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SEM studies on age hardened Laser welded dissimilar Ti/Al sheet metal weldments

K. Kalaiselvan[1], A. Elango[2], and NM. Nagarajan[3]

[1]Department of Mechanical Engineering,
Meenakshi Ramasamy Engineering College,
Ariyalur, Tamilnadu, India

[2]Vice Principal,
Alagappa Chettiyar College of Engineering and Technology,
Karaikudi, Tamilnadu, India

[3]Professor (Retd),
Department of Mechanical Engineering,
National Institute of Technology,
Calicut, Kerala, India

ABSTRACT: Laser beam welding of light weight and high strength Ti and Al alloy is very attractive for aerospace and automotive industries. The development of dissimilar welding is having a bearing on maximum temperature at the weldment and heat transfer rate in heat affected zone. Also grain coarsening may cause if the thermal cycle is not properly checked. For maintaining good mechanical properties of the weld joints, phase transformation during rapid thermal cycles is required. Such cycles occur during welding of Ti/Al sheets and heat treatment after welding. Ti and Al alloys are sensitive to heat due to their high difference in melting temperatures. This may cause changes in microstructures infusion and heat affected zones. The aim of this study is to examine the changes in the microstructures, heat affected zones of the TI6AL4V (Ti) and AA2024 (Al) alloy thin sheets welded joint using SEM and EDS analysis of different variants before and after precipitation hardening. Test results reveal that laser arc, focusing on Ti side gives better-refined age hardened structure than from Al side, and EDS analysis is also supporting the view.

KEYWORDS: Laser beam welding; Ti; Al/Age hardening; SEM; EDS.

1 INTRODUCTION

Laser Beam Welding (LBW) of Ti/Al dissimilar metal joints is a challenging welding process due to the difference in their melting temperatures and chemical affinity towards oxygen [1-3]. Also high solidification shrinkage, high solubility in molten stage and high thermal conductivity cause reduction in mechanical properties [4, 5].

Nowadays dissimilar weld joints are preferred in industries based on the need of high mechanical properties including high strength [6-11]. The application of such industries is listed as aircraft industries, space vehicles, nuclear, marine and chemical industries based on dissimilar weld joint properties namely good strength, weldability and corrosion resistance [12-16]. Different materials and formation of brittle intermetallic compounds, which have the low melting ability, are the main concerns for obtaining a perfect joint using the conventional welding methods. Ti/Al is widely used in practical, and engineering applications and hence high quality of weldments made from these materials is a challenge. These materials are incompatible metals due to their higher affinity towards oxygen and producing brittle intermetallics in the interfaces [17, 18].

Intermetallic phases infusion zones (FZ) are found redissolved after solution heat treatment, and quenching retains a somewhat supersaturated solid solution in the matrix alloying precipitation hardening to occur upon aging [19]. More solute is available for strengthening in the matrix than the boundaries because the grain interiors in the fusion zone to become more homogeneous with less of a solute gradient. Precipitation hardening to occur, lower ductility at long aging times is needed. A study on FZ and HAZ are 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, Ti and Al alloys used for welding are sensitive to heat due to their high difference in individual melting temperatures. This may cause changes in microstructures infusion and heat affected zones.

Microstructure analysis has been carried out using Scanning Electron Microscope (SEM) to find changes in the different zones in the weldment namely fusion zone, heat affected zone and unaffected zone. Also, Energy Dispersive Spectroscopy (EDS) device is used to find chemical composition of Ti and Al alloy weldment before and after precipitation hardening. The laser has been carried out at different welding speed.

2 MATERIALS AND METHODS

The materials used in the investigation are Ti and Al alloy sheets of 1.0 mm thickness, 75mm width and 150mm length. In Ti, alloy titanium has above 90% and in Al alloy aluminum has above 92%. Al melting point is 660˚C whereas for titanium it is 1668˚C. For welding Nd: YAG Pulsed laser welding unit is used with pulse range 20Hz, the pulse width range 8.5ms, focusing length 200mm and gas flow rate 10 lit/min. Dissimilar metal is welded by varying welding speeds such as 200, 210, 220, 230 and 240mm/min. Laser offset distance is kept at 0.3mm focusing from Ti and Al joint interface. Weld joint gap is maintained with 0.1mm and butt joint is made using two jig plates. No edge preparation is carried out before laser welding, and argon gas is used as a shielding gas with a constant flow rate. In particular the Ti-Al dissimilar joints are positioned, and the laser beam is projected from Ti as well as Al side, forming the weld between the two alloys.

