reduction of the Si chemical potential. This causes the phenomenon of Si element gathering at the interface. In the case of Ti melting mode element Si not only gets together at the interface but also further diffuses to liquid Ti due to slight melting of Ti substrate.

Möller et al [7] reported that the heat conduction welding process is a feasible process for joining aluminium and titanium hybrid sheet structures. Moreover they demonstrated that the deformation prior to welding influences the deformation after welding. The thermo mechanical simulation gave information about distortion and residual stresses of the specimens after welding. One important result of the thermo mechanical simulation is that the height distortion is caused by an occurring longitudinal plastic compression zone in the titanium component part. This plastic zone extends nearly over the total length of the specimen and is created by the presence of a large direction specific resistance to the large local thermal expansion.

Woizeschke et al [8] has studied the failure behavior of aluminum-titanium hybrid seams within a novel aluminum-CFRP joining concept. They observed failure modes within the aluminum and carbon fiber reinforced plastics joints of the novel foil concept. However, failing of the Al and Ti interface at the front side of the titanium laminate has been detected at all specimens. Hence a modification of the Al and Ti joining zone would be necessary to make the entire specimen suitable for higher seam loads. Additionally a buckling of the external titanium foils of the laminate occurred next to the Al/Ti transition at several specimens. They proposed such local plastic deformations of the joint should be avoided at an early stage of loading even though the buckling has not shown significant influence on the seam strength in this investigation.

Michael Kreimeyer et al [9] developed a process for joining aluminum to titanium in butt joint configuration. For the production of this kind of tailored blank a conventional CO_2 laser working head was used. By the integration of a shielding gas nozzle positioned above the weld seam it was possible to join aluminum to titanium under local gas protection as shown in Fig. 2.

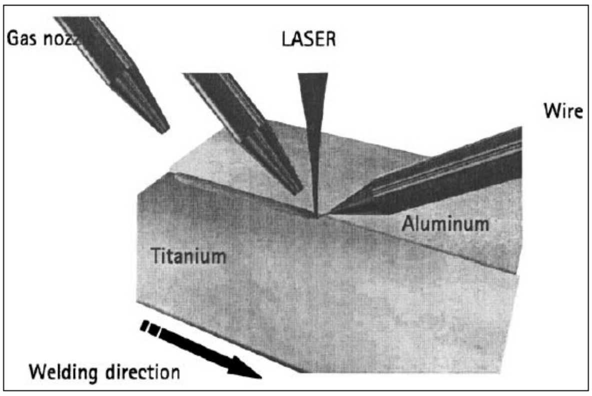

Fig. 2 Set up for joining Titanium and Aluminum in butt joint configuration

Joints with minimal intermetallic phase layers <2µm were realized through process adjustment using the deep penetration effect. The process parameters were pre determined by FEM simulation allowing a sufficient estimation of the process parameters with respect to temperature time control and beam positioning with a constant energy input per unit length. The experiments have shown that the growth of the intermetallic phase has only a minor dependence on the energy input per unit length probably due to the limited diffusibility of aluminum in the titanium aluminide phases Ti_2Al_3. However on the upper and lower side of the samples areas were found where both metals melt and due to weld pool dynamics a mixture of both materials occur. Therefore areas with three phases like aluminum, intermetallic phase and titanium are formed. These three phase areas depend heavily on the energy input per unit length. Investigation has shown that a decrease in the energy input per unit length results in a decrease in the size of the three phase areas. Static tensile strength of about 200MPa was detected as represented in Fig. 3.

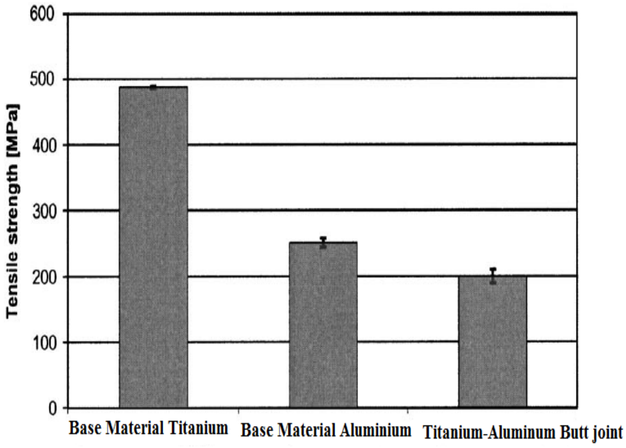

Fig. 3 Tensile strength of the Titanium and Aluminum butt joint in comparison with the base materials

This is equivalent to 80% of the aluminum base material. Failure of the samples occurs in the HAZ with the crack propagating from the HAZ of the Al towards the intermetallic phase.

