

ABSTRACT

Titanium alloys are joined to nickel alloys for applications in aerospace engines. Titanium alloys are joined to stainless steels for nuclear applications. Conventional fusion welding is not a feasible technique to join these kinds of dissimilar joints due to the formation of chemical, mechanical and structural heterogeneities. Solid state joining is a suitable alternate to overcome the difficulties.

Diffusion bonding gives a sound bond without any macroscopic deformation because it involves only inter-atomic diffusion of atoms across the interface between the two metals being bonded. Energy required for the movement of atoms depends on the applied stress and temperature. One important advantage of the diffusion bonding is that the individual characteristics of the base materials are retained after bonding, except probably at the interface.

Friction welding is a solid state welding process that produces a weld under a compressive contact stress between the work pieces while rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces. When a suitable high temperature

has been reached, rotational motion ceases, additional stress is applied and coalescence occurs. The short duration is the main advantage of friction welding process.

The main purpose of the present study is to investigate and compare the characteristics of dissimilar joining of Ti-6Al-4V with Inconel 718 and Ti-6Al-4V with SS 304L using diffusion bonding and friction welding processes. The investigation is done by making dissimilar joints of the two combinations of materials by the two solid state welding processes, for varied combination of the key parameters of the processes. For the diffusion bonding, temperature, stress and time are the key parameters. For friction welding, rotational speed, upset load, friction load and burn-off-length are the key parameters. An attempt is also made to study the use of an interlayer, between the two materials to be joined, in improving the bond quality. The study will also investigate the suitability of ultrasonic C-scan, a nondestructive testing method for diffusion bonded and friction welded industrial components.

The scope of the work includes making of dissimilar joints with each of the two chosen solid state processes by varying the key process parameters, characterising the joints by various methods and relating the parameters with bond characteristics. The characterization tests include ultrasonic C-scan analysis, optical microscopy, SEM-EDS and hardness

survey. Since formation of intermetallic compounds is usually an important cause deteriorating the bond quality in dissimilar joints, an attempt is made to find out the presence of intermetallics formed. An attempt is also made to avoid these intermetallics by using appropriate interlayer material in between the metals to be joined.

Diffusion bonding experiments for the two combinations of joints namely (i) Ti-6Al-4V with Inconel 718 and (ii) Ti-6Al-4V with SS 304L were carried out by varying the temperature from 800 to 900°C, stress from 20 to 30 MPa and time from 1 to 3 hours. Friction welding experiments for the above said combinations of joints were carried out by varying the rotational speed (RS) from 800 to 1800 rpm, upset load (UL) from 5 to 10 ton and friction load (FL) from 2 to 5 ton. A few experiments on diffusion bonding and friction welding were also attempted with the use of suitable interlayer materials.

A maximum joint efficiency of 45.9% was obtained in the case of diffusion bonded Ti-6Al-4V - Inconel 718 joint obtained at the temperature of 850°C, stress of 20 MPa and time of 2 hours. It was 64.4% for the diffusion bonded Ti-6Al-4V - SS 304L joint obtained at the temperature of 800°C, stress of 20 MPa and time of 3 hours.

The optimised process parameters for friction welding of Ti-6Al-4V - Inconel 718 joints are rotational speed of 1000 rpm, upset load of 6 ton, friction load of 2 ton for which the joint efficiency obtained was 28%. The same for friction welding of Ti-6Al-4V - SS304L joints are rotational speed of 1500 rpm, upset load of 6 ton and friction load of 4 ton for which the joint efficiency obtained was 70%.

The results of ultrasonic C-scan analyses on diffusion bonded joints of the two material combinations are in good correlation with their joint efficiency, whereas, no useful information is obtained from the results of ultrasonic C-scan analyses on friction welded joints as the interface region in friction welded joints is not flat and parallel to the top surface. The results of SEM-EDS analyses on diffusion bonded joints and friction welded joints of the two material combinations are in good correlation with the transverse hardness survey carried out at their joint interface.