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Microstructure and EDS analysis on titanium/aluminium dissimilar laser welded joint subjected to age hardening

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Laser beam welding of titanium and aluminium alloy is very much needed for aerospace and automotive industries due to its high strength and light weight. The dissimilar welding is having a bearing on high temperature at the weldment and grain coarsening may cause if thermal cycle is not checked. In order to maintain good weld joint properties, phase transformation during rapid thermal cycles is required. Such cycles occur during welding of titanium/aluminium dissimilar sheets and age hardening heat treatment after welding. Titanium and aluminium alloys are sensitive to heat due to their difference in melting temperatures. This may cause changes in microstructures in weldment. The aim of this study is to analyse the changes in titanium (TI6AL4V) and aluminium (AA2024) alloy thin sheets welded joint using SEM and EDS studies before and after age hardening heat treatment. From the results, it is observed that laser beam focusing from titanium side gives well refined age hardened structure and EDS reveals that the bond is metallurgical one.

Keywords: Laser beam weldin,; Tiitanium/aluminium, Age hardening, Microstructure, EDS

Laser beam welding (LBW) of titanium/aluminium dissimilar sheet metal joints is a challenging welding process due to melting temperatures and chemical affinity towards oxygen[1-3]. Also high thermal conductivity, solubility in molten stage and solidification shrinkage cause changes in mechanical and metallurgical properties[4,5].

Recently dissimilar metal weld joints are preferred in many modern manufacturing industries[6-11]. The industries such as aircraft, aerospace industries, nuclear and chemical industries good properties such as weldablity, strength and corrosion resistance need in dissimilar weldment[12-16]. Different material combinations and formation of brittle intermetallic compounds (IMC), which have the low melting ability, are the concerns for a perfect joint using the conventional welding methods. Titanium/aluminium is used in practical engineering applications and high quality weldment from these metals is a challenge. These are incompatible metals due to their higher affinity towards oxygen and producing brittle intermetallics in interfaces[17,18].

Intermetallic phases infusion zones (FZ) are observed redissolved after solution heat treatment and quenching retains a supersaturated solid solution in the matrix alloying precipitation hardening to occur upon aging[19]. Higher solute is available for strengthening in the matrix than the boundaries because the grain structures in the fusion zone is to become high homogeneous with less of a solute gradient. Precipitation hardening to occur, low ductility at long aging times is needed. A study on FZ and heat affected zone (HAZ) is essential to produce flawless welding. Immediately after welding many metallurgical changes are taking place in HAZ[20]. The peak temperatures at the fusion and immediate heat transfer to HAZ are having a bearing on weld quality. Also grain coarsening may cause if the thermal cycle is unchecked. Further, titanium and aluminium alloys used for welding are sensitive to heat due to their difference in individual melting temperatures. This may cause changes in microstructures heat affected zones and fusion zone.

In the present study, microstructure analysis has been carried out using scanning electron microscope (SEM) to find changes in the titanium/aluminium dissimilar weldment namely heat affected zone from both sides and fusion zone before and after age hardening heat treatment. Additionally, chemical compositions of weldments are observed.

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Materials and Methods

The metals used in this investigation are titanium (TI6AL4V) and aluminium (AA2024) alloy sheets of 1.0 mm × 75 mm × 150 mm. Tables 1 and 2 show the chemical compositions of these base metals. The welding parameters of weld joints used for microstructural and EDS properties are shown in Table 3. For welding Nd: YAG Pulsed laser welding unit is used with pulse range 20 Hz, the pulse width range 8.5 ms, focusing length 200 mm and gas flow rate 10 L/min. Dissimilar metal is welded by varying welding speeds such as 200, 220 and 240 mm/min.

To meet the differences both in terms of heat conductivity and reflectivity between titanium and aluminium alloy, an offset distance of 0.3 mm, laser beam focused from titanium and aluminium has been suggested by Kreimeyer[21]. Laser offset distance is maintained at 0.3 mm focusing from titanium and aluminium joint interface in the present investigation. Weld joint gap is maintained with 0.1 mm and butt joint is made using two jig plates. Argon gas is used as a shielding gas with a constant flow rate. In particular the titanium/aluminium dissimilar joints are positioned and the laser beam is focused one sample from titanium and for another from aluminum side.

