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Influence of LBW parameters on properties of Ti6Al4V/AA2024 dissimilar alloy joint

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Light weight dissimilar metal joints are very much needed for aerospace, automobile and similar such industries. While assessing the feasibility of joining dissimilar metals to produce sound weldment, numerous factors are to be considered. In the present investigation an attempt is made to join Ti6Al4V and AA2024 dissimilar metals using laser beam welding (LBW) under different weld speeds. For evaluating microstructure, scanning electron microscope (SEM) analysis has been adopted. Experimental investigations reveal that weld speed is found to be a significant variable to enhance strength of weld joint. Finer grains with homogeneous distribution at higher speeds as seen using SEM support this finding.

Keywords: Joining parameters, Dissimilar metals, Laser beam welding, Scanning electron microscope

Research activities are in progress to find new material combination and methods[1] for joining dissimilar metals suitable for air craft industries. Laser beam welding (LBW) is found as one of the options while comparing with conventional joining methods. Nd: YAG pulsed laser beam welding method is widely used in the recent years. The combination of various pulsed laser processing parameters such as travel speed, spot area, pulse energy, pulse duration, pulse frequency and pulse shape[2]. These parameters are more suitable for welding sheets to characterize the welded beads[3].

By the development of a suitable system technology, the process development would be described, focusing on the main influencing parameters of the weld joint appearances and properties. Dissimilar welding of Ti and Al using single mode fibre laser with extremely high speed results suggested an excellent configuration possibility of a strong weldment[4]. An experimental study of the physical phenomena discussed the interaction between the plasma plume, the laser beam and the shielding gas by using a spectroscopic investigation under various operating conditions[5].

The effects of the variation of the main process parameters such as, travel speed, gas flow rate, beam focus position and nozzle distance on the bead profiles are observed[6]. Butt configuration by focusing a fibre laser onto the titanium side, close to the weld centreline. The keyhole was made entirely of titanium side and the fusion of the aluminium achieved by heat conduction[7]. To understand the possible correlation between process parameters and porosity formation, an analysis of variance statistical approach is exploited[8]. Aluminium alloys A5052 and A5083 combinations welded under different welding conditions[9]. The results confirmed that increasing shielding gas flow rate, within a limit and the angle of laser beam improved melt ability and penetration depth.

Experimental work involved examination of the welding parameters for joining a titanium alloy using the JK760TR Nd: YAG pulsed laser. It has determined that the ratio between the pulse energy and pulse duration is the most important parameter in defining the deep penetration depth[10]. Process conditions examined such as beam mode, irradiance spot size, shielding gas flow, edge quality and fit up. The weldment quality variations with the different parameters are consistent with physical phenomena and threshold irradiance[11]. The most challenging factor for successful crack fusion is related to the plate flatness which affects the relative position of the laser focusing point and the location[12].

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The application of a laser source has mainly used for titanium and aluminium alloys welding. In recent years, Nd: YAG pulsed laser have widely used due to the shorter wavelength, more stable keyhole and weld pool with a higher welding efficiency[13]. However, limited published work is available on the weldability of titanium and aluminium alloy sheets using Nd: YAG pulsed laser. The intent of this paper is to report on the effect of various welding speeds on the weld quality, microstructure and properties of autogenously welded Ti6Al4V and AA2024 alloy sheets using a Nd: YAG pulsed laser.

Materials and Methods

The base materials are Ti6Al4V and AA2024 alloy sheets with a thickness of 1.0 mm used for welding. The chemical compositions and mechanical properties of the base materials listed in Tables 1 and 2. The plates are cut and machined into rectangular specimens of 150 mm × 75 mm.

