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Studies on weldment performance of Ti/Al dissimilar sheet metal joints using laser beam welding

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Abstract. Laser beam welding is more advantageous compared to conventional methods. Titanium/Aluminium dissimilar alloy thin sheet metals are difficult to weld due to large difference in melting point. The performance of the weldment depends upon interlayer formation and distribution of intermetallics. During welding, aluminium gets lost at the temperature below the melting point of titanium. Therefore, it is needed to improve a new metal joining techniques between these two alloys. The present work is carried for welding TI6AL4V and AA2024 alloy by using Nd:YAG Pulsed laser welding unit. The performance of the butt welded interlayer structures are discussed in detail using hardness test and SEM. Test results reveal that interlayer fracture is caused near aluminium side due to low strength at the weld joint.

Keywords: titanium; aluminium; laser welding; interlayer characteristics

1. Introduction

Laser beam welding (LBW) is one of the non-conventional welding techniques used to join metals by laser beam. The beam provides a concentrated heat source, allowing narrow, deep welds with high welding rates. The mechanism of direct heating involves absorption of the beam energy by the material surface and subsequent transfer of energy into the surrounding material by conduction. Butt welds can be made by directing the energy towards the joint line at an offset distance through metals at one side of the joint (John 2005, Brandon *et al.* 1997). Titanium/Aluminium alloys are used for automotive, electronic and aerospace (Miller *et al.* 2000, Faller *et al.* 2001, Sze 1983, Rendigs *et al.* 1997, Heinz *et al.* 2000, Williamson *et al.* 1982) applications due to their attractive properties, such as low density, high conductivity, high specific strength and stiffness (ASM Handbook 1990). To obtain sound joints attempts are made using several processes such as diffusion bonding, friction stir welding (FSW), laser beam welding

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(LBW) and gas tungsten arc welding (GTAW) (Alhazaa *et al.* 2010, Mirjalili *et al.* 2013, Dressler *et al.* 2009, Bang 2013).

The interfacial reaction of non-homogeneity in titanium/aluminium-welded joint is improved by adopting rectangular spot laser (Chen *et al*. 2011). Interfacial properties of Ti/Al laser beam welded joint is improved by making a U-slot groove in aluminium side (Vaidya *et al*. 2010). Ti/Al interfacial microstructure is improved by adding element Zr into Al based filler metal during gas tungsten arc welding (Lv *et al.* 2013). The term interface also referred as interlayer is a narrow mushy zone consisting of a partially melted base material that has not got an opportunity for mixing. This zone separates the fusion zone and heat affected zone (ASM Metals Hand Book 1989).

In the present investigation, Ti (TI6AL4V) and Al (AA2024) alloy dissimilar metals are welded adopting Nd: YAG pulsed laser welding unit. Compared with continuous laser welding, pulsed Nd: YAG laser offers control of heat input due to the combination of various parameters (Tzeng 2000). Ti/Al thin sheets alloy are more suitable for pulsed laser welding. Also, the solidification time is shorter than continuous LBW due to periodic heating and cooling of the weld pool by the pulsed laser. However not much work has been reported on the effects of weldment interlayer and microstructures on mechanical properties using pulsed laser-welding. Hence the present investigation has been carried out with to study the effect of interlayer performance on hardness at an optimum welding speed and the microstructure of interlayer on fracture.

2. Experimental procedures

Commercially available TI6AL4V and AA2024 alloy sheets with dimensions of 150 mm length, 75 mm width and 1mm thickness are used for the welding process. The chemical composition of Ti is: Ti: base, Al: 5.5-6.5%, V: 3.5-4.5%, H: 0.015% in wt% and Al is Al: base, Cu: 3.3-5%, Mg: 0.2-0.8%, Mg: 0.3-1.2%, Si: 0.5-1.2% in wt%. Welding is performed using JK 600HP Nd: YAG pulsed laser unit. The welding conditions are as follows: Energy: 25J, Focusing distance: 200mm, Gas flow rate: 10 lit/min, Height; 30%, Width: 8.5 mm, Frequency rate: 20 Hz and Speed: 200 mm/min to 240 mm/min at an interval of 10 mm/min. Generally insufficient clamping resulting in small contacting areas leads to some poor joints being obtained. So, these two sheets are kept very close by observing online monitoring system of the unit and are perfectly clamped with the welding jig using backup plates

Argon shield gas is used for the welding process and the offset distance of 0.3 mm focused from titanium side. Laser offset has a great influence on the thickness of interfacial intermetallic compound layer and the mechanical property of joint. After welding, standard grinding and polishing procedures are adopted to prepare cross-section samples. Morphologies of the Ti/Al interface are observed using Hitachi SU6600 Scanning Electron Microscope (SEM).