After welding, age hardening heat treatment is carried out on the weldment in a heat treatment furnace operating with a capacity 7.5 kW and maximum temperature range of 1150°C. During age hardening heat treatment, the temperature is maintained at 550°C. Welded samples are kept inside and the thermocouple is used to measure inside temperature of the furnace. After heating, at 550°C and 5 min soaking, samples are quenched in water at 27°C and allowed to cool for 24 h air. Thus, the solution heat treatment and aging are carried out for other samples welded at the minimum speed 200 mm/min and maximum speed 240 mm/min, respectively. Only natural age hardening is carried out for all experiments. SEM studies are mainly carried out after aging with the magnification 2500 (X 2500). In this investigation, Hitachi SU6600 Scanning Electron Microscope (SEM) is used to study the microstructure of weldment including FZ, HAZ, and BM zones. Also, energy-dispersive spectroscopy (EDS) attached with SEM is utilized to find out the chemical composition of elements.

Results and Discussion

Macrostructure of weldment

Macrostructure appearances of the titanium (Ti)/aluminium (Al) joint after welding at the speed of 200 mm/min, 220 mm/min and 240 mm/min are found good as shown in Fig. 1. No cracks are formed on the surface of the weld bead. Smooth surface is observed on the weldment. Cross-section sample of the weld joint is shown in Fig. 2. It indicates different zones such as base metal, heat affected zone (HAZ) and fusion zone (FZ). Titanium interacts with liquid metal to form a complex interface resulting good combination of weldment. The weldment cross-section of heat affected zone and fusion zone are seen from titanium side as well as from aluminium sides and are studied using SEM.

Microsturctural analysis

The SEM analysis on weldment for welding with the minimum speed of 200 mm/min and maximum of 240 mm/min are reported. Figure 3(a) shows the microstructure of the base metal titanium alloy sheet

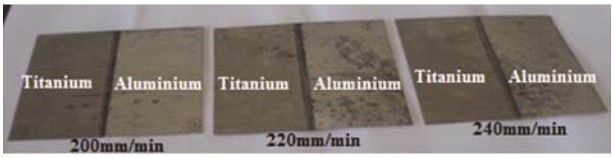

Fig. 1 — Macrostructure of the weldment

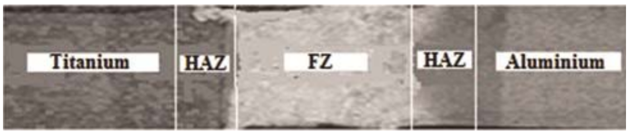

Fig. 2 — Weldment cross-section

Table 1 — Chemical composition of Ti6Al4V (wt%)

Al (%)	V (%)	H (%)	Ti (%)
5.5- 6.75	3.5-4.5	0.015 (max)	Balance

Table 2 — Chemical composition of AA2024 (wt%)

Si (%)	Cu (%)	Zn (%)	Fe (%)	Mg (%)	Ti (%)	V (%)	Pb (%)	Mn (%)	Al (%)
0.500 -1.200	3.800 - 5.000	0.063	0.700	0.200- 0.800	0.010	0.001	0.028	0.300- 1.200	Balance

Table 3 — Welding conditions for pulsed 600W Nd: YAG laser

Sl.No	Rate (Hz)	Width (ms)	Height (%)	Energy (J)	Speed (mm/min)	Focus (mm)	Gas flow rate (L/min)
1.	20	8.5	32	24.8	200	200	10
2.	20	8.5	32	24.3	220	200	10
3.	20	8.5	32	25.2	240	200	10

and 3(b) shows the microstructure of aluminium sheet base metal. The titanium alloy had an elongated primary α grain in the α/β matrix and aluminium represents elongated grains along rolling direction with a random distribution of black particles.

