Weldability of Ti/Al dissimilar sheet metal joints using Nd: YAG Pulsed laser

K.Kalaiselvan, A.Elango, NM.Nagarajan and K.Sekar

***Abstract*—**These The use of Nd: YAG Pulsed laser for the structure manufacturing sector has more advantages over the conventional welding due to its high productivity, non-contact treatment, automation, good finishing operations, less cost and better weldment quality. Titanium and aluminium alloys lead to many technical issues in laser welding. In particular, Ti6Al4V and AA2024 aluminium alloy thin sheets are investigated in this paper, being it is used extensively in the aerospace industries. Butt autogenous laser weldment tests were examined morphologically and micro-structurally. The mechanical features of the weld bead were evaluated. In addition to the speeds which are traditionally referred to, beam defocusing was considered. Softening in the fused zone is discussed via Rockwell hardness testing. Tensile test and fracture mode analysis were conducted on the specimens.

***Keywords*—**Dissimilar metals, microstructure, mechanical features, Nd: YAG Pulsed laser.

I. INTRODUCTION

NOWADAYS dissimilar metal joints are preferred in industries based on the need of high mechanical properties including high strength. The application of such industries listed as aircraft industries, space vehicles, nuclear, marine and chemical industries [1]. Laser beam welding (LBW) applicability to aluminium alloys is limited, as they have high reflectivity, high thermal conductivity and low viscosity. This study analysed under conduction regime with properties of the weld beads such as the microstructural and microhardness [2]. Morphology and phase content of dissimilar interface formed between Al rich and Ti rich melted zones are performed by high-speed Yb: YAG laser welding. [3].

T40/A5754 alloys are welded using a laser beam and spot is positioned on the aluminium side to provoke spreading and wetting of the lower titanium sheet, with relatively low speeds. Good mechanical strength is produced on a high range of laser power and speeds [4]. For skin stringer component produced by 6013-T4 aluminium alloy using a high power Yb-fiber laser, the parameters associated are, beam focal position, seam angle, and beam positioning about weld centreline. These investigated to find the weldment microstructural features [5]. The structures are built with titanium and aluminium combinations using laser beam welding, the process stability should increase and straightening for precision manufacturing [6].

Based on experimental observations, it is demonstrated that welding with suitable ramping of the laser pulse can lead to the elimination of solidification cracking. [7]. The instability of the keyhole is a dominant cause of macro porosity formation during welding. Under fill is observed at the root of full penetration welds, deep notches, which are harmful to the properties of the welds [8]. A study aiming at comparing properties of the Ti6Al4V alloy joints between pulsed Nd: YAG laser welding and traditional welding. LBW welding method produced joints with higher strength, ductility and more suitable for welding thin alloy sheet than Tungsten Inert Gas (TIG) welding [9].

Geometry, mechanical, microstructure and corrosion properties of the Nd: YAG laser welded Ti6Al4V alloy are studied and compared with the gas tungsten arc (GTA) butt welded joints. The laser welded specimens had a higher hardness of the fusion zone, inferior impact and corrosion properties [10]. Compared with base metal, the heterogeneous micro plastic deformation is obtained in the weldment under fatigue load due to large microstructure gradient, which promotes crack initiation in the LBW joint [11].

Fatigue crack growth behaviour of welds is correlated with mechanical properties and microstructural characteristics. The joint fabricated by laser beam welding shows higher fatigue crack growth resistance due to the presence of fine lamellar microstructure in the weld metal [12]. Laser assisted joining of aluminium alloys–titanium have been examined with high power Nd: YAG and diode lasers. Results indicated that laser welding produces competitive joints without cracks or pores in the weld seam between dissimilar metals joints [13], [14].

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Several approaches about Ti and Al dissimilar welding have been made using filler metals [15], [16]. But few reports and lack of data on butt welding of Ti and Al dissimilar metals without filler metals. Therefore, a study of the butt welding and mechanical behaviour is an important of Ti and Al dissimilar welding. Especially, a difference of microstructural changes in the weldment under various welding condition and fractured surface of welded joints after failure were investigated as an important viewpoint in this study.