After welding, age hardening heat treatment is carried out on the weldment in a heat treatment furnace operating at a temperature of about 600˚C as shown in Fig. 1 with capacity 7.5KW and maximum temperature range 1150˚C.

Fig. 1. High-temperature furnace

During precipitation heat treatment (Age hardening), the temperature is maintained at 550˚C. Welded samples are kept inside, and the thermocouple is used to identify inside temperature of the furnace. After heating, at 550˚C for 5 minutes samples are quenched at 27˚C for 5 minutes and maintained 24 hours air cooling. The solution heat treatment and aging are carried out for samples welded at speed 200mm/min, 220mm/min and 240mm/min respectively. Only natural age hardening is carried out for all the set of experiments. SEM studies are mainly carried out on very fine precipitates after ageing by increasing the magnification to 10,000 times (X 10000) as these are not identified with an optical microscope. 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 present in the weld dissimilar metals.

3 RESULTS AND DISCUSSIONS

3.1 MICROSTURCTURE ANALYSIS

The SEM analysis on weldment for weld speed from 200mm/min, 220mm/min and 240mm/min are reported in the investigation. Fig. 2(a) shows the microstructure of the base metal Ti alloy sheet and 2(b) shows the micro structure of the Al sheet base metal with X 10000 magnification.

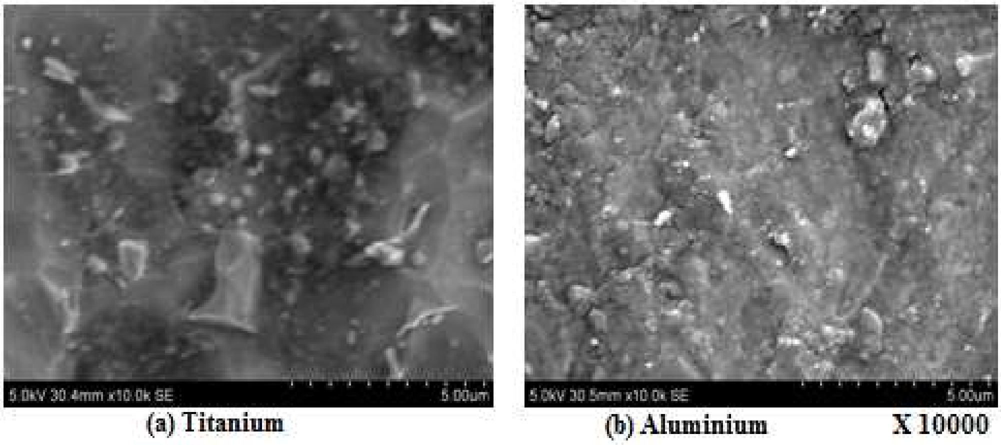


Fig. 2. Base metal microstructure (a) Ti and (b) Al

3.1.1 LASER BEAM FOCUSED FROM TI SIDE

By keeping offset distance of 0.3mm laser is focused from Ti side. The microstructure taken on HAZ of Ti side before and after precipitation hardening heat treatment is given in Fig. 3(a) and (b) respectively with weld speed of 200mm/min. The structure is similar to the base metal with the slightly difference in contrast on before precipitation. Dark dots are present on after precipitation. The magnification X 10000 is maintained in all zones observed. The fusion zone microstructures are shown Fig. 3(c) and (d), after heating the weldment at 550°C being the solution treatment temperature. The structure after heat treatment clearly shows refined grain structure as present in Fig. 3(d).

