Weld speed effects on quality of Ti/Al dissimilar metal joints using laser beam welding

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Abstract: Laser beam welding produces good quality welds with minimum shrinkage for sheet metal joints. The quality of welded joint depends upon surface morphology, hardness, mixing of liquid phases and metallurgical non-homogeneity induced by gradients of temperatures and cooling rate at the weld interface. In the present investigation, Titanium Grade5 (Ti) and AA2024 (Al) alloy dissimilar sheet metals are joined using Nd:YAG pulsed laser beam and the effect of welding speed on crack tendencies, the strength of weldment based on hardness and composition changes are studied. Test results reveal that higher welding speed eliminates cracks in weldment and improves surface morphology. From hardness test, it is observed that the strength of fusion zone is considerably improved at higher weld speed and the findings are supported by SEM and EDS studies.

Keywords: laser beam welding; LBW; morphology; hardness; microstructure; composition.

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1 Introduction

Laser beam welding (LBW) opens up many opportunities for designing and economically joining machine parts. Several potential applications of dissimilar Ti and Al weld components are found in aircraft cabin structures (Kocik et al., 2004, 2006), parts of engine cowlings, seat tracks (Kleiner et al., 2009; Möller et al., 2010), components of storage tanks (Leyens and Peters, 2003; Chen et al., 2011a) and elements of the wings (Chen and Nakata, 2009; Katayama, 2009b). These assemblies can be found by adopting welding processes (Katayama, 2009a). The quality of welded dissimilar joints depends upon the cracking tendency, surface morphology, hardness, mixing of liquid phases and metallurgical non-homogeneity induced by gradients of temperature and cooling rate at the weld interface (Squillace et al., 2012; Chen et al., 2011b). Dissimilar welding of Ti and Al using laser beam with extremely high welding speed was tried and the microstructural characteristics of the interface zone in the Ti and Al weld were investigated (Lee et al., 2013; Squillace et al., 2012).

The microstructural characteristics in the heat affected zone (HAZ) and fusion zone have been changed after LBW. These are strongly influenced by the welding conditions (Liu et al., 2012). LBW is one of the most efficient joining techniques, due to its flexibility, precision and capability to produce restricted HAZ and deep penetration (Casalino et al., 2014). In particular, pulsed lasers generate a high quality beam, with a low divergence and with a wavelength suitable for the absorption by a wide range of materials (Vänskä and Salminen, 2012; Kraetzsch et al., 2011). LBW processing parameters and physical properties such as laser power, beam diameter, welding speed, focal point position, beam reflectivity, thermal diffusivity, surface tension, edge surface roughness, atmosphere pressure, shielding gas type and shielding gas flow rate (Katayama et al., 2010; Salminen et al., 2010) have a strong effect on the process and weld penetration.

Better the beam quality, the higher the welding speed. While welding with high power, good beam quality, and wavelength are affected. These are due to high absorption and power density (Zhang et al., 2013). Strength increases with an increase in the welding speed, and therefore extremely high welding speed is good to dissimilar weldability for Ti and Al (Lee et al., 2013). The development of an appropriate system technology and the process development are described, focusing on the main influencing parameters of the process on joint properties (Moller et al., 2011). Temperature, and corresponding heating and cooling rates generate during laser processing of metallic glass. Rapid heating rates during laser processing led to a shift in the onset of crystallisation temperature to a higher level. Faster cooling rates prematurely arrested the crystallite growth yielding much finer crystallite sizes (Joshi et al., 2015).

Considering the above observations the following parameters such as welding speed, heat energy, gas flow rate and focus point position have been selected for this investigation. Experiments with laser welding are carried out to determine the practical operating range by using at various speeds to produce an acceptable quality welding of the dissimilar metals. LBW process has been adopted to produce Ti and aluminium Al alloys thin sheet joints. In the present paper, some aspects of Ti/Al dissimilar metal joints such as cracking, surface morphology, hardness, microstructure and composition of fusion zone have been observed and discussed. From this literature survey, it is found that not much work has been reported on dissimilar welding of Ti/Al sheet metal. Hence, the present work is under taken to study the welding parameters on quality of weldment.