II. MATERIALS AND METHODS

The materials used in this study were Ti6Al4V and AA2024 sheets. These specimens size is 1.0 mm thickness, 75 mm width and 150 mm length as shown in Fig. 1(a). The titanium and aluminium alloys are high strength alloys which are available in sheet form. The manual shearing cutting machine is used to cut the sheets as shown in Fig. 1(b). The Ti used this study has over 90% Ti and Al has about 90% Al. Mechanical properties of materials used show Table 1. The mechanical properties of Ti and Al have great differences in melting point, thermal conductivity, thermal expansion, etc. During the welding process, Al is easily lost at the temperature below the melting point of Ti. As a result, it is difficult to sound welds.

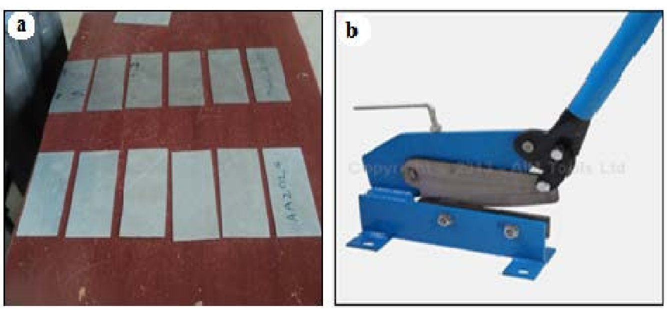

Fig.1 (a) Base metals (b) Shearing cutting machine

Nd: YAG pulsed laser which used in this welding has high quality and high efficiency comparison with others heat sources. Fig. 2(a) shows the laser welding unit for dissimilar laser butt welding of Ti and Al. Specimens were tightly fixed to a clamping device as shown in Fig. 2(b). The pulsed laser installed in this study has the 600W maximum power, fibre diameter 600µm and beam quality-28mm.mrad. The high power density laser beam was focused on the work piece surface using laser head. The laser beam was directly irradiated on 1.0 mm thick material sheets. Welding conditions used in this experiment for Ti and Al dissimilar laser welding were rate: 20Hz, width: 8.5ms, height: 32%, and the welding speed of 200, 220 and 240 m/min.

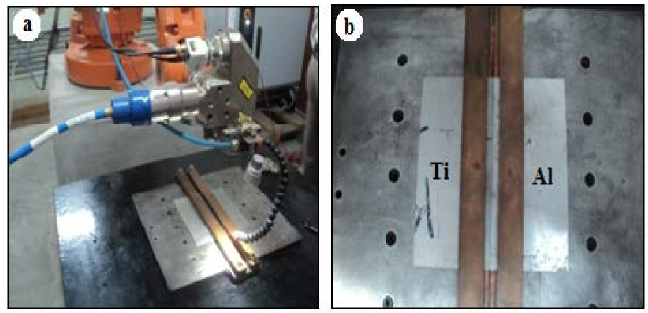

Fig.2 (a) Laser unit (b) Clamping device

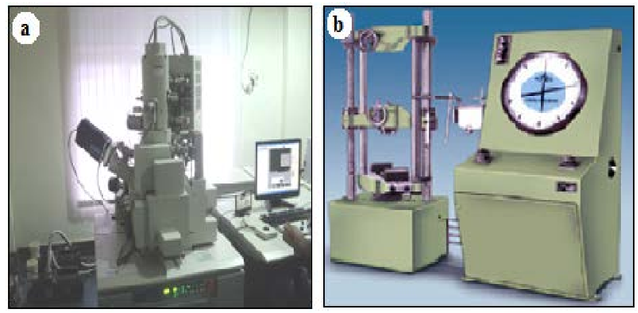

Fig. 3 (a) Scanning electron microscope (b) Universal testing machine

The laser focal condition was a 0.3 mm defocused distance from Al side. An argon shielding gas of 10 L/min was used to suppress oxidation of the molten surface during welding. The weldment elastically strains in response to the stresses caused by the contraction of the weld metal and causes irregular strain with macroscopic distortion. Using vernier height gauge with a magnifying glass, distortion on weldment after welding has been measured. Microstructure of the cross sections of the weld zones was observed using a Scanning Electron Microscope (SEM) to understand a strong weldment resulting from the various speeds welding process as shown in Fig. 3(a). Hardness testing was conducted using a Rockwell hardness testing machine. Hardness value is determined using the diamond cone indenter C scale. The mechanical properties of the weldment were evaluated by the Universal Testing Machine (UTM) as shown in Fig. 3(b).