The hardness of weldment has been evaluated using Rockwell hardness tester with C scale as per ASTM standard. The Rockwell hardness test is a hardness measurement based on the net increase in depth of impression as a load is applied. Hardness numbers have no units and are commonly given in the R, L, M, E and K scales. The higher the number in each of the scales means the harder the material. The depth of penetration of an indenter under certain arbitrary test conditions is determined. The indenter is a spherical diamond-tipped cone of 120 angle and 0.2 mm tip radius. The type of indenter and the test load determine the hardness scale A, B, C, etc. (Chen *et al*. 2011). The hardness number read directly from the scale. This test measures the difference in depth caused by two different forces, using a dial gauge. Using standard hardness conversion tables, the Rockwell hardness value is determined by the load applied using the diamond cone indenter. The American Society for Testing and Materials (ASTM) has standardized a set of scale ranges for Rockwell hardness testing (Donachie 1989). As per ASTM direction, HRC scale is used for uniformity to find hardness of Ti and Al alloy dissimilar weld as the hardness range of both metals are above HRC 20. Fracture analyses have been carried after tensile test and the nature of fracture is observed and reported. All the test results are observed at the optimum welding speed of 240 mm/min.

3. Results and discussions

Appearance of the Ti/Al joint after welding is found good. No cracks are present on the surface of the weld metal. Smooth surface is observed on the weldment as shown on Fig. 1. Cross section sample of the weld joint is shown in Fig. 2. It indicates different zones such as Base metal, Heat Affected Zone (HAZ), Interlayers and Fusion Zone (FZ). Ti interacts with liquid metal to form a complex interface resulting a good combination of the weldment. The weldment cross section of fusion zone and interlayer zone are seen from titanium side as well as Al sides and are studied using SEM. The details of investigations are as follows.

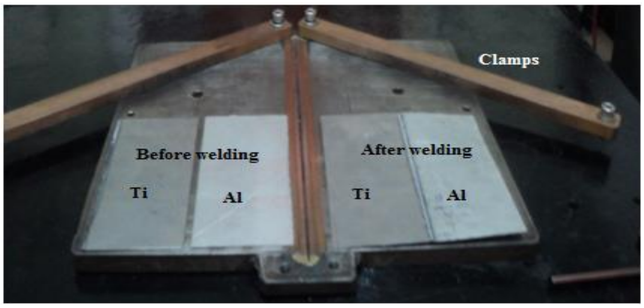

Fig. 1 Weld surface before and after welding

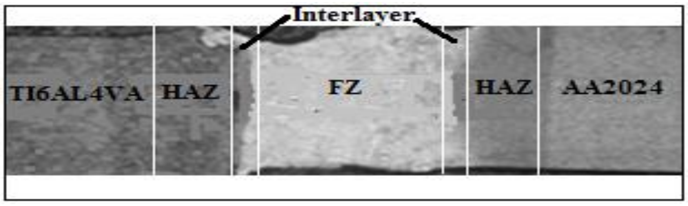

Fig. 2 Cross section of the weldment

3.1 Interlayer in Ti side

SEM images in different positions are given in Fig. 3 along the titanium FZ interface with variations in the heat input. A distinct interfacial layer is observed at the interface and it indicates the occurrence of atomic diffusion and metallurgical bonding at the interface of Ti. A nonuniform, a thick interfacial reaction layer is found from the joint head due to temperature gradient resulting from the laser heat. However, smooth surface profile is seen infusion zone adjacent to Ti side.