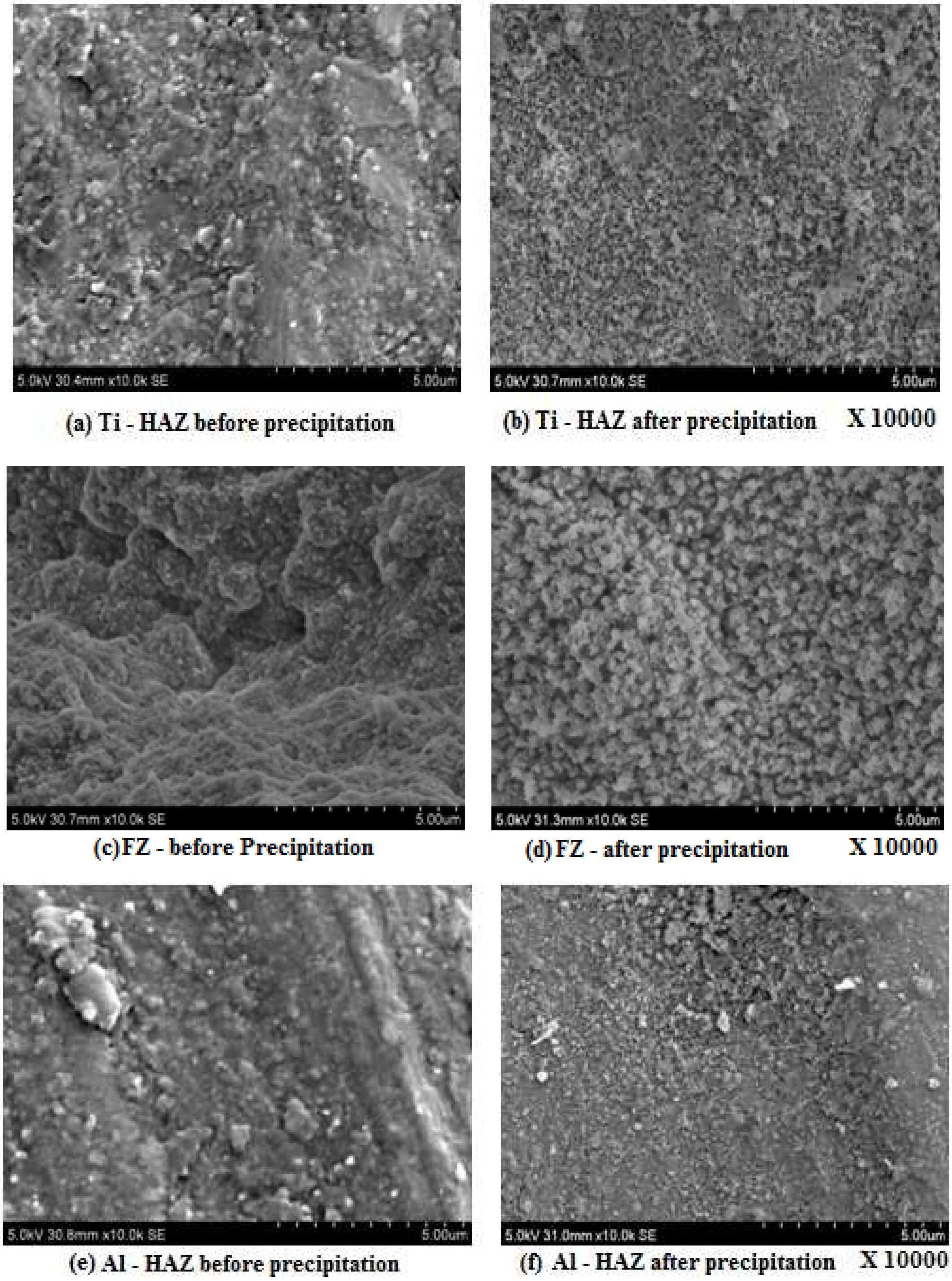


Fig. 3 Microstructure at 200mm/min from Ti side (a) Ti – HAZ before precipitation (b) Ti – HAZ after precipitation(c) FZ – before precipitation (d) FZ – after precipitation (e) Al- HAZ before precipitation (f) Al – HAZ after precipitation

Similarly Fig. 3(e) and (f) represent HAZ taken on Al sheet side. Heat treated Al as per Fig. 3(f) reveals very fine grains, which may have the bearing on strong weldment.

