Friction Stir Welding of Dissimilar Alloys of Titanium & Aluminum: A Review

PRADIP GUNAKI[1], DEVARAJ S[2], KARTHIK S[3]

[1]*Assistant Professor,* [2]*Professor,* [3]*Assistant Professor,*
School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India

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Abstract - *In this work, the current understanding and development of friction-stir welding of titanium and aluminum alloys are briefly reviewed. The critical issues of dissimilar alloys are addressed. A particular emphasis is given on the strength at welded part as compared to fusion welding process and other factors which affects the strength of dissimilar alloys of Ti & Al. This paper also explains about the effect of probe offset distance on the interfacial microstructure and mechanical properties of the welded joint and gives the information about the proper range of probe offset distance so that sound dissimilar joints are produced, which have comparatively high tensile strength and fracture. In this review it was observed that the hardness, tensile strength, appearance, interface macrograph of Ti and Al alloy of the welded part using friction stir welding.*

Key Words: *Intermetallic Compound, dissimilar alloys, density mechanical properties & Friction stir welding.*

1. INTRODUCTION

Materials with high specific strength are widely used in the field of automotive, aerospace and marine vehicle industries. In order to satisfies the requirements of these sectors Ti alloys plays very important role because of their low density, high corrosion resistance and specific strength. In some conditions, combination of Ti & Al are required such as improved strength, decreased mass and cost. Hence joining of the Ti alloys & Al alloys is a major problem to be solved in industries application. However it is not so easy to get sound weld of dissimilar alloys because of the major difference in their crystal microstructure, melting point, heat conductivity and performance. Using fusion welding process, Al content is severely lost at temperature below the melting point of Ti. The composition of the weld part is not symmetric & intermetallic compound. To solve this problem special welding methods have been incorporated to build sound joint between these dissimilar alloys. Friction stir welding (FSW) which is a solid-state welding process patented by the Welding Institute (TWI) in 1991 is a potential candidate for the joining of dissimilar materials due to its advantageous lower process over conventional fusion welding [1]. There are several studies on the FSW of Ti/Al dissimilar alloys at present in the world.

2. LITERATURE REVIEW

Chen Yu-hua et al. explained about Lap joints of Ti alloy and Al alloy dissimilar materials were fabricated with the help of friction stir welding and corresponding interface characteristics were investigated.. Considering the selected welding parameters, good surface appearance forms but the interface macrograph for each lap joint cross-section is different [1].

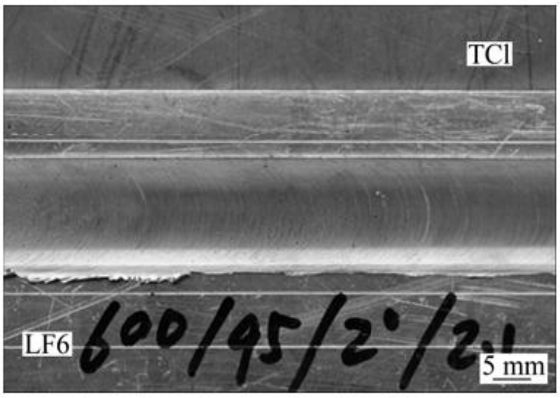

Fig-1: Surface appearance of Ti/Al dissimilar alloys lap joint prepared by FSW [1]

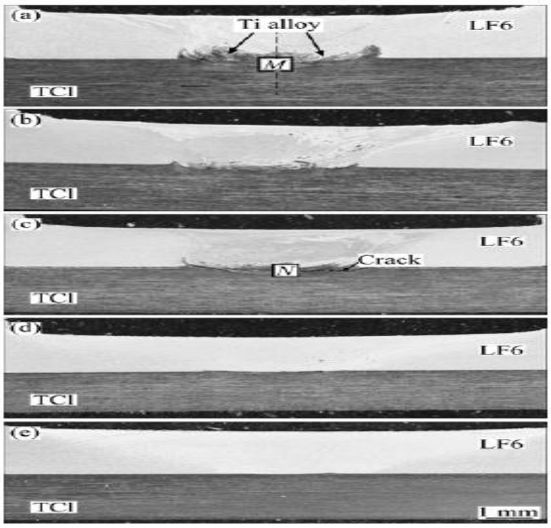

Fig-2: Interface macrographs of lap joint of Ti/Al dissimilar alloys [1]

The typical surface appearance of friction stir welded Ti/Al joints shown in figure 1 it can be seen clearly, the surface is smooth without any defects, indicating an excellent surface appearance in all samples and the interface macrographs for each lap joint cross-section are very different with respect to tool rotation rate & welding speed is which shown in figure 2. This paper gives the information about the failure load decreases with the increase of welding speed [1].