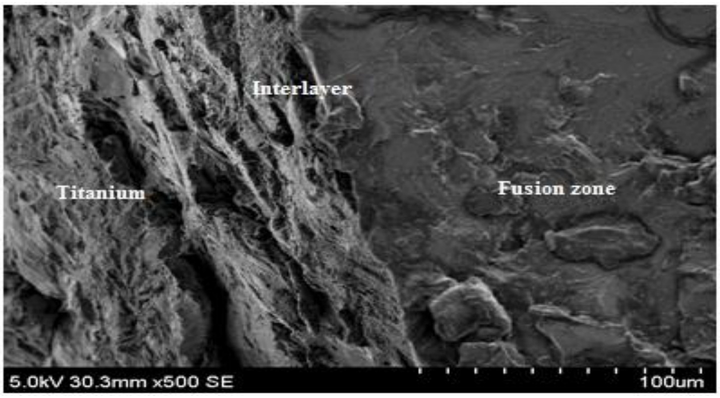

Fig. 3 Fusion interface in Ti side

3.2 Interlayer in Al side

During laser welding, the microstructure near the Al fusion interface is observed and Fig. 4 shows the features near the interlayer. Here dendrites are seen growing, leading to the formation of a bigger dendritic band at the interlayer. The coarse structure may reduce the strength of interface.

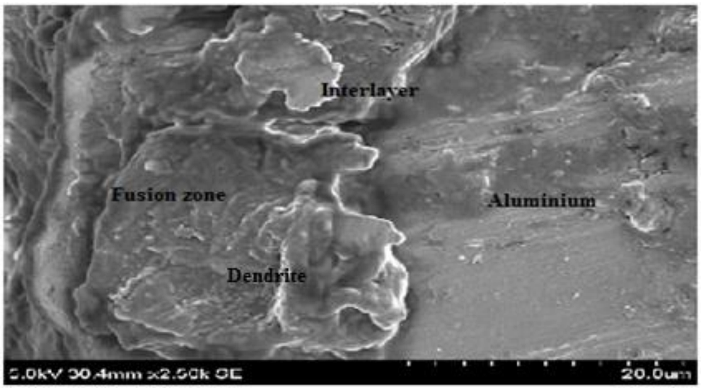

Fig. 4 Fusion interface in Al side

3.3 Fusion zone in the middle

The fusion zone in the middle of weldment is observed in Fig. 5. Fine grains as well as mixed dog bone coarse grains are combined in the fusion zone. It indicates that fusion zone is uniformly mixed resulting intermetallic compounds.

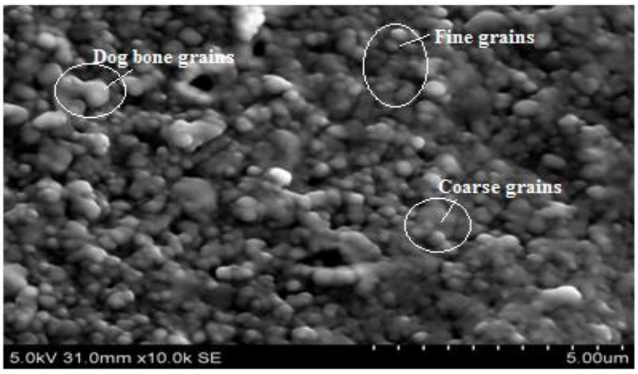

Fig. 5 Fusion zone in the middle

3.4 Hardness

Tests have been carried on weldment to study weld interlayer, hardness and fracture morphology in the weldment interlayer. Even though hardness is defined as a measure of resistance to wear or indentation or penetration on metal, the change in hardness is generally proportional to changes in tensile strength. Hence, the hardness and tensile can be related. But in weldment, the hardness distributions at various interfaces are different and cannot be related to tensile strength as tensile strength test gives the overall strength of the weldment.

Hardness distribution at various locations in the weldment is shown in Fig. 6 by taking average of three readings to avoid measured error. It is noted that the interlayer hardness between FZ and titanium HAZ is observed higher values whereas the interlayer between FZ and Al HAZ gives the lowest hardness values. In laser beam welding, a narrow HAZ is observed. As the welding speed is increased to 240 mm/min being the highest in the welding setup. Hardness is increased in between Ti interlayer and fusion zone due to thermal stresses. However in between fusion zone and HAZ Al, the hardness is reduced and is due to a low melting point of Al with higher metal deposition rate.