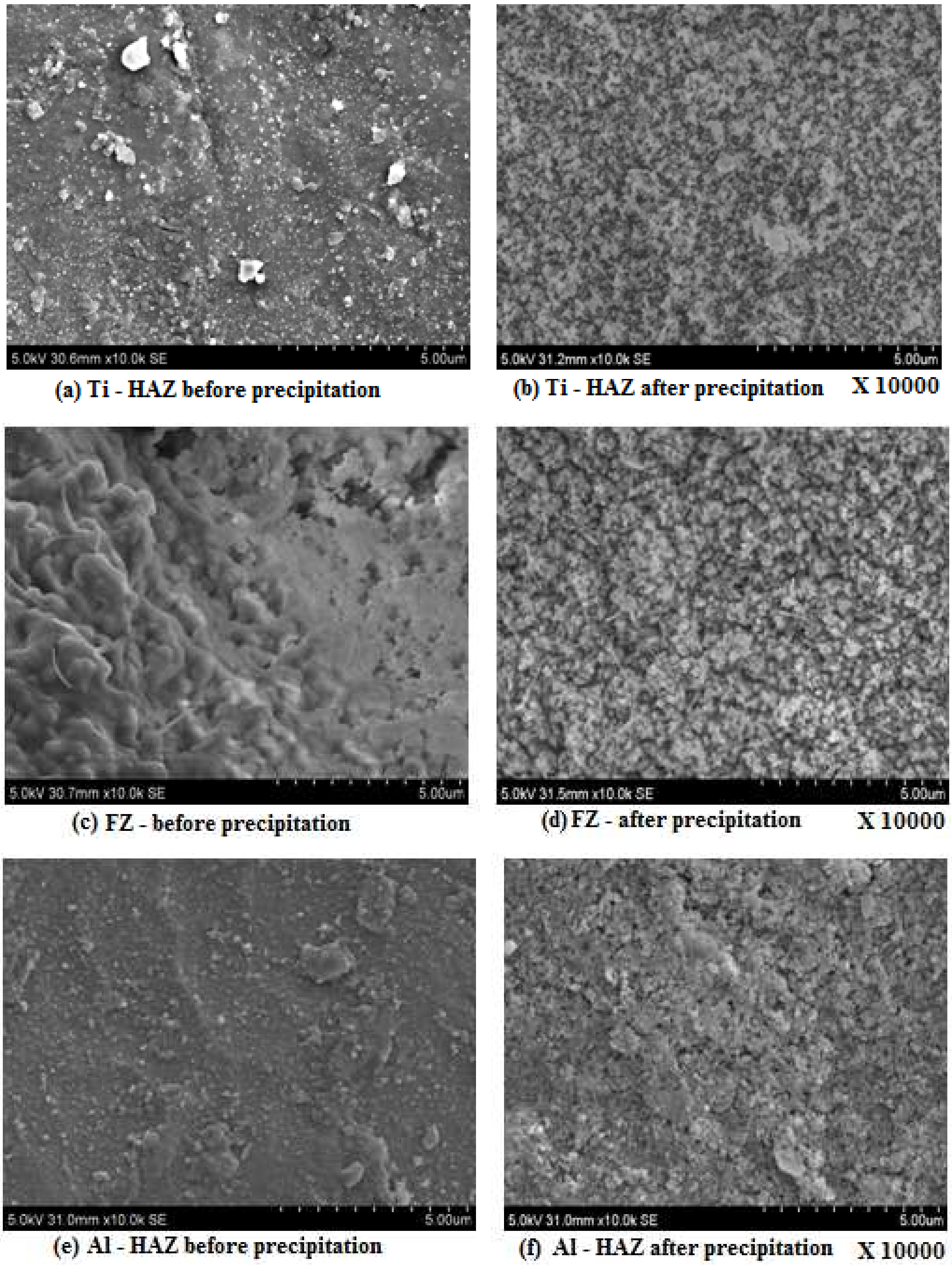


Fig. 4. Microstructure at 240mm/min from Ti side (a) Ti – HAZ before precipitation (b) Ti – HAZ after precipitation (c) FZ before precipitation (d) FZ after precipitation (e) Al- HAZ before precipitation (f) Al – HAZ after precipitation

By increasing the weld of 240mm/min, the structures have been further refined after heat treatment as seen in Fig. 4(b), (d) and (f) in the heat affected and fusion zones.

3.1.2 LASER BEAM FOCUSED FROM AL SIDE

The laser beam is focused from Al side, and the details of the structure are given in Fig 5(a) and (b). It is found that at welding speed 200mm/min heat concentration is more due to slow speed that result in partial grain coarsening. From the Fig. 5(c), it is observed that grain coarsening is resulted due to lower welding speed in the fusion zone. However after heat treatment the grains on refined as shown in Fig. 5(d). Fig. 5(e) and (f) refer SEM pictures before and after precipitation hardening. Grain refining is observed in both the cases. Also, interlaced structure is formed, and it shows that the dissimilar sheets are bonded well.