2 Experimental details

The metals used for the investigation are commercially available Titanium Grade5 (Ti) and AA2024 (Al)alloy sheets of 1.0 mm thickness, 75 mm width and 150 mm length. The chemical composition of base metals is listed in Tables 1 and 2.

Table 1 Chemical composition of Ti (wt. %)

Al (%)	V (%)	H (%)	Ti (%)
5.5–6.75	3.5–4.5	0.015 (Max)	Balance

Table 2 Chemical composition of Al (wt. %)

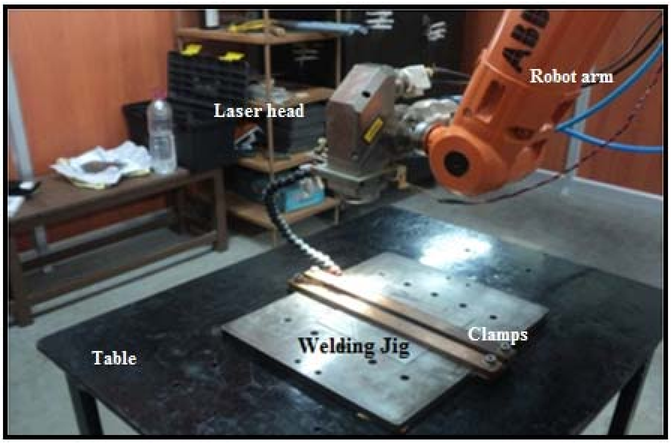
Si (%)	*Cu (%)*	*Zn (%)*	*Fe (%)*	*Mg (%)*	*Ti (%)*	*V (%)*	*Pb (%)*	*Mn (%)*	*Al (%)*
0.500–1.200	3.800–5.000	0.063	0.700	0.200–0.800	0.010	0.001	0.028	0.300–1.200	Balance

For welding, Nd:YAG Pulsed laser welding unit is adopted with repetition pulse range 20 Hz; typical laser power at work piece 500 W; standard beam diameter-600 µm; pulse width ranges 8.5 ms; focusing length 200 mm and gas flow rate 10 lit/min. Dissimilar metal is welded by varying welding speed namely 180, 190, 200, 210, 220, 230 and 240 mm/min. Argon shielding gas is used to prevent oxidation of molten surface during welding. Laser offset distance is kept at 0.3 mm focusing from the Al side and weld joint gap is maintained with 0.1 mm. A butt joint is made using two jig plates. No special heat treatment and edge preparation are carried out before laser welding. In particular, the

Ti-Al dissimilar joints are positioned and the laser beam is projected from the Al side, forming the weld between the two alloys.

Figure 1 shows the welding jig installed for dissimilar welding of Ti and Al alloy thin sheets. After welding, the macrostructure of weldment is examined using Tool Makers Microscope (Model: CM0646). Test specimens from the weldment are cut to the required dimensions and then polished using different grades of emery papers and are subjected to metallographic examinations using scanning electron microscope (SEM-Hitachi SU6600) and energy dispersive spectroscope (EDS), which is used to reveal various features of the joint including percentage composition. Hardness distribution on weldment is carried out using Rockwell Hardness Tester (LS 1586-1968).

Figure 1 Welding jig (see online version for colours)



3 Results and discussions

The effect of weld speed on variables such as crack tendency and surface morphology, hardness, microstructure and composition changes are found and discussed below.

3.1 Crack and surface morphology

Figure 2 shows the appearances of weld beads of Ti and Al dissimilar welding at 180mm/min under focal conditions. Full penetration weld is obtained and longitudinal crack has been seen on the weld bead surface. These weld cracks and surface morphology are viewed using Tool Makers Microscope with magnification X10.