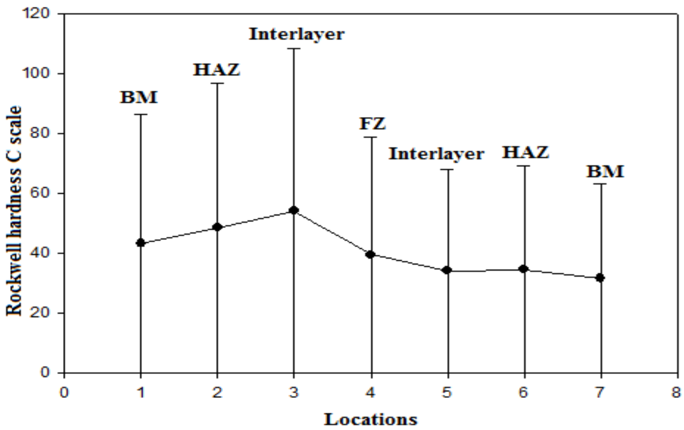

Fig. 6 Hardness distribution

3.5 Fracture morphology

Fracture is noted after the weld test coupon is subjected to the tensile test. The fracture surface of Ti/Al weldment in the macro level picture is shown in Fig. 7(a). The fracture cross section is observed by tilting at 90° and is shown in Fig. 7(b). It depicts similar fracture surface along Ti, and Al sheet surfaces after testing. It is evident that penetration of welding along the cross section is uniformly covered.

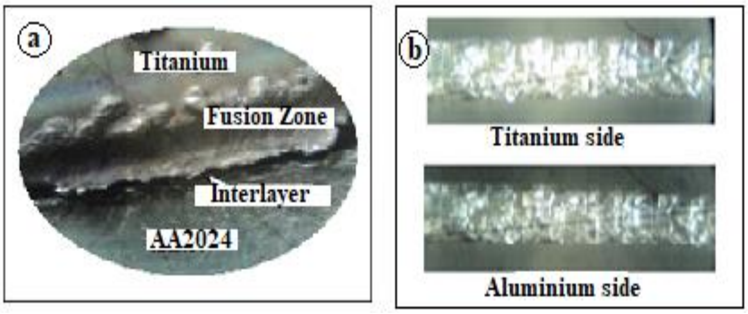

Fig. 7 Fracture surface (a) Al interlayer side (b) Ti side and Al side

Fracture is found in the interlayer zone between fusion zone and Al interface. As Al yield stress is much lower than titanium alloy, the fracture is found occurring in Al interlayer. Fig. 8(a) and (b) shows X 10,000 magnified micrographs of the fracture surfaces. From Ti surface, large numbers of dimples with different depth are observed as shown in Fig. 8(a). From Al surface regions, some cleavage planes with segregation are noted as shown in Fig. 8(b).

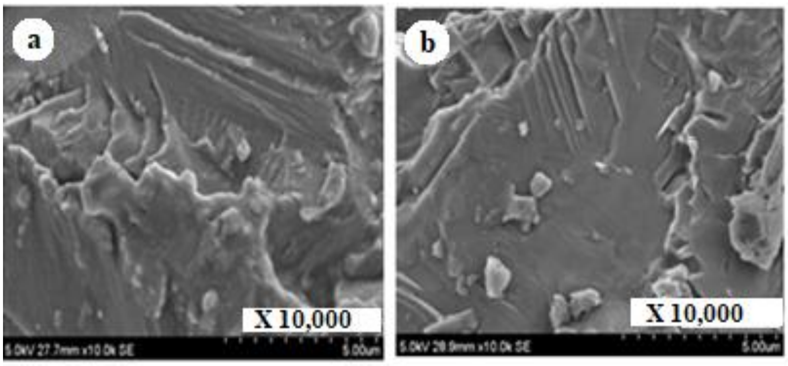

Fig. 8 Fracture surface (a) Ti surface (b) Al surface

SEM studies further reveal that the quasi-cleavage fracture with tearing ridges on the fracture surfaces of the joints is seen in Fig. 8. Hence, the fracture occurred along the weldment in tensile testing is a brittle one. The fracture occurs mainly in Al alloy interlayer instead of the middle of the weldment due to lower strength of Al alloy. It is advisable to perform bending or similar forming process away from weldment.

4. Conclusions

Based on test results, following are the conclusions:

• Ti/Al alloy thin sheets are butt welded using Nd: YAG Pulsed laser welding machine and no macro defects are found on the weldment.

• Hardness distribution studies on weldment indicate that the interlayer near Al side has a lower hardness than Ti side.

• Cross section morphology reveals that interlayer adjacent to aluminium side is weaker than titanium.

• SEM studies on fractured interlayer shows that brittle intermetallic compound leads to stepped segments with cleavage rupture.

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