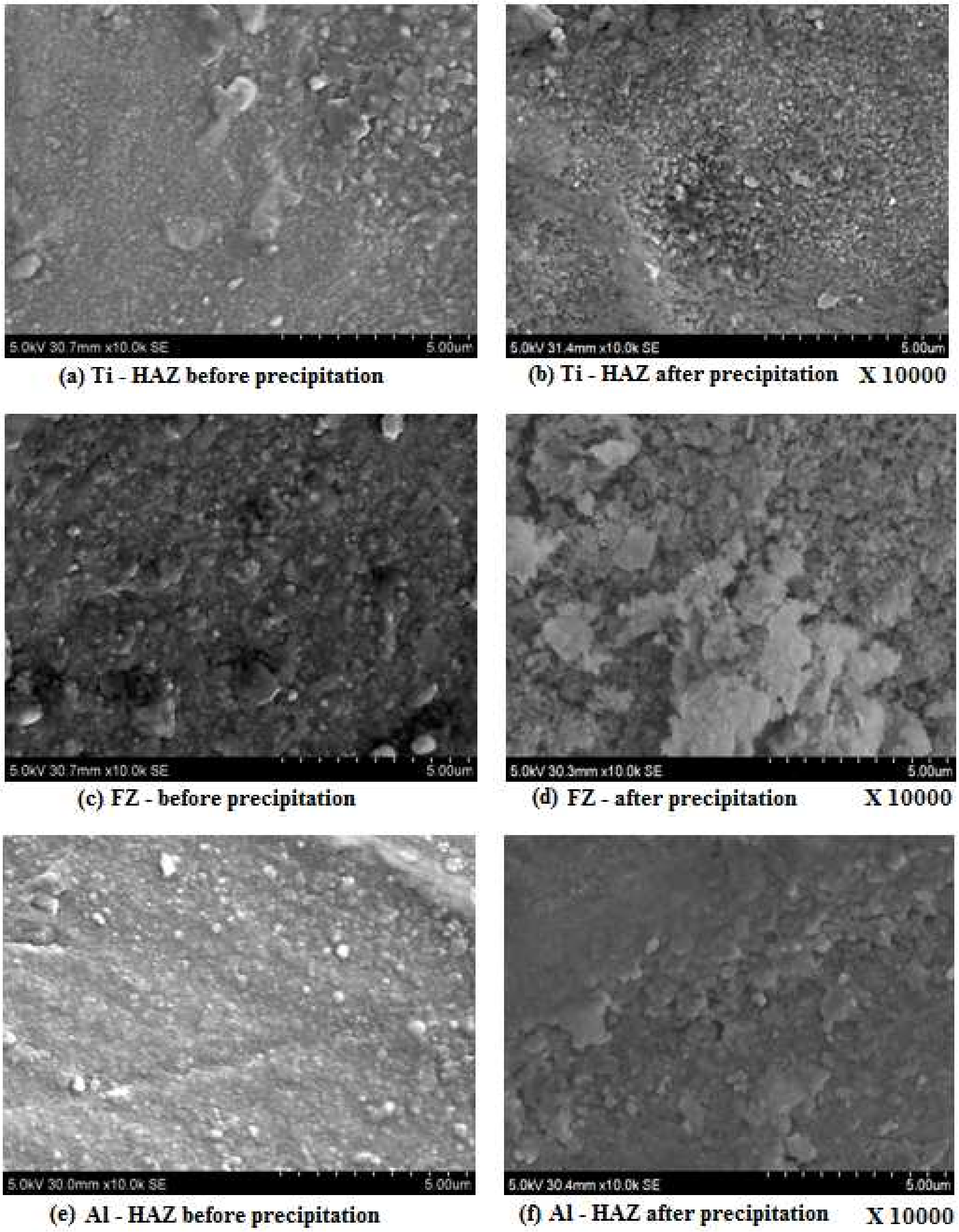


Fig. 5. Microstructure at 200mm/min from aluminium side (a) Ti – HAZ before precipitation (b) Ti – HAZ after precipitation (c) FZ – before precipitation (d) FZ – after precipitation (e) Al- HAZ before precipitation (f) Al – HAZ after precipitation.

Fig. 6(a) and (b) show fine grain structures at the speed of 240mm/min. Grain size decreases with increasing speed having a periodic change of grain size. Comparing to laser source focused from Ti side, Al side grain structures are uniformly distributed and are smooth in texture.