These cracks are formed due to uneven heat flow between Ti and Al sides results the formation of the intermetallic compound (Chen et al., 201). Relatively good welds and surface morphology are observed in all the weld beads at higher weld speeds except crack formation at lower speeds observed namely 190 mm/min and a180 mm/min. The weld bead width is getting narrower with an increase in weld speed from 200 mm/min to 240 mm/min. Figure 3 shows surface morphology of weld bead at 240 mm/min.

Figure 2 Crack at speed 180 mm/min (see online version for colours)

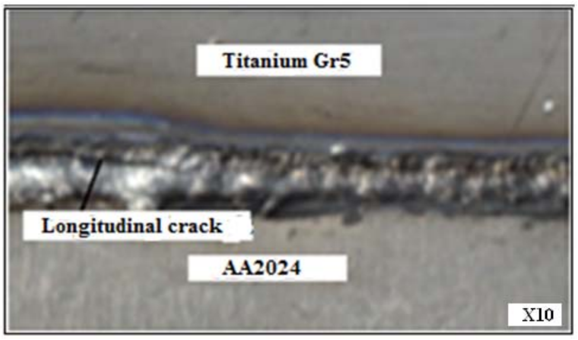
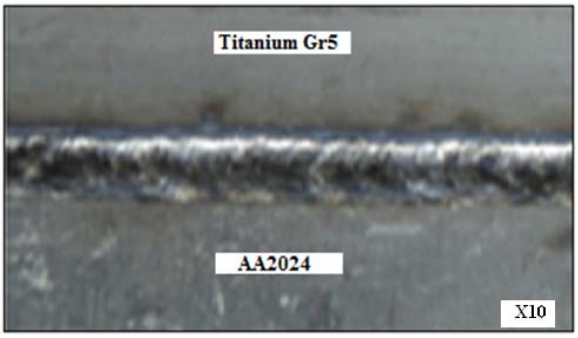


Figure 3 Surface morphology at speed 240 mm/min (see online version for colours)

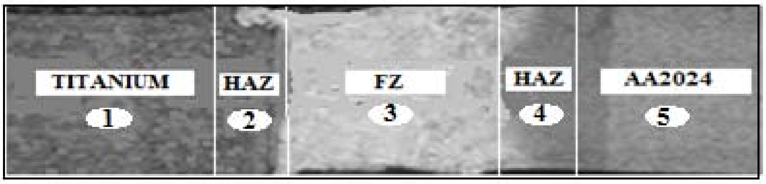


As the welding speed increases, crack formation tendency gets eliminated in Ti/Al joints. Also, clean surface morphology is noted at higher welding speeds.

3.2 Hardness

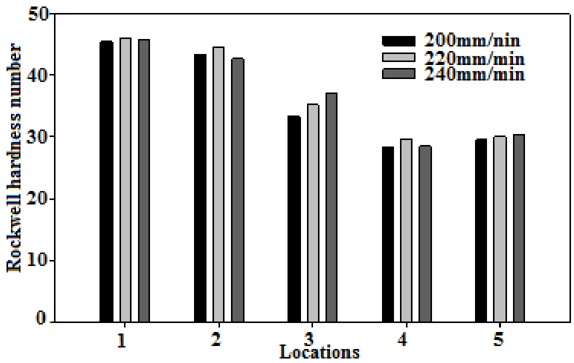
The strength of the weldment is estimated based on hardness values. Heat energy is focused from the Al side with an offset distance of 0.3mm and the sheets are welded using a laser beam. After welding, the hardness values are measured using Rockwell Hardness (HRC) scale (https://en.wikipedia.org/wiki/Rockwell_scale). As per American Society for Testing and Materials (ASTM-E18: Standard methods for Rockwell hardness) direction, diamond indentor is used for C scale readings. Accordingly in the present investigation, only HRC scale is used for uniformity to find hardness of Ti and Al alloy dissimilar weld. Hardness tests are performed to evaluate the hardness distribution across the weld line, namely the base metals and HAZ on both sides of the weld region left and right. Hardness measurements are taken on the test piece with 1 mm gap as per the locations shown in Figure 4 and the laser beam is focused from the Al side for welding.