Welding is performed using Nd: YAG pulsed laser system. The laser beam is directed to the workstation via standard fiber of 600 µm in diameter. The laser beam is focused just on the surface of the specimen with a focal length of 200 mm and 600 W power. Pulse energy is 25 J, pulse rate is 20 Hz and gas flow rate is 10 L/s used for this welding operation. The welding speed is varied from 180, 200, 220 and 240 mm/min. Laser offset distance of 0.3 is focused from titanium side for carrying welding. To get an overview on the weldability, preliminary tests are carried out on sheets in butt joint configuration. Laser offset distance has a great influence on the formation of joints[14,15]. For studying the structure and variation, offset distance focusing from Ti side.

Figure 1(a) represents the experimental arrangement of Nd: YAG pulsed laser welding unit. During welding a high speed video camera system is utilized to observe the laser plasma behaviour under different welding conditions. Argon is used as shielding gas. During welding, the titanium and aluminium sheets are placed horizontally on a backing plate and the weld region is filled with shielding gas.

After completion of the welding, defects on weldment such as porosity and solid inclusions are investigated using Tool Makers Microscope with magnification X10. Preparation for metallographic examination and analysis involved from the butt joints by sectioning transverse to the welding direction. The specimens are ground and polished to produce a mirror like finish. The microstructural examination is carried out using scanning electron microscopy (SEM) as shown in Fig. 1(b). For each condition, at least three weld cross-sections are analysed such as titanium side heat affected zone (HAZ-Ti), fusion zone (FZ) and aluminium side heat affected zone (HAZ-Al).

Hardness testing is conducted using a Rockwell hardness tester with 150 kg load as shown in Fig. 1(c). Using standard hardness conversion tables, the Rockwell hardness value is determined by the diamond cone indenter. The American Society for Testing and Materials (ASTM) has standardized a set of scale ranges for Rockwell hardness testing[16]. The tensile testing of the joints conducted in a Universal Testing Machine (UTM) with load capacity 400 kN is shown in Fig. 1(d). The average ultimate tensile strength (UTS) is estimated.

Results and Discussion

The various parameters taken into consideration for the work are: speed, microstructure, hardness, tensile strength and fracture

Weld crack and macrostructure

Welding has been carried out at different speeds such as 180, 200, 220 and 240 mm/min. The laser beam is focused on Ti side. Welding with the speed of 180 mm/min, weld cracks are found by visual examinations and longitudinal cracks along the weld face are found on the weld sheets. Figure 2(a) shows longitudinal crack at 180 mm/min of welding speed. These cracks formed due to the concentration of heat at weldment and formation of the intermetallic

Table 2 — Mechanical properties of the base metals Ti6Al4V and AA2024

Base metal	Ultimate tensile strength (MPa)	Yield strength (MPa)	% Elongation (E)	Hardness HRC
Ti6Al4V	950	880	14	46
AA2024	210	96	12	31

Table 1 — Chemical composition (wt%) of the base metals Ti6Al4V and AA2024

Metals	V	H	Si	Cu	Zn	Fe	Mg	Pb	Mn	Ti	Al
Ti	3.5-4.5	0.015 (max)	-	-	-	-	-	-	-	Bal.	5.5-6.75
Al	0.001	-	0.5-1.2	3.8-5.0	0.063	0.7	0.2-0.8	0.028	0.3-1.2	0.01	Bal.

compound. Heat energy is focused from Ti side with weld speed of 200 mm/min and the imperfections are found to have reduced as shown in Fig. 2(b).

The weld joint at the speed range of 200, 220 and 240 mm/min is found good without cracks. When the welding speed increased crack, tendency came down on the interface between Ti alloy and Al alloy. Also, surface roughness and grooves reduced by focusing heat energy from Ti side. The weld bead width is getting narrower with the increase in weld speed. The macrostructure views of weldment surface for the speeds of 220 and 240 mm/min are given in Fig. 2(c) and (d). From the figures, it is found that laser beam welding produced good weld.

Microstructure

The effect of weld speeds on microstructure at various zones of weldments has been studied. These microstructural features in the weld joint at different welding speeds are important aspects that are affecting the microstructure of joint produced by laser beam welding. The various zones such as fusion zone (FZ), heat affected zone (HAZ) and base metal zone (BM) are shown in Fig. 3. From the various cross-section zones of the weldment, the metallic bond observed in the region for all welding speeds.