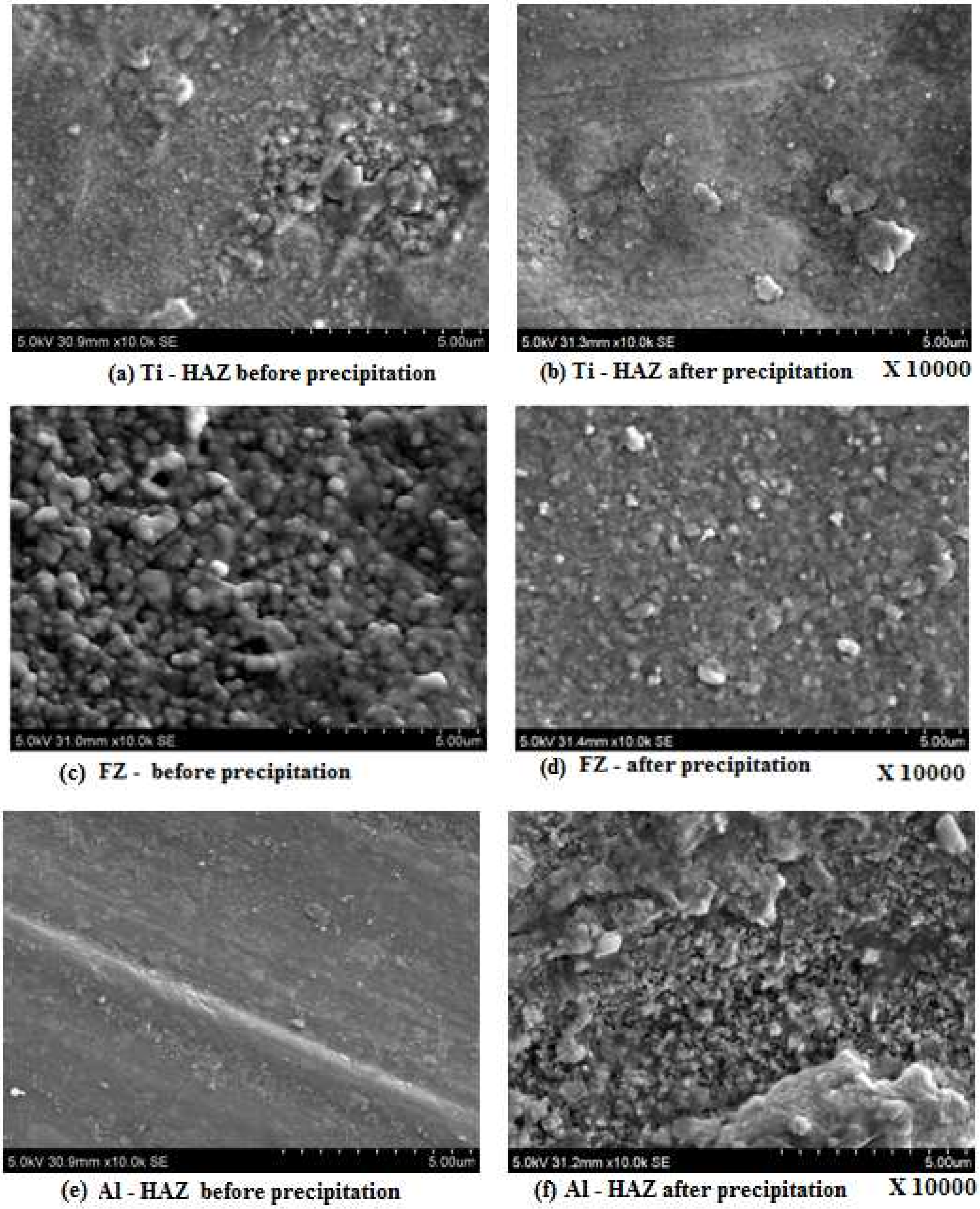


Fig. 6 .Microstructure at 240mm/min from aluminium side (a) Ti – HAZ before precipitation (b) Ti – HAZ after precipitation (c) FZ before precipitation (d) FZ after precipitation (e) Al- HAZ before precipitation (f) Al – HAZ after precipitation

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 Fig. 6(c) and (d) before and after precipitation. Further in Fig. 6(e) and (f) there is no coarse-grained structure seen in HAZ. In a similar way, no refined size is observed at 240mm/min weld speed. Here it is clear that focusing the laser beam from Ti side gives well-refined grain structure leading to better mechanical properties.