Laser beam focusing from titanium side

By keeping offset distance of 0.3 mm, laser beam is focused from titanium side. The microstructure taken on titanium side-HAZ before and after age hardening heat treatment is given in Figs 4(a) and (b) respectively with minimum weld speed of 200 mm/min. The structure is similar to the base metal with the slightly difference in contrast on before age hardening. Dark dots are present on after age hardening. The magnification X 2500 is maintained in all zones observed. The fusion zone microstructures are shown Figs 4(c) and (d), after heating the weldment at 550°C being the solution treatment temperature. The structure after age hardening heat treatment clearly shows refined grain structure as present in Fig. 4(d).

Similarly Figs 4(e) and (f) represent HAZ taken on aluminium sheet side. Heat treated aluminium as per Fig. 4(f) reveals very fine grains, which may have the bearing on strong weldment. By increasing the weld speed of 240 mm/min, the weldment microstructures have been further refined after heat treatment as seen in Figs 5(b), (d) and (f) in the heat affected and fusion zones respectively.

Laser beam focusing from aluminium side

The laser beam is focused from aluminium side and the details of the microstructure are given in Figs 6(a)

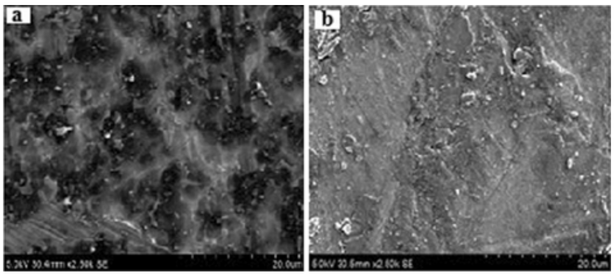

Fig. 3 — Base metal microstructure (a) Titanium and (b) Aluminium

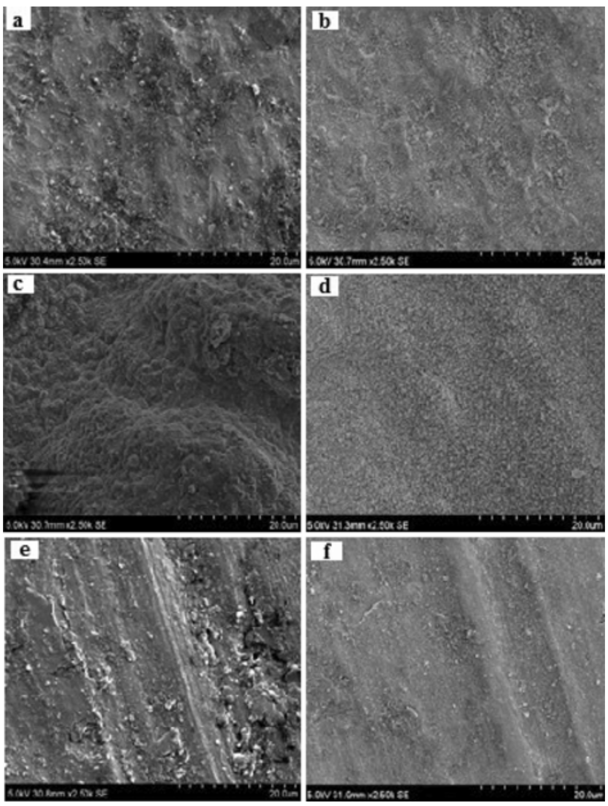

Fig. 4 — Microstructure at 200 mm/min from Ti side (a) Ti – HAZ before age hardening, (b) Ti – HAZ after age hardening, (c) FZ – before age hardening, (d) FZ – after age hardening and (e) Al- Hage hardening(f) Al – HAZ age hardening

