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Experimental investigation of Ti−6Al−4V titanium alloy and 304L stainless steel friction welded with copper interlayer

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Abstract

The basic principle of friction welding is intermetallic bonding at the stage of super plasticity attained with self-generating heat due to friction and finishing at upset pressure. Now the dissimilar metal joints are especially popular in defense, aerospace, automobile, bio-medical, refinery and nuclear engineerings. In friction welding, some special alloys with dual phase are not joined successfully due to poor bonding strength. The alloy surfaces after bonding also have metallurgical changes in the line of interfacing. The reported research work in this area is scanty. Although the sound weld zone of direct bonding between Ti−6Al−4V and SS304L was obtained though many trials, the joint was not successful. In this paper, the friction welding characteristics between Ti−6Al−4V and SS304L into which pure oxygen free copper (OFC) was introduced as interlayer were investigated. Box−Behnken design was used to minimize the number of experiments to be performed. The weld joint was analyzed for its mechanical strength. The highest tensile strength between Ti−6Al−4V and SS304L between which pure copper was used as insert metal was acquired. Micro-structural analysis and elemental analysis were carried out by EDS, and the formation of intermetallic compound at the interface was identified by XRD analysis.

Keywords: Friction welding; Ti−6Al−4V; SS304L; Oxygen free copper; Interlayer; Microstructure; Interface

1. Introduction

Friction welding (FW) is a solid-state joining technique, by which significant heat is generated on the faying surfaces of two components under a certain combination of pressure, time, speed and surface roughness of weld face. Heat is generated by the friction which softens the materials to be joined before deforming them plastically. After an interfacial region is plasticized, a metallurgical bond is finally formed under the action of axial forging force instantly due to relative movement. In this process, the plastic deformation in the weld zone results in grain refinement, in a flow line orientation the impurities are pumped out to the outer region and the whole process is finished in few seconds [1]. Ti alloy is more expensive than other materials, but due to its higher strength and better mechanical properties it has attracted attention and introduction of Ti alloy has spurred interest. The forged aluminum used to manufacture the commander's hatch in a fighting vehicle has been replaced with forged titanium with a weight saving of 35% and with a great improvement of ballistic protection. Other components, such as torsion bar, lightweight armor, road arm, support arm, road wheel, and gear housing, in the battle tank were made of high-strength beta titanium alloys by friction welding [2]. Ti helium vessel must be joined to a stainless steel in cryogenic plumbing system [3]. Ti and stainless steel have been widely applied for nuclear industry pipe lines and accessories in oil rig. Steel−titanium coupling is used in biomedical applications like dental implants and articulation replacement. Ti alloy and

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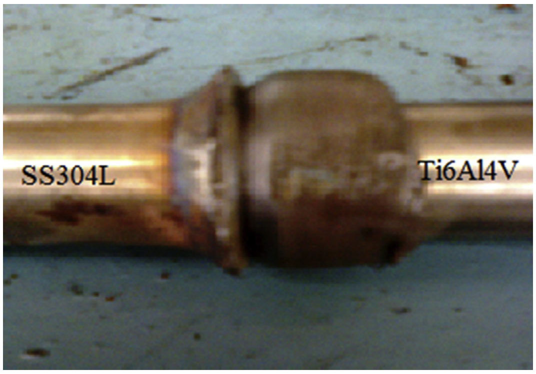

Fig. 1. Ti–6AL–4V and SS 304L without interlayer.

stainless steel are used to weld aircraft engine blades (titanium), discs (stainless steel), and aero engine casing with high service temperature [4,5].