3.2 Energy Dispersive Spectroscopy (EDS) Analysis

Fusion zone microstructure is influencing considerably the properties at the welding zone. The best sample at the speed of 240mm/min formed at Ti side is examined by (EDS) before and after precipitation hardening and is shown in Fig. 7(i) and (ii). Table 1 and 2 shows the composition of fusion zone and the laser offset distance is focused from Ti side.

Table 1 Spectrum Processing: Fusion zone at 240mm/min from Ti side before precipitation hardening.

Element	Series	Weight%	Atomic
M_g	K series	10.22	12.53
Al	K series	67.12	74.17
T_i	K series	16.13	10.04
V	K series	1.64	0.96
C_u	K series	4.88	2.29
Total 100%			

Table 2 Spectrum Processing: Fusion zone at 240mm/min from Ti side after precipitation hardening.

Element	Series	Weight%	Atomic
M_g	K series	5.62	6.78
Al	K series	77.97	84.75
T_i	K series	4.98	3.05
Mn	K series	2. 02	1.08
C_u	K series	9.41	4.34
Total 100%			

The heat source is focused from Ti side, and percentage of Al is found to be 67.12% and 16.13% Ti as major components in fusion zone before precipitation hardening. After precipitation treatment, Al is found to be 77.97% and Ti 4.98% as major components. Hence after heat treatment the amount of Al presence is more resulting in the quality weldment.

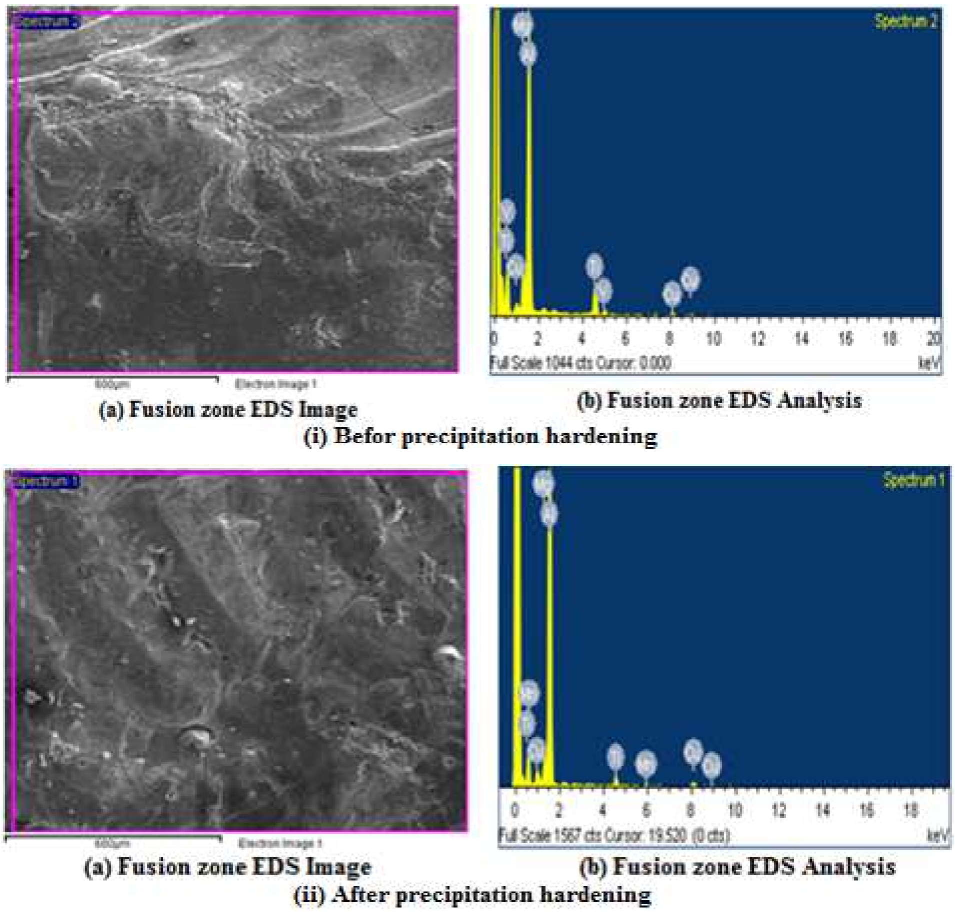


Fig. 7. EDS (i) Before precipitation and (ii) After precipitation at 240mm/min from Ti side