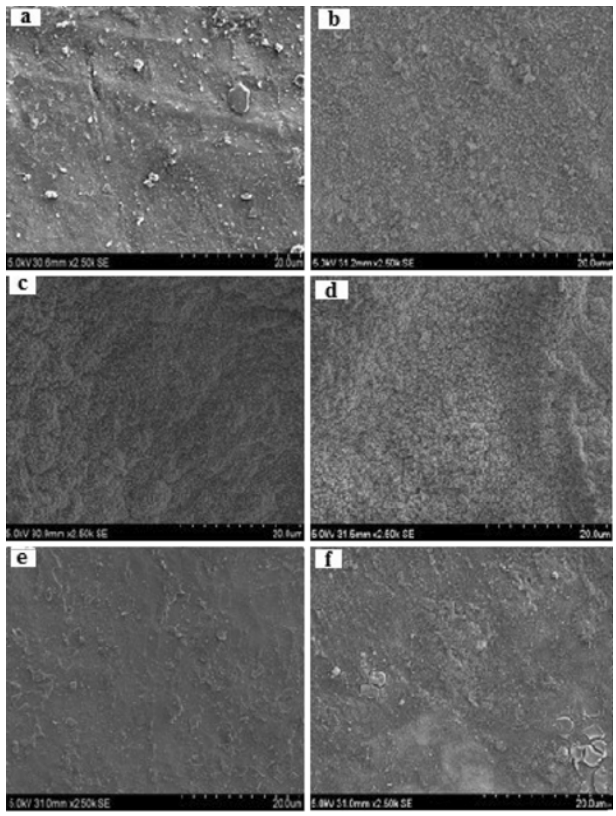

Fig. 5 — Microstructure at 240 mm/min from Ti side (a) Ti – HAZ before age hardening, (b) Ti – HAZ after age hardening, (c) FZ beforeage hardening, (d) FZ after age hardening, (e) Al- HAZ before age hardening and (f) Al – HAZ after age hardening

and (b). It is found that at welding speed 200 mm/min heat concentration is more due to slow speed that result in partial grain coarsening. From Fig. 6(c), it is observed that grain coarsening is resulted due to lower welding speed in the fusion zone. However, after heat treatment the grains are refined as shown in Fig. 6(d). Figures 6(e) and (f) refer SEM pictures before and after age hardening. Grain refining is observed in both the cases. Also, interlaced structure is formed and it shows that the dissimilar sheet metals are bonded well.

Figures 7(a) and (b) show fine grain structures at the highest speed of 240 mm/min. Grain size decreases with increasing speed having a periodic change of grain size. Comparing to laser source focused from titanium side, aluminium side grain structures are uniformly distributed and are smooth in texture.

During precipitation, hardening fusion zone provides sufficient amounts of grain-refining elements to effect grain refinement. These elements act as nucleation sites during quenching resulting in fine grain size. It is likely that fluctuation of the cyclic changes in growth rate at the interface producing bands of different grain sizes as shown in Figs 7(c) and (d) before and after precipitation. Further in Figs 7(e) and (f) there is no coarse-grained structure seen in HAZ. In a similar way, no refined size is observed at 240 mm/min weld speed. Hence, it is clear that focusing laser beam from titanium side gives well-refined grain structure leading to better mechanical properties.

EDS analysis

Fusion zone (FZ) microstructure is influencing considerably the properties at the weldment. The best sample at the speed of 240 mm/min formed at titanium side is examined by (EDS) before and after age hardening heat treatment. Figure 8 shows EDS spectrum processing of fusion zone analysis before age hardening, the laser offset distance is focused from titanium side.

The heat source is focused from titanium side and percentage of aluminium is found to be 67.12% and 16.13% titanium as major components in fusion zone before age hardening heat treatment. After age