III. RESULTS AND DISCUSSIONS

A. *Macrostructure and weld bead*

Ti and Al dissimilar butt welds produced using Nd: YAG pulsed laser at various welding speeds. To produce sound welds, welding speed were tried because formation can be suppress. Fig. 4(a) shows macrostructure and Fig. 4(b) shows surface appearances of weld beads of Ti and Al welds made with various welding speeds from 200, 220 and 240 mm/min. Full penetration welds were obtained under all the conditions. The weld bead width was getting narrower with an increase in welding speed.

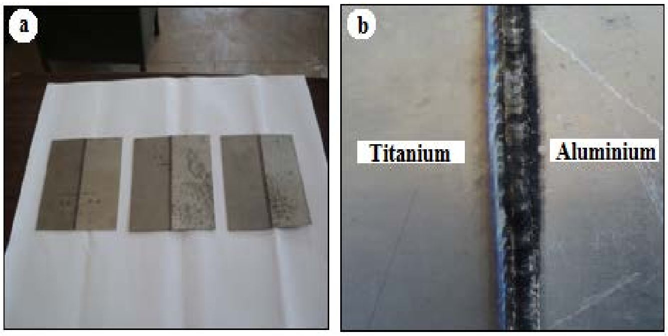

Fig. 4 (a) Macrostructure of the weldment (b) Weld bead

B. Distortion measurements

Ti and Al alloy sheets are welded by using different speed ranges. During welding operation the temperature of weld metal increased causing metal expansion and this behaviour is hindered by the base metal. So the transverse shrinkage distortion is generated and the displacements are slowly increased. The moving of laser head results in transverse and longitudinal shrinkage of weld metal and the increase of displacements. The maximum distortions founded at room temperature are shown in Fig. 5(a).

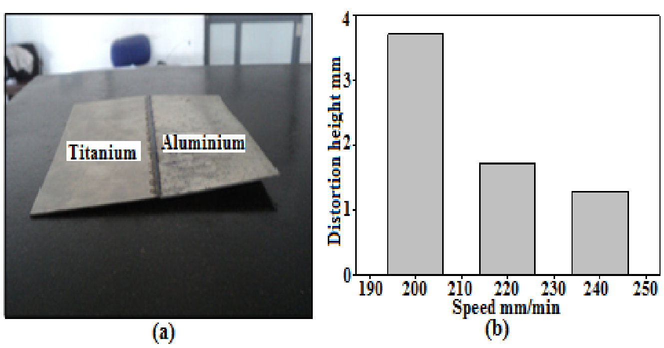

Fig. 5 (a) Maximum distortion at room temperature (b) Effect of distortion on welding speed

Distortion at Ti and Al weldment was measured by using vernier height gauge, By adjusting the vernier height gauge using the main scale and vernier scale, distortion height variation is measured. Distortion height is found to vary with different welding speeds. The effect of distortion on speed is shown in Fig. 5(b). While comparing weld speed at 200mm/min, less distortion different is found at higher speeds namely 220 and 240mm/min. It was observed that distortion was produced by buckling or bending. Because welding involves highly localised heating of joint edges to fuse the metal, non-uniform stresses are set up due to expansion and contraction of metal.

C. Microstructure

The laser beam is focused from Al side with an offset distance of 0.3mm and the microstructure changes are observed at weld speed of 200, 220 and 240mm/min with the magnification of X10000. The grains structure at weld speed 200mm/min are shown in Fig. 6(a), (b) and (c). Due to higher heat input associated with lower welding speed, the HAZ close to fusion zone are noted accordingly.