Masayuki Aonumaa and Kazuhiro Nakatab carried out the experiment on the effect of alloying elements on the microstructure of dissimilar joints of a Mg–Zn–Zr alloy (ZK60) and titanium by using FSW. They did investigation on the effect of alloying elements of ZK60 Mg–Zn–Zr alloy on the microstructure of the dissimilar joint interface. Zn and Zr of alloying elements formed a thin reaction layer with titanium at the joint interface by friction stir welding.

They concluded that Zn and Zr of alloying elements of Mg–Zn–Zr alloy improved the tensile strength of titanium and magnesium joints by forming the thin reaction layer at the joint interface during friction stir welding. Chemical compositions of titanium and Mg–Zn–Zr alloy is shown in the following table No1. Commercially used Mg–5.5 mass% Zn–0.57 mass% Zr alloy (ZK60) and 99.5 mass% magnesium (Mg) were joined to commercially used 99.5 mass% titanium (Ti) by FSW. In ZK60 alloy, Zn is soluble in magnesium, and Zr partly forms the compound with Zn.

Table.1: Chemical Composition of Base Metals [2]

Alloy	**Chemical Composition (Mass %)**					
	C	H	O	N	Fe	Ti
Ti	0.003	0.0022	0.079	0.004	0.070	Bal
	Chemical Composition (Mass %)					
	Zn	Zr	Mg	-	-	-
ZK60	5.5	0.57	Bal	-	-	-

The effect of alloying elements of ZK60 Mg–Zn–Zr alloy on the microstructure of the dissimilar joint interface with titanium and the joint strength in comparison with pure magnesium and titanium has been investigated. Zn and Zr of alloying elements formed a thin reaction layer with titanium at the joint interface by friction stir welding.

The tensile strengths of the Ti and ZK60 joints increased with increasing the probe offset and reached to 237 MPa, at 1.5 mm offset, which was 69% of that of ZK60 base metal, and much higher than that of Ti and Mg joint, 135 MPa the probe offset 1.5 mm, though, in the Ti and Mg joint, little change was observed in the tensile strength with increasing the travel speed [2].

Zhihua Song et al. Showed the effect of probe distance on the interfacial microstructure and mechanical properties of the butt joint. When the probe offset distance is high then formation of intermetallic compounds are formed at the joint interface and its adjacency, leading to fracturing roughly along the joint interface during a tensile test. They suggested the optimum range of range of probe offset distance results in sound dissimilar butt joints, which have comparatively high tensile strength and fracture strength [3].

Table.2: Chemical Composition of Base Metals [3]

Alloy	Chemical Composition (Mass %)								
	Ti	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**
A6061T6	0.02	Bal	0.63	0.29	0.27	0.07	1.00	0.17	0.001
	Chemical Composition (Mass %)								
	Ti	Al	Fe	V	C	O	N	H	
Ti6Al4V	Bal	6.2	0.13	3.93	0.023	0.12	0.003	0.002	

Table.2 explains about chemical composition of base metals of A6061T6 and Ti6Al4V with which different offset distance is to maintained and it is shown in table. no 3.