Figure 4 Hardness measurements locations



Hardness distribution across the weld region is given in Figure 5. Test results reveal that the hardness of the fusion zone is slightly lower than that of HAZ and base metal as seen from titanium side. However, from Al side, the hardness at the fusion zone is higher. This may be due to the difference in melting temperature of dissimilar metals (Al-660°C, Ti-1660°C). This is similar that of High Speed tool Steel where 18 percentage Tungsten addition in steel results increase in hot hardness value. However, proper mixing of these two metals is observed in the weld zone as the hardness value of fusion zone is found higher than HAZ and base metal zone, viewed from Al side.

Figure 5 Hardness distributions across the weld region

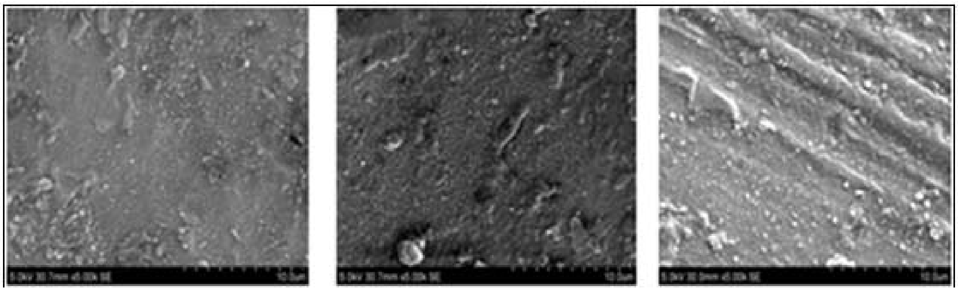


Higher heat input associated with weld speed leads to increase in hardness at HAZ. However as the laser beam heat affects the Al side, Al gets softened due to its low melting point and hardness is considerably reduced even at the base metal zone.

3.3 Microstructure

In welding, the grain boundaries in the HAZ can be linked with the fusion zone. During solidification, elements can diffuse into the HAZ from the fusion zone along the grain boundaries. The dissolved elements and impurities diffuse more rapidly along the grain boundaries resulting in a local reduction of melting temperature. The microstructures in the fusion zone are a result of solidification behaviour and subsequent solid-phase transformation, which are controlled by composition and weld cooling rates. Fusion zone of a dissimilar metal joint depends on the melting ratio of the two metals to be joined and related to welding parameters. The grain structure with a magnification of X5000 at the position of HAZ and FZ for speed at 200mm/min is shown in Figure 6(a), Figure 6(b) and Figure 6(c). It is observed that higher heat input associated with lower welding speed results fine grains in titanium HAZ (a) and coarse grains in aluminium HAZ (c). All samples are viewed through SEM after surface preparation explained under experimental details.

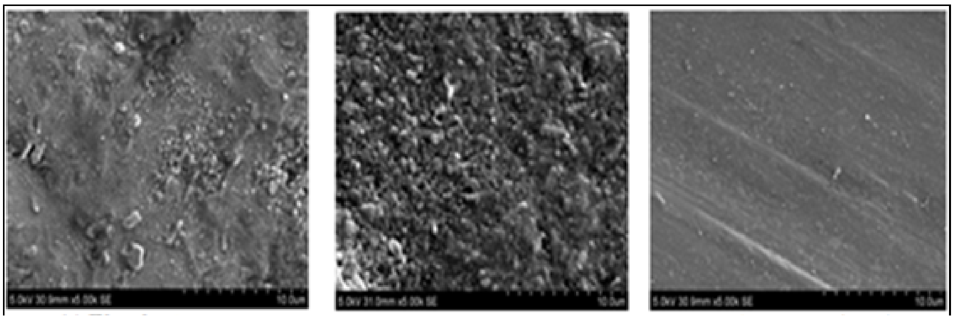
Figure 6 Microstructure at 200 mm/min, (a) Ti-HAZ (b) fusion zone (c) Al-HAZ



(a) (b) (c)

Figure 7(a), Figure 7(b) and Figure 7(c) show fine grain structures at the speed of 240 mm/min. it is noted that grain size decreases with increase in speed. Comparing with weld speed 200 mm/min, at 240 mm/min grain structures are uniformly distributed and are smooth in texture. Thus, higher welding lead to grain refinement both in fusion and HAZs.