Figures 4(a), (b) and (c) show the SEM microstructure of various zones at 200 mm/min. Due to high heat concentration on fusion zone at low speed, the rapid metal transfer is seen from Al side resulting coarse grains. However, coarse grains are seen in HAZ of Ti indicating higher heat addition. The grain structures are changed to smooth texture at the speed of 220 mm/min as shown in Figs 5(a), (b) and (c). This speed is a major factor to change the microstructure from coarse to fine.

Figures 6(a), (b) and (c) represent typical microstructures at a welding speed of 240 mm/min. The microstructure of Ti alloy HAZ is seen with elongated grains with a random distribution. However, smooth texture is maintained in HAZ of Al. In welding, finer and homogeneous distribution of particles are noted infusion zone. Comparing with 200 and 220 mm/min speeds, it gives better grain structure in fusion zone. Hence, the structure in weldment is better with higher speeds than at lower weld speeds.

Hardness

Hardness tests are performed to evaluate the hardness distribution across the weld line, the base metal and HAZ on both sides of the weld region. Hardness measurements taken on the test piece with a

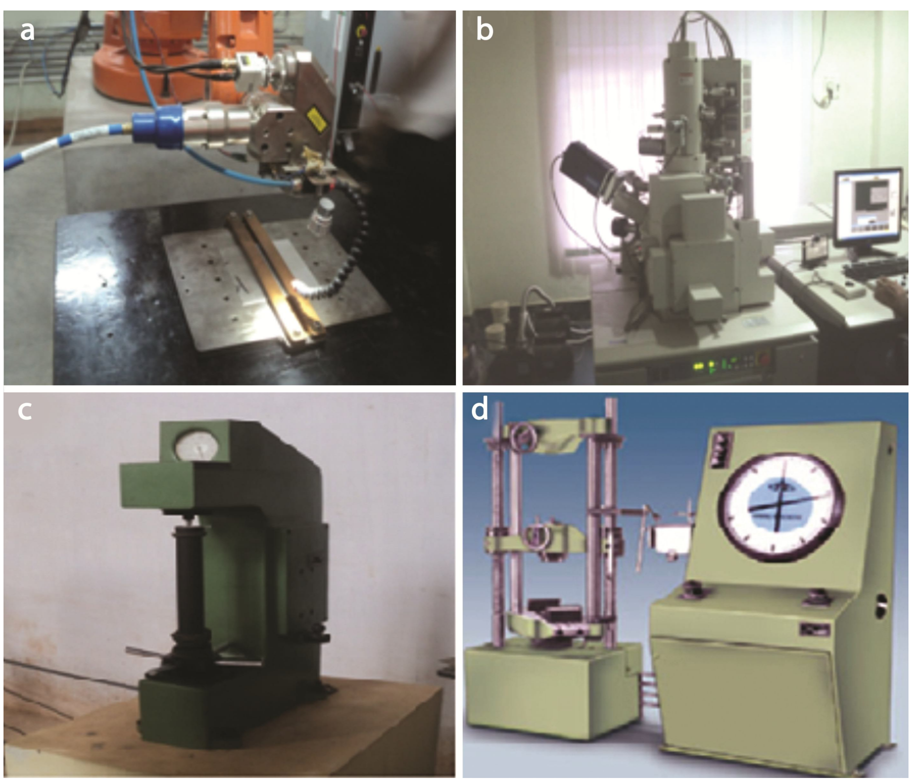

Fig. 1 — (a) Laser welding unit, (b) scanning electron microscope, (c) rockwell hardness tester and (d) universal testing machine