Table.3: Parameters for Dissimilar Butt-Welding of Ti6Al4V and A6061[3]

Particulars	Specification
Tool Material	WC-CO
Shoulder diameter	15
Probe diameter	6
Probe length	1.9
Axial Tool Force	7.5
Tool Rotation Speed	750, 1000
Welding Speed	120
Tilt Angle	3
Probe Edge Offset in to the Ti alloy	0,0.3, 0.6, 0.9, 1.2

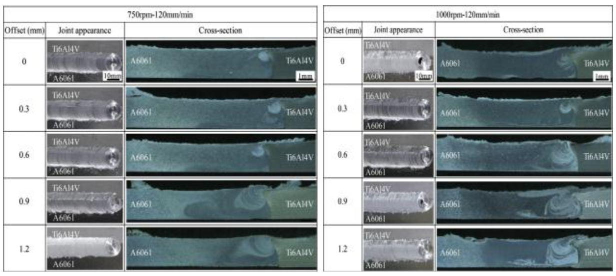

Fig.3: Surface appearance and cross-section macrostructure of joints with various probe offset distances [3].

The Strong weld joint between the Ti and Al alloys and appearance, cross-section macrostructure of Ti6Al4V/ A6061 FSW joints with various probe offset distances at 750 rpm and 1000 rpm are shown in Figure 3. The probe offset distance has a great influence on the formation of joint. At the rotation speed of 750 rpm, the titanium and aluminum plates are well bonded together at the upper part of the joint but no bonding or kissing bonding exists at the root part of the joint interface when probe offset distance is 0.6 mm or smaller. The two plates are soundly joined together when the offset is increased to 0.9–1.2 mm. With the rotation speed increased to 1000 rpm, the two plates are soundly joined together when the probe offset distance exceeds 0.6 mm. The hardness profiles of cross-section of the joints with 0.9 and 1.2 mm in probe offset distance and 1000 rpm in rotation speed is about 370 HV on the titanium alloy side. A sharp decrease to approximately 100 HV occurs at the interface of titanium and aluminum alloy. It is obsereved that the probe offset distance has a highly influence on the tensile strength of joints. When rotation speed is 750 rpm, the tensile strength of the joints with probe offset distance of 0.9 mm and 1.2 mm are 192 MPa and 193 MPa respectively [3].

Amlan Kar et al. conducted experiment on friction Stir Welding of aluminum (Al) to titanium (Ti) in presence of niobium (Nb), due to the presence of finer particles of niobium interlayer and significant improvement in the tensile ductility had been observed. The presence of Nb in the weld improves the microstructural evolution and tensile properties by reducing the formation of intermetallics. In this paper the FSW of Al to Ti with Nb interlayer has been characterized in detail. Elongation of Ti and Nb depends on the physical properties and morphology of these particles. The formation of NbTi.

Phase forms diffused interfaces and hence particles restricted the development of intermetallic brittle phase at the welded part. Aluminum with weld part forms inhomogeneous material flow and non uniform temperature distribution hence the hardness decreases from titanium side to aluminum because of the defects present around the Nb flakes.

Figure 04 explains about the variation of the hardness from Ti to Al. In the joining part of Ti & Al welded part the hardness decreases from Ti to Al where as the ductility property improves and in presence of Nb which helps to produce better appearance of welded part of alloy.

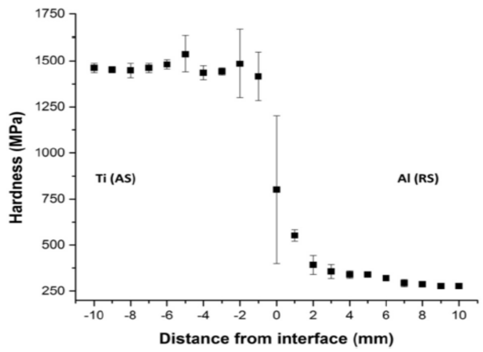

Fig.4: Hardness variations from Ti zone to Al zone [4]

Micro-hardness profiles were taken at 1.0mm intervals across the weld cross section at a distance of 1.5 mm, 2.0mm and 2.5mm from the bottom of the weld to obtain statistical distribution. Using Vickers indenter applying 200 g load for 10 s. The hardness of base Ti and base Al are 1432 HVN (Vickers hardness number) and 265 HVN respectively. FSW, being a high strain rate deformation process, at a welding temperature<500 °C, Ti was subjected to high deformation near the faying interface, and hence a slight increase in mean-hardness [4].