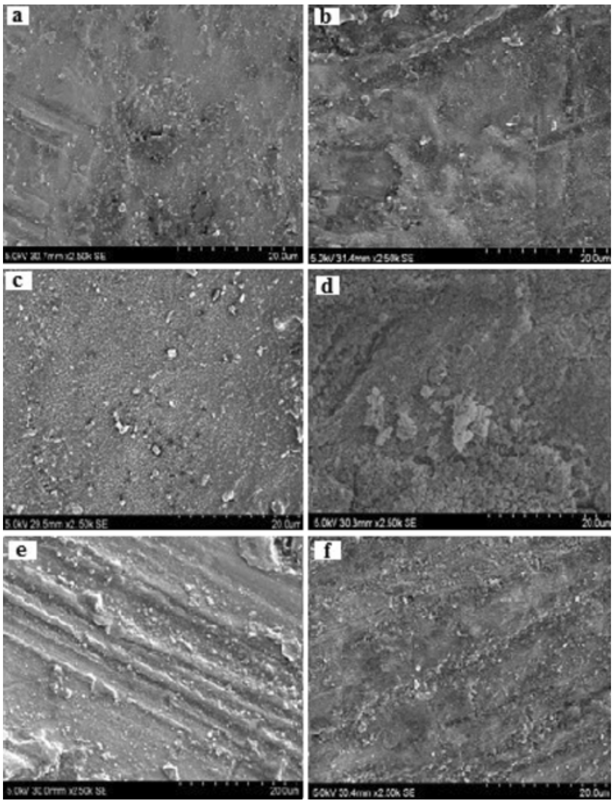

Fig. 6 — Microstructure at 200 mm/min from aluminium side (a) Ti – HAZ before age hardening (b) Ti – HAZ after age hardening (c) FZ – before age hardening (d) FZ – after age hardening (e) Al- HAZ before age hardening (f) Al – HAZ afterage hardening

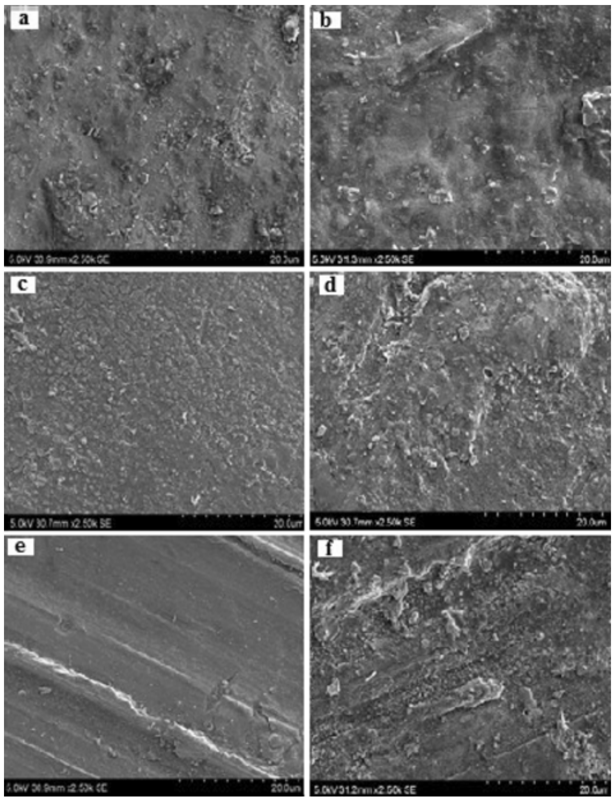

Fig. 7 — Microstructure at 240mm/min from aluminium side (a) Ti – HAZ before age hardening, (b) Ti – HAZ after age hardening, (c) FZ before age hardening, (d) FZ after age hardening, (e) Al-HAZ before age hardening and (f) Al – HAZ after age hardening

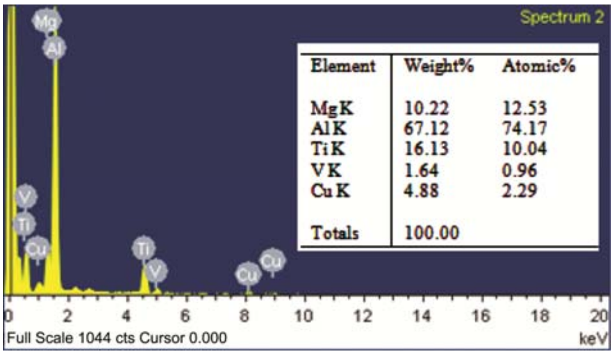

Fig. 8 — EDS analysis before age hardening heat treatment laser focused from titanium side