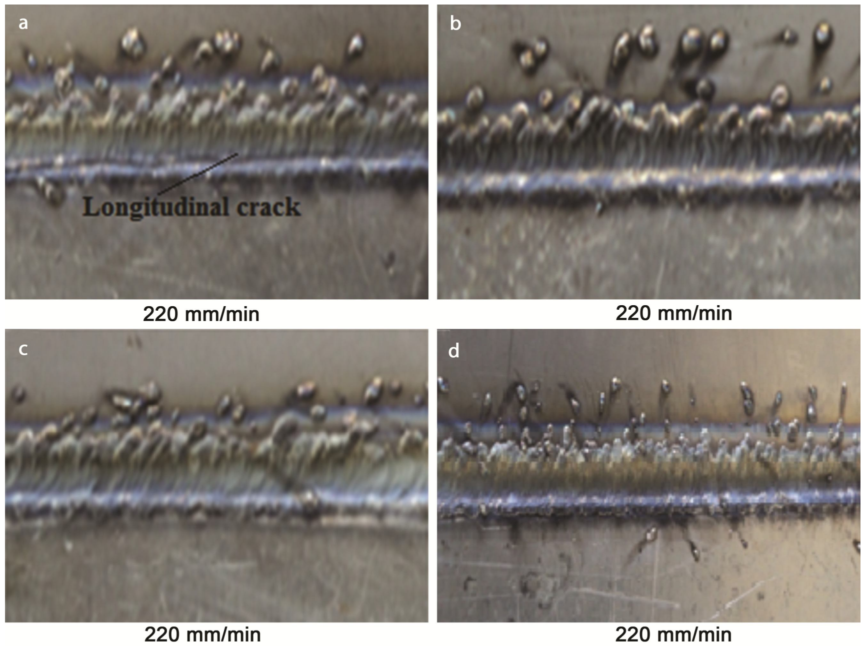

Fig. 2 — Macrostructure of the weldment (a) 180 mm/min, (b) 200 mm/min (c) 220 mm/min and (d) 240 mm/min