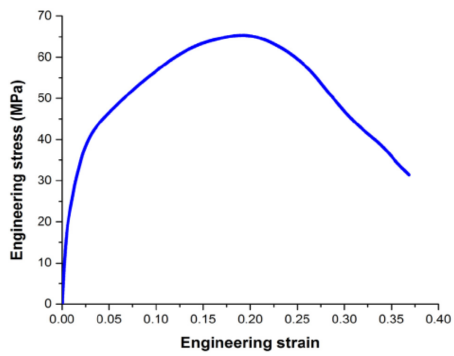

Fig.5: Engineering stress-strain graph of the weld. [4]

Figure 05 explains the about the ductility of the weld increases substantially than that of base material Al due to the presence of high fraction of fine particles in welded part. The weld exhibited poor tensile strength (UTS) but higher ductility compared to the base Al. The reduction in the UTS was due to the formation of defects around the Nb flakes present in the weld nugget.

3. SUMMARY OF LITERATURE REVIEW

As joining of Ti alloy and Al alloys welding is a challenge due to their difference in thermal conductivity, melting point, limited solid solubility and formation of brittle intermetallic phases which reduces the mechanical properties but this problem can be overcome by the help of friction stir welding with the combination of Ti and Al alloys in presence of Zr and Nb. And by proper maintaining the offset distance of the prob we can achieve sound joints and appearance at the welded part. The following observations are made during the literature review.

- Friction stir welding is suitable for lap jointing of TC1 Ti alloy and LF6 Al alloy dissimilar materials. An excellent surface appearance can be obtained easily.
- The interface macrograph of the lap joint crosssection at different parameters significantly changes. Accompanying with the increase of welding speed or the decrease of tool rotation rate.
- The failure loads of the lap joints decrease with the increase of welding speed. The largest failure load of the joint welded occurs at the tool rotation rate of 1500 r/min and welding speed of 60mm/min, in contrast to that of 0 at tool rotation rate of 1500 r/min and welding speed of 150mm/min.
- The probe offset distance has a influence on the interfacial microstructures and mechanical properties of joints. If the probe offset distance is optimum, sound dissimilar butt joints are produced, which have comparatively high tensile strength and fracture at HAZ of the aluminum alloy during a tensile test.

REFERENCES

[1] CHEN Yu-hua, NI Quan, KE Li-ming. 2012. Interface characteristic of friction stir welding lap joints of Ti/Al dissimilar alloys, Trans. Nonferrous Met. Soc. China 22, .299_304.

[2] Masayuki Aonumaa and Kazuhiro Nakatab, 2012. Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding, Materials Science and Engineering B 177,543– 548.

[3] Zhihua Song et al. 2014. Influence of probe offset distance on interfacial microstructure and mechanical properties of friction stir butt welded joint of Ti6Al4V and A6061 dissimilar alloys, Materials and Design 57, 269–278.

[4] Amlan Kara et al. 2018 Effect of niobium interlayer in dissimilar friction stir welding of aluminum to titanium, Materials Characterization 145, 402–412.

[5] Yanni Weia et al. 2012. Joining aluminum to titanium alloy by friction stir lap welding with cutting pin", Material Characterization 7 1, 1 – 5.

[6] Yu Zhang et al. 2008. Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds, Materials Science and Engineering A 485, 448–455.

[7] L. Zhou et al. 2010. Effect of rotation speed on microstructure and mechanical properties of Ti–6Al–4V friction stir welded joints, Materials and Design 31, 2631–2636.

[8] M. Esmaily et al. 2013. Microstructural characterization and formation of a0 martensite phase in Ti–6Al–4V alloy butt joints produced by friction stir and gas tungsten arc welding processes, Materials and Design 47 (2013), 143–150.

[9] A. Farias, et al. 2013. Tool wear evaluations in friction stir processing of commercial titanium Ti–6Al–4V, Wear 302, 1327–1333.

[10] S.D. Ji et al. 2014. Formation and mechanical properties of stationary shoulder friction stir welded 6005A-T6 aluminum alloy, Materials and Design 62, 113–117.

[11] Shuhan Li et al. 2019. Interfacial microstructures and mechanical properties of dissimilar titanium alloy and steel friction stir butt-welds, Journal of Manufacturing Processes 40, 160–168.