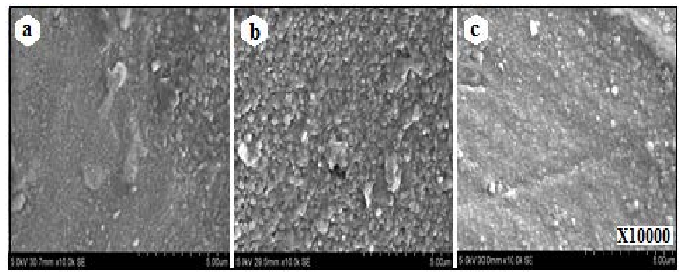

Fig. 6 SEM structure at 200mm/min (a) HAZ-Ti side (b) FZ (c) HAZ-Al side

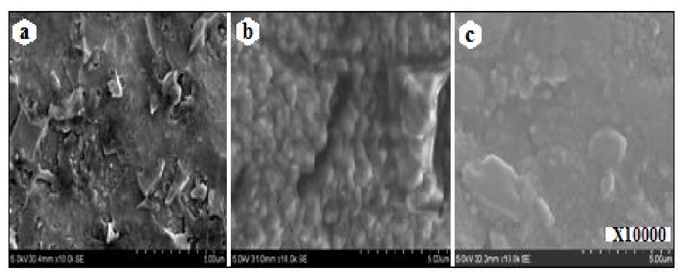

Fig. 7 SEM structure at 220mm/min (a) HAZ-Ti side (b) FZ (c) HAZ-Al side

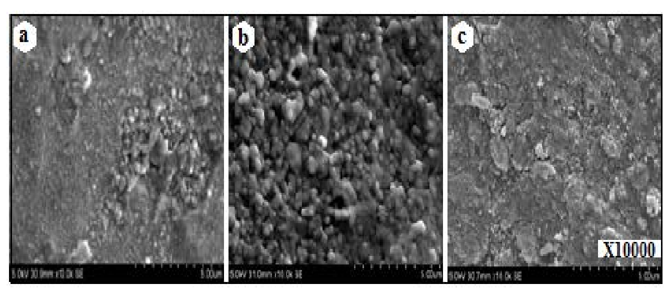

Fig. 8 SEM structure at 240mm/min (a) HAZ-Ti side (b) FZ (c) HAZ-Al side

The interlaced structure is formed both in Ti and Al HAZ side and it showed that the dissimilar sheets are bonded together. Fig. 7(a), (b) and (c) showed the structural changes at weld speed 220mm/min coarse grains and are seen at fusion zone. Fig. 8(a), (b) and (c) show the structures at the speed of 240mm/min. While compared with fusion zone at 220mm/min, the fusion zone at 240mm/min gives fine grains with small size indicating good strength at the fusion zone. Hence, it is concluded that finer grain indicating better mechanical properties.

D. Hardness distribution

Hardness tests are performed to evaluate the hardness distribution across the weldment. The various zones such as Fusion Zone (FZ), Heat Affected Zone (HAZ) and Base Metal Zone (BM) are identified and are shown in Fig. 9(a). Also, Fig. 9(b) showed the various cross-section zones at weldment for both Ti/Al sides. The metallic bond was observed in the region for at the highest welding speed of 240mm/min as shown in Fig. 9(c). HRC scale on the test piece is used to measure hardness as per ASTM standards [17].

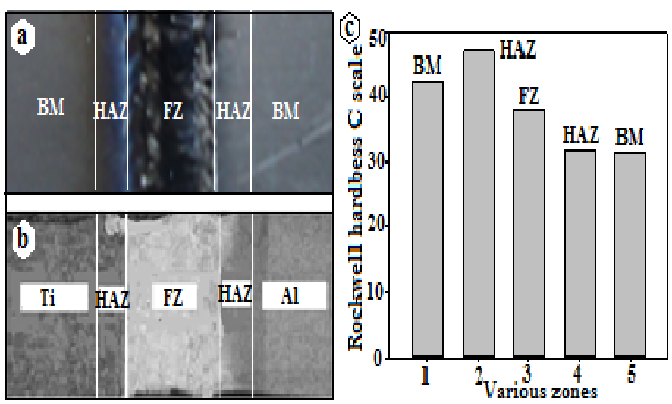

Fig. 9 (a) Various zone at weldment (b) Cross section zones (c) Hardness distributions

The results show that the hardness of the fusion zone is slightly lower than that of HAZ and base metal. Laser beam makes the fusion zone soft with recrystallised structure. Higher heat input associated with weld speed leads to increase in hardness. However, as the laser beam heat affects the Al side, Al gets softened due to its low melting point and hardness is considerably reduced even at the base metal zone. These different patterns at various locations may be due to melting temperature, density, direction of focussing flame and thermal conductivity of dissimilar metals.