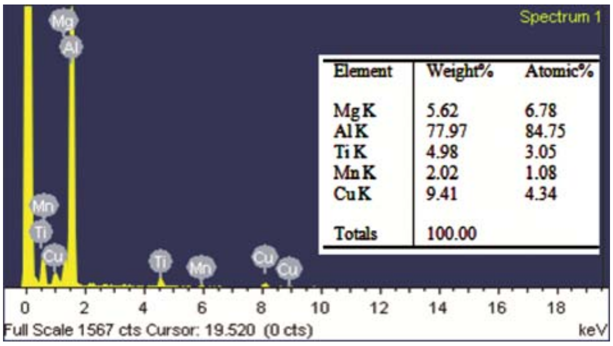

Fig. 9 — EDS analysis after age hardening heat treatment laser focused from titanium side

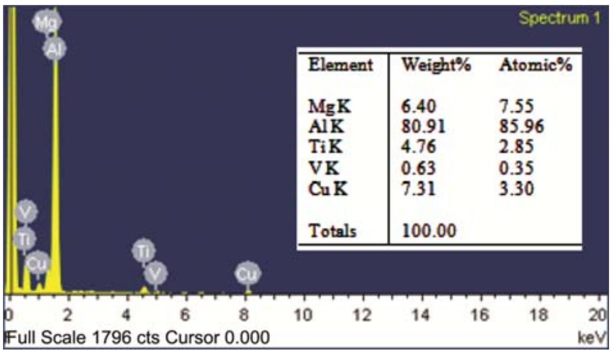

Fig. 10 — EDS analysis before age hardening heat treatment laser focused from aluminium side

hardening treatment, EDS analysis is shown in Fig. 9. From the spectrum aluminium is found to be 77.97% and titanium 4.98% as major components. Hence, after heat treatment the amount of aluminium presence is more resulting in the quality weldment with improved ductility and toughness. Thus, the bond is considered as a metallurgical one due to mutual migration of titanium and aluminium atoms.

Figure 10 shows elements presented in the fusion zone and spectrum processing of before age hardening

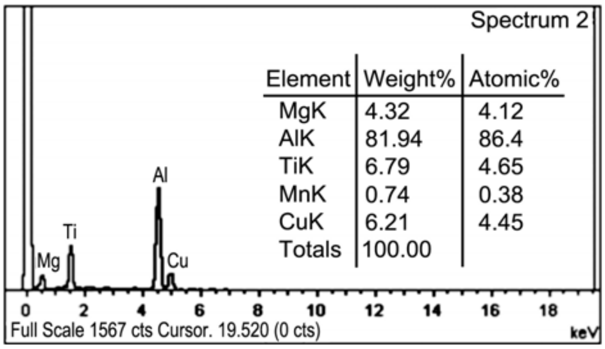

Fig. 11 — EDS analysis after age hardening heat treatment laser focused from aluminium side

at the maximum speed of 240 mm/min, laser beam focused from aluminium side. Spectrum processing indicates that aluminium content is enhanced to 80.91% whereas titanium content is reduced to 4.76% before age hardening and aluminium 81.94% whereas Ti 6.79% after age hardening heat treatment as shown in Fig. 11. Hence, not much change in aluminium content is observed during age hardening on weldment, while focusing the arc from Al side.

Conclusions

In this investigation a comparative analysis on weldment focusing laser beam from titanium side and also from aluminium side are reported with minimum weld speed of 200 mm/min and maximum of 240 mm/min using SEM analysis. It is observed that at higher weld speed, the microstructure is found refined while comparing with lower weld speed leading to improvement in joint strength. Weldment subjected to age hardening results grain refinement better than without heat treatment. Also EDS analysis reveals that focusing weld arc from titanium side results more amount of atoms migration than from aluminium side. Hence, it is concluded that titanium/aluminium dissimilar weld joint is possible with laser beam welding to produce metallurgical bond leading to mechanical strength with toughness.

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