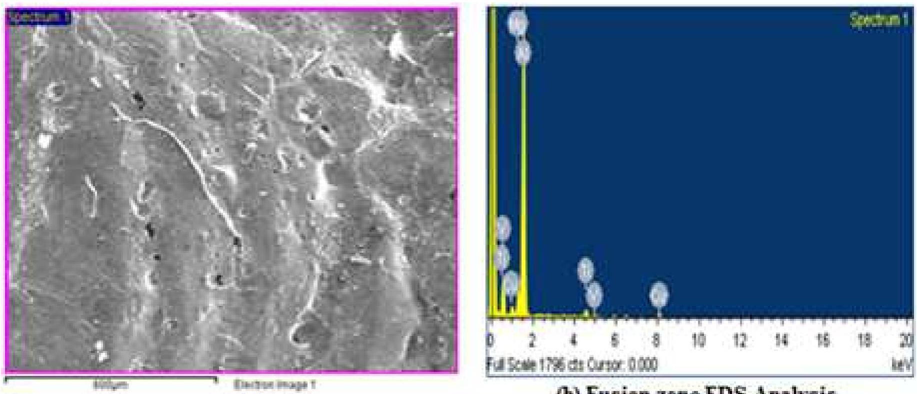
Fig. 8(i) and (ii) indicates smooth texture caused due to the rapid flow of Al during the dissimilar laser welding process. Table 3 and 4 represents elements presented in the fusion zone before and after precipitation hardening.

Table 3 Spectrum Processing: Fusion zone at 240mm/min from Al side before precipitation hardening

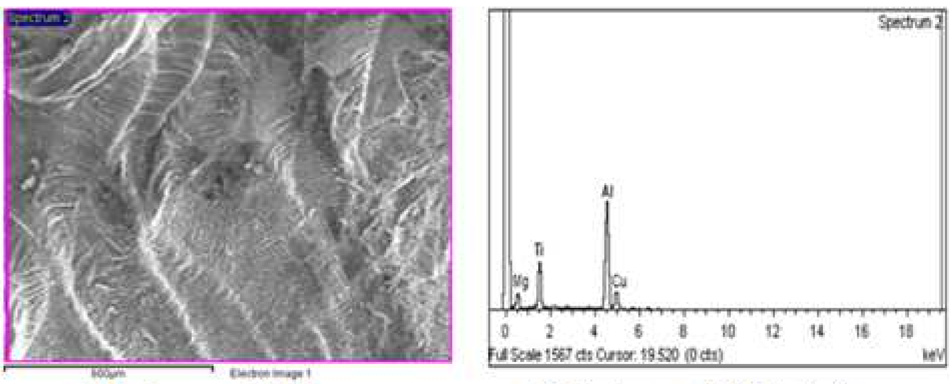
Element	Series	Weight%	Atomic
M_g	K series	6.40	7.55
Al	K series	80.91	85.96
T_i	K series	4.76	2.85
V	K series	0.63	0.35
C_u	K series	7.31	3.30
Total 100%			

Table 4 Spectrum Processing: Fusion zone at 240mm/min from Al side after precipitation hardening.

Element	Series	Weight%	Atomic
Mg	K series	4.32	4.12
Al	K series	81.94	86.4
Ti	K series	6.79	4.65
V	K series	0.74	0.38
Cu	K series	6.21	4.45
Total 100%			



(a)Fusion zone EDS Image (b) Fusion zone EDS Analysis
(i) Before precipitation hardening



(a) Fusion zone EDS Image (b) Fusion zone EDS Analysis
(ii) After precipitation hardening

Fig. 8. EDS (i) Before precipitation and (ii) After precipitation at 240mm/min from Al side

Spectrum processing indicates that Al content is enhanced to 80.91% whereas Ti content is reduced to 4.76% before precipitation and Al 81.94% whereas Ti 4.65% after heat treatment. Hence, not much change in Al content is observed during precipitation hardening on weldment, while focusing the arc from Al side.

4 CONCLUSIONS

1. The welding speed at 240mm/min gives more refined age hardened structure than at lower speeds, selected for the investigation.
2. Welding arc focusing from Ti side gives better-refined precipitates than arc focusing from Al side.
3. EDS analysis also reveals that arc focusing from Ti side gives a better quality of age hardened Al structure.

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