E. Tensile strength

Weld coupons are cut from weldment made at the optimum weld speed of 240mm/min. The three test specimens are prepared from each welded plates and sized as per ASTM standard is given in Fig. 10(a). Subsequently, specimens are subjected to a tensile test using UTM and the average of the three results is 166MPa. The stress–strain diagram for the tensile test result is shown in Fig. 4.38. Stress strains graphs showed that the strain value of the specimen at the fracture point is only 0.03 where as the ultimate tensile stress value is 79% of Al base alloy.

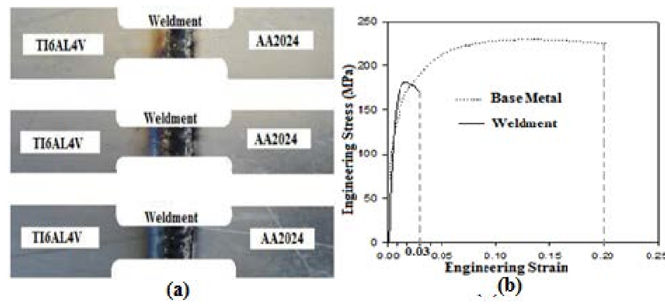

Fig. 10 (a) Test specimens (b) Stress-Strain diagram

However, the yield strength of AA2024 Al alloy is noted as 96MPa [18] whereas the yield stress of Ti/Al alloy weldment is observed 166MPa. Hence it is clear that the yield stress of the weld joint is much higher than the yield stress of the Al alloy. It is found that the weldment is a homogeneous one with proper mixing of both Ti and Al alloys leading to metallurgical bond. Also, it is proved that dissimilar metals namely Ti and Al alloys are amenable for welding using a laser beam, by selecting appropriate welding speed.

F. Fracture mode analysis

Fracture surface is observed after tensile testing of the welded samples. These are analyzed using Tool Makers Microscope (X10) to determine the fracture mode on the weld pool. As per Fig. 11(a) under low magnification, observation of the fracture surfaces reveals that the fracture occurred near the aluminium side of weldment rather than titanium side. The fracture cross-section observed by tilting at 90˚ and is shown in Fig. 11(b). It depicts similar fracture surface along titanium and aluminium sheet surfaces after testing. It is evident that penetration of welding along the cross-section is uniformly covered.

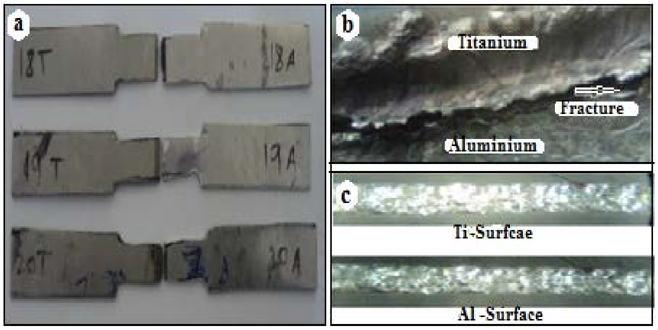

Fig. 11 (a) Fractured specimen (b) Fracture interface position (c) Fracture surface

IV. Conclusions

In the present study, titanium and aluminium alloys joined by LBW under different welding speeds were investigated. Summarizing the main features of the results and following conclusions can be drawn:

1. Full penetration welds were obtained under all the conditions and weld bead width was narrower with an increase in welding speed.
2. Comparing weld speed at 200mm/min, less distortion different is found at higher speeds.
3. Fusion zone structure at the speed of 240mm/min gives fine grains with small size indicating good strength.
4. The ultimate tensile stress value is 79% of Al base alloy. It is found that the weldment is a homogeneous one with proper mixing of both Ti and Al alloys.
5. The fracture surfaces reveal that the fracture occurred near the aluminium side of weldment.

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