Figure 7 Microstructure at 240 mm/min, (a) Ti-HAZ (b) fusion zone (c) Al-HAZ

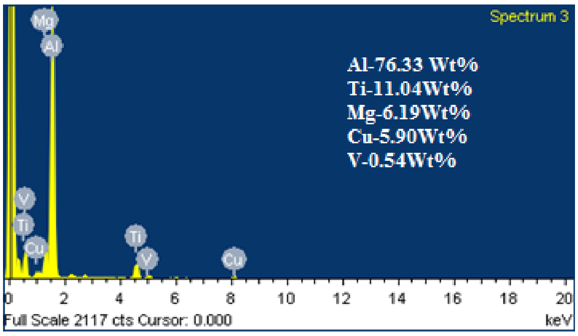


(a) (b) (c)

3.4 Chemical composition of the weld region analysis

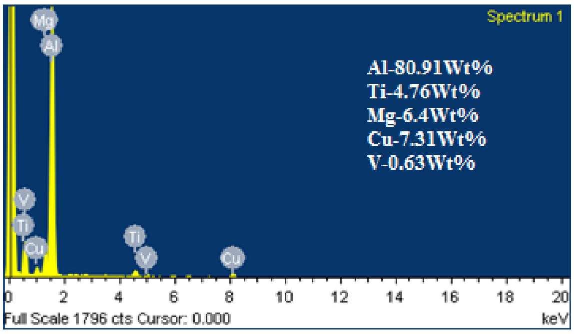
Energy dispersive X-ray spectroscopy (EDS) spectrum and chemical composition analysis are carried out on weld seam region at speed 200 mm/min and is shown in Figure 8. Spectrum processing indicates that Al with original composition 92% in parent metal is reduced to 76.33% of weight in fusion zone, whereas Ti content is increased to 11.04% from 0.01% (Table 2). Thus, the strength of weld joined is improved due to increased mixing of Ti content.

Figure 8 EDS fusion zone analysis at 200 mm/min (see online version for colours)



It is seen that welding speed is an important factor on heat flow in welding. These, in turn, affect the metal penetration depth, shape and final solidification structure of the fusion zone. Both shape and microstructure of the fusion zone are influencing considerably the properties at the weldment. The sample at the speed of 240 mm/min formed at the fusion zone is observed by EDS and is shown in Figure 9.

Figure 9 EDS fusion zone analysis at 240 mm/min (see online version for colours)



Spectrum analysis indicates that Al content is enhanced to 80.91% whereas Ti content is reduced to 4.76% and results further increase in hardness at 240 mm/min. It is observed that reduction in Ti is not affecting the increasing trend of hardness, as 0.01% Ti is enhanced to 4.76% in Al alloy. This finding is also supported by the higher hardness distribution at fusion zone viewed from the Al side as per Figure 5. Hence, higher welding speed improves the strength of dissimilar weld joints.

4 Conclusions

From the experimental investigations, the following are the conclusions.

1 As the welding speed increases interface cracking tendency in Ti/Al alloy weldment gets reduced and eliminated. Also, clean surface morphology is obtained.

2 At high speeds, the hardness on fusion zone is improved compared with base metal, viewed from the Al side.

3 SEM studies reveal that increase in weld speed improves grain refinements resulting strong weldment.

4 Spectrum analysis indicates that increase in weld speed increases Al content and Ti content in the weldment and improves the strength of dissimilar sheet metal joints.

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