In advanced engineering and technology the process steps and process materials are more efficient to meet the industrial demands with the optimized condition [6,7]. Friction welding is vastly attractive for joining difficult-to-weld and high performance dissimilar alloys. Ti alloy and stainless steel without interlayer was initially fabricated at constant speed, and other FW parameters were varied. Even though the findings are moderate in mechanical and metallurgical evaluation, the failure happened in the weld zone due to insufficient heating in stainless steel side and the formation of martensitic structure (Fig. 1 and Fig. 2) [8]. Ti–6Al–4V with interlayer of Ni, WC, Nb in the form of foil was studied. This joint performs well in the case of multiple layer of material foils and fails when a single foil is used, as it is peeled from the interfacial region due to high friction pressure [9]. To overcome this difficulty, a pure titanium and stainless steel joint was attempted with an interlayer of copper and nickel which yielded good bonding strength. The same materials were investigated with the intermediate materials of nickel, vanadium and tantalum in between the dissimilar base metals and nickel retained the bonding than other materials [10,11]. Maraging steel friction welded with low alloy steel by using solid nickel as an

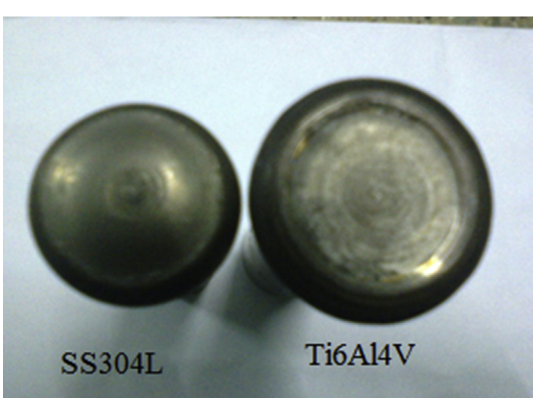

Fig. 2. Failed joint without interlayer subjected to drop test.

Table 1
Chemical composition of materials under study.

Material	Elements (wt. %)									
SS304L	C	Si	Mn	P	S	Cr	Mo	Ni	N	Fe
	0.030	0.36	1.58	0.03	0.02	18.37	0.13	8.28	0.03	Bal.
	Elements (wt. %)									
Ti–6Al–4V	C		Ni		Al	V			Fe	Ti
	0.030		0.01		6.33	4.32			0.05	Bal.
	Elements (wt. %)									
OFC	Ni	P					Sn	Zn		Cu
	0.075	0.007					0.021	0.014		Bal.

interlayer after post weld heat treatment was evaluated by mechanical and metallurgical analysis. In this process Ni acted as an effective diffusion barrier between the parent materials and avoided carbon migration in weld region [12]. The friction welding of incompatible materials and the feasibility of the method were experimented for different material combinations of brass/copper, bronze/steel and titanium/nickel with suitable third metal interlayer. With careful experimental analysis, the joint efficiency was increased by 40% [13,14]. The effects of friction welding parameters and heat treatment on nickel alloy joints were established and the best results were obtained [15]. Friction welding of austenitic stainless steel and copper was experimentally investigated with various parameters through Taguchi orthogonal array, and the outcomes were evaluated for its joint strength. It concluded that more friction pressure with low upset pressure increases the tensile strength [16]. Friction welding of pure titanium and pure copper was established and the performances of joints were analyzed. Due to higher purity of copper, the bonding strength in the faying surfaces was tremendously increased by selecting the optimum parameter and fine surface finish [17]. TiAl alloy casting and AISI4140 commercial steel rod were fabricated by friction welding with pure copper as intermediate material. From the evaluations it was found that the direct bonding let to crack through interface due to brittle reaction; but in case of copper interlayer the joint was free from defects. Considering the above literature studies, Ti–6Al–4V and SS304L were friction welded with oxygen-free copper (OFC) as an interlayer. The reason for choosing OFC as an interlayer material is that it has higher ductility, higher linear expansion coefficient and minimizes the residual stresses near the bonding surfaces. The heat-affected zone (HAZ) on stainless steel side is minimized by the reduction of brittle martensitic phase during thermal cycle, showing higher weldability of stainless steel and Ti alloy. Moreover, the pure copper has high thermal conductivity; it can transfer the weld heat from the interface. It can minimize the width of heat-affected zone on the stainless steel side, such

Table 2
Mechanical properties of base metal.

Material	Yield strength/Mpa	Ultimate tensile strength/Mpa	Hardness HV	Elongation/%
Ti–6Al–4V	880	950	349	15
SS304L	200	550	213	45
OFC	69	221	75	40