Fig. 3 — Cross section of the weldment

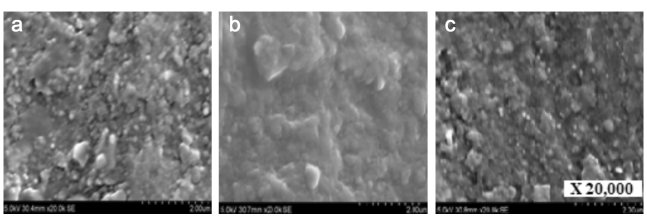

Fig. 4 — SEM structures at 200 mm/min (a) HAZ-Ti side (b) FZ and (c) HAZ-Al side

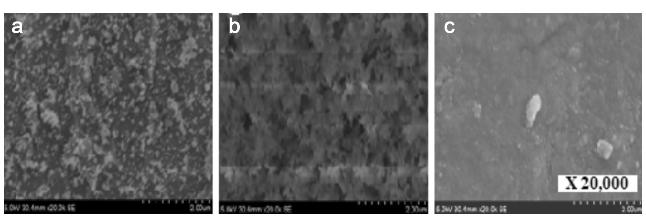

Fig. 5 — SEM structures at 220 mm/min (a) HAZ-Ti side (b) FZ and (c) HAZ-Al side

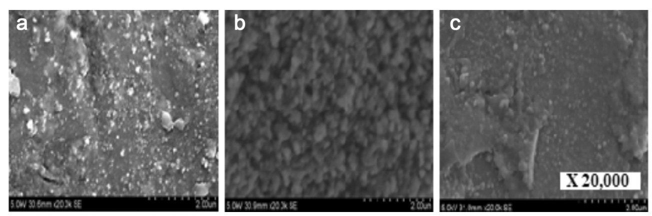

Fig. 6 — SEM structures at 240 mm/min (a) HAZ-Ti side (b) FZ and (c) HAZ-Al side

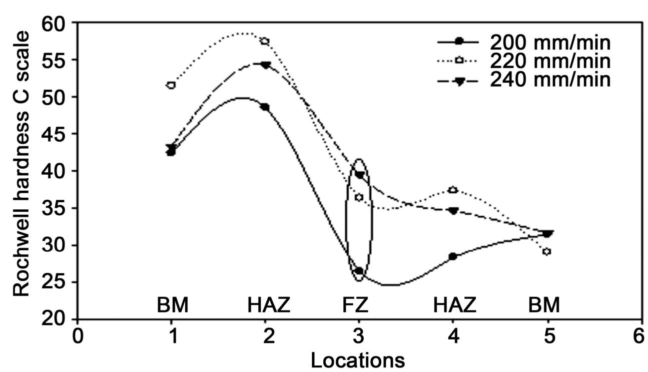

Fig. 7 — Hardness distribution at 200, 220 and 240 mm/min

1 mm gap. HRC scale on the test piece is used to measure hardness as per ASTM standards[17]. Figure 7 shows 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 recrystallized structure. As the speed increases the weldment hardness increases, due to increase in cooling rate.

Tensile strength

Weld coupons are cut from weldment at the weld speed of 200, 220 and 240 mm/min. Three test specimens are prepared from each welded plates and are sized as per ASTM standard. Subsequently, samples are subjected to a tensile test using UTM. Figure 8 illustrates the results of the tensile test under various welding speed conditions. For the joints with

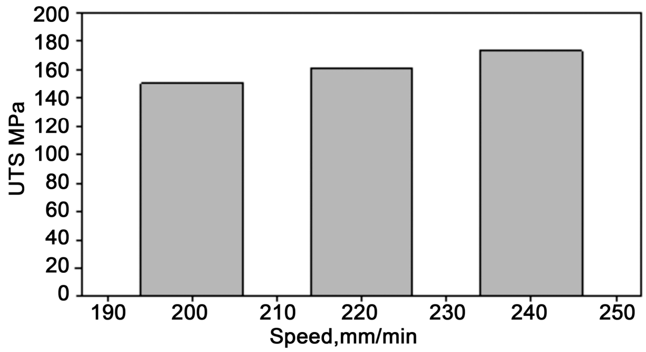

Fig. 8 — Weldment ultimate tensile strength

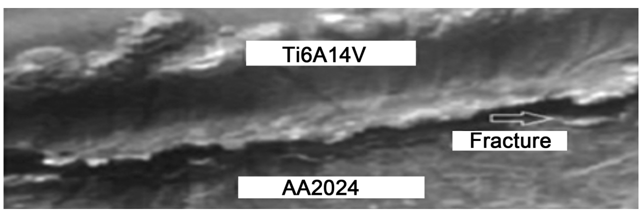

Fig. 9 — Fracture interface position

a speed of 220 mm/min, the tensile strength slightly varied according to the welding speed of 200 mm/min. The maximum ultimate tensile strength increased at the speed of 240 mm/min was 82% of the base metal AA2024 alloy. The hardness property also agrees with tensile strength behaviours as the speed increases.

Fracture analysis

Fracture surface is observed after tensile testing of the welded samples at the speed of 240 mm/min, being the highest in the weld machine. These are analysed using Tool Makers Microscope (X10) to determine the fracture mode on the weld pool with low magnification. Observation of the fracture surface reveals that the fracture is occurred near the aluminium side of weldment rather than titanium side as seen in Fig. 9.

Conclusions

In the present study, Ti6Al4V and AA2024 alloys joined by laser beam welding under various speeds investigated. Summarizing the main features of the results, following conclusions can be drawn:

(i) Lower weld speed below 200 mm/min results weld cracks whereas higher weld speeds results crack free weldment.

(ii) SEM studies reveal that coarse grains at lower welding speeds have been changed into finer grain at higher speeds leading to strength improvement in strength of the dissimilar metal joint.

(iii) The tensile strength is enhanced to 82% of base aluminium alloy AA2024 at 240 mm/min weld speed, being the highest in the welding machine.

(iv) From fracture analysis it is observed that fracture occurs near aluminium side of the weldment rather than titanium side.

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