Woizeschke et al [10] have reported the possibility of joining a titanium wire loop structure to an aluminum sheet by a single pass laser process as shown in Figs. 4 (a) and (b). An observed seam defect at the front side of the wires could be explained by a shadowing effect due to the laser beam orientation.

The strength of the joint exceeds the strength of a 1 mm wire loop in tensile tests. An increase of the wetting length results in an extended recrystallization zone which decreases the fracture force per loop. A joining of CFRP and aluminum parts by the novel approach of a titanium laminate as transition structure could be achieved by a combined welding and brazing process. The cross sectional area of the titanium laminate compared with the double row loop structure is six times higher which indicates a higher potential of the foil concept with respect to the maximum achievable strength.

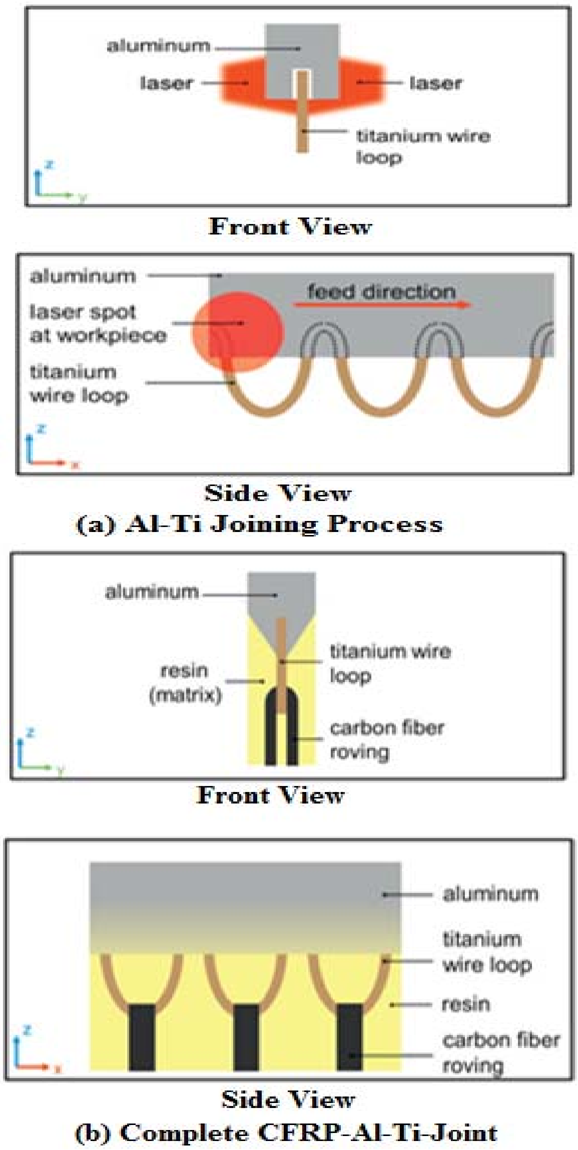

Fig. 4 (a) Principle of the Al-Ti-joining process by a double sided laser beam within the wire concept (b) Sketches of the complete Al-Ti-CFRP joint

Mohammed Naeem et al [11] have highlighted the differences in the behaviour of laser welding and compared to other fusion welding processes such as arc welding. The mixing in the weld pools was relatively poor and there were usually two distinct regions in each weld cross section and corresponding to where the pool was surrounded by each sheet. Where there were large differences in melting point between the sheets of Ti and Al and there was a region within the lower melting point sheet which had melted but not mixed with the main weld pool. Few problems were anticipated with joints between dissimilar copper alloys. Although austenitic stainless steel and copper alloys were characterized by a mixture of copper and iron rich phases these welds were mostly sound. However the joints with the aluminium alloy sheets contained significant cracking. Both welds to copper and stainless steel plated copper contained at least some regions where brittle intermetallic phases were present and cracks were observed in these regions. 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.

IV. Conclusion

From the research work conducted by the above researchers the following are the conclusions:

1. Laser welding process parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld bead geometry, mechanical properties and distortion.
2. Laser welding is particularly useful in reducing the heat affected zones and providing deep penetrative beads.
3. Laser welding produces competitive joints without cracks or pores in the weld seam between dissimilar metals.
4. Failure in the HAZ with the crack propagating from the HAZ of the Al towards the intermetallic phase.
5. The cross sectional area of the titanium laminate compared with the double row loop structure is six times higher which indicates a higher potential of the foil concept with respect to the maximum achievable strength.
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

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