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EXAMINATION OF WELDING PARAMETERS FOR STRENGTH ANALYSIS IN FRICTION WELDING

Praveen R[1], Rajasekaran T[2], Rajkumar S[3] and Balasubramanian V[4]

[1,2]School of Mechanical Engineering, SRM University, Kattankulathur, 603203, Tamilnadu, India.
[3,4]CEMAJOR, Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar, 608002 Tamil Nadu, India

ABSTRACT

Friction welding is one of the higher state, economical, highly productive method used to join different metallic materials. Advantages of this welding are low production time, high material save. It is also possible to join circular as well as rectangular cross sections. In friction welding joining occurs below the melting temperature of the work piece. The dissimilar metal joint of Titanium and 304 Stainless Steel is essential in the nuclear industry for the dissolution of spent fuel that is carried out boiling nitric acid in the dissolved solution. Welding dissimilar materials makes use of advantages of different materials to unique solutions, like combination of good mechanical properties such as specific weight, corrosion resistance etc.

In this project, Friction welding is carried out on two dissimilar materials such as 304 Stainless Steel and Titanium grade 5. Welding is carried out by varying different parameters such as spindle speed, upset pressure, upset time and subjected to mechanical testing such as tensile and hardness to study the effect of welding parameters. Further microstructure of the flash is examined through optical microscope.

Keywords: *Austenitic, Titanium, Friction welding, Tensile test and Microstructure.*

1. Introduction

In friction welding, heat for welding is produced by relative motion of the two surfaces being joined, and under normal conditions no interfacial melting occurs. The friction welding process is well understood and has been used extensively for joining similar and dissimilar metals in commercial scale since 1940s. There are three variants of friction welding process, i.e., rotary, linear and orbital. Rotary friction welding can be used only for circular cross section and in this process one component is rotated about its axis while the other remains stationary with simultaneous application of pressure for joining. Based on the manner by which rotational energy is transferred to make the weld, rotary friction welding is further divided into two classes: direct drive (continuous drive) and inertia drive (stored energy). Direct drive friction welding uses a motor running at constant speed while inertia drive uses the kinetic energy stored in a rotating flywheel to input energy to the joint during friction stage [1]. In the case of linear friction welding, one part is stationary and another part moves in a reciprocating fashion under friction pressure through a small linear displacement [2]. Linear friction welding has become a key manufacturing and repair technology for aero-engine blisks in the aeronautical engine manufacturing. Orbital friction welding is a combination of linear and rotational friction welding where the two parts to be joined are rotated around their longitudinal axes in the same constant angular speed. Here the two longitudinal axes are parallel but with a small linear distance offset. When motion of the components stops, the parts need to be correctly aligned to form a weld. Linear and orbital friction welding can weld noncircular parts and the heat generation is almostuniform throughout the joint cross section unlike rotary friction welding. However, the rotary friction welding which is oldest is still the most popular method [6].

Since friction welding is a well-established solid state joining process and it is being used successfully for joining Ti–304 SS combination as reported above, therefore in the present study, as a first step, friction welding was attempted for joining Ti to 304 SS required for nuclear fuel reprocessing plant. The joints were evaluated for their mechanical properties using tensile tests and guided bend tests. Micro hardness measurements and optical microscopy were carried out across the weld interface to identify the different zones formed during welding. SEM studies were also carried out to investigate the inter-diffusion of elements acrossthe weld interface. The fracture surfaces were observed in SEM to determine the failure modes of the joints. The Ti/304 SS joints were also subjected to post-weld heat treatment (PWHT) to study its effect on ductility of the joint [3].

The friction welding has a lot of advantages: easy control of welding parameters, excellent efficiency

**Corresponding Author - E- mail: rajasekaran2k@gmail.com*

of work, low energy consumption for joining, and higher welding exactness than arc welding. It is used to steering shaft, tulip shaft, aluminium guide roller, and track roller, gear coupling body, flange gear, and engine valve in automobile industry [4]. The friction-welded exhaust valve of internal combustion engine is operated under repeated load functionally, the fatigue strength and weld ability as well as heat-resistance, anti-corrosiveness, and anti-abrasion are simultaneously and specially required for utilize those friction-welded components of heat resisting [5].

2. Experimental Procedure

The chemical compositions and mechanical properties of the Ti and 304 SS rods used are given in Tables 1 and 2, respectively. As stated above, the main welding variables in direct drive friction welding are friction pressure, upset pressure, burn-off length (reduction in axial dimension), upset time and spindle rotation speed. Friction time is an alternative parameter to burn-off length, which is used by few friction welding machine manufacturers.

Table 1: Chemical composition of Ti and 304 SS rods used

Ti grade5	Al	Fe	C	V	N	Ti
	5.710	0.16	0.05	3.720	-	Balance
304SS	Ni	Cr	Mn	C	Si	Fe
	8.7	18.95	1.18	0.028	0.042	Balance

Table 2: Mechanical properties of Ti and 304 SS used

Elements	YS (MPa)	UTS (MPa)	% Elongation	Hardness (VHN)
Ti grade 5	552	599	29	345
304 SS	473	780	47	250

Friction welding was carried out in a direct drive friction welding machine shown in Fig. 1 of 20 KN capacities. In this machine, the axial force is applied by hydraulic cylinder. Load cell is used to measure the axial force onthe job and it is controlled in a closed loop by means of hydraulic servo valve.

The spindle is driven by an AC spindle motor and can be rapidly broken by line-regenerative braking. With regenerative braking system, the braking of the spindle puts the electric motor to run in reverse direction and the motor acts as an electric generator and converts the kinetic energy into electrical energy at a voltage slightly higher than the bus voltage and the energy will flow back to the system. Thus, without burning off the energy in the resistors it is usefully employed. All important parameters like axial thrust, spindle speed, loss of length, and spindle torque are read and plotted on-line during welding [7].

For the experimental trials, Ti and 304 SS rods used have different faying surface diameters of 16 mm, with each of them being of 75 mm length. Prior to friction welding, the mating surfaces of Ti and 304 SS were surface finished down to roughness of 0.7 and 0.3_m, respectively. During welding, the 304 SS rod was kept stationary and Ti was made to revolve. Among the friction welding parameters, different combinations of friction pressure and burn-off length were used Table 3.

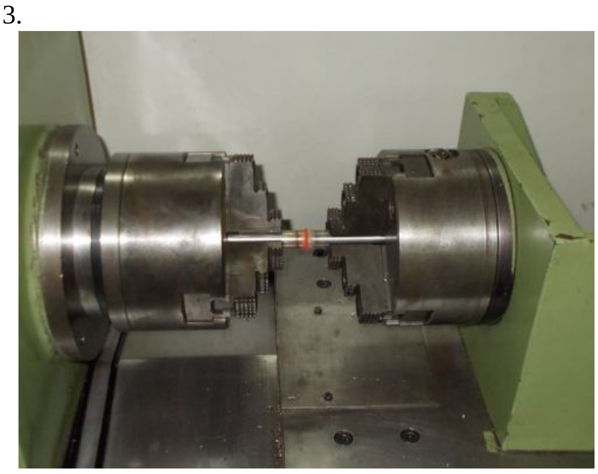

Fig. 1 Friction welding machine-flash formation

Table 3: Friction welding parameters used

Friction pressure MPa	Friction time sec	Forging pressure MPa	Forging time sec	Spindle speed rpm
80	6	80	6	2100

Fig. 2 Friction weld joint

In nuclear industries, the requirements of this Ti to 304 SS dissimilar joints are in pipe geometry and hence all mechanical tests were carried out in pipe geometry. For tensile testing, pipes were machined out from the welded rods. The outer diameter of the pipe was 14mmand inner diameter was 8mm, i.e., with wall thickness of 3mm. The tensile tests were carried out in pipe geometry as per ASME Section IX requirements. The friction welding parameters were optimized so as to obtain optimum tensile properties [8].

3. Result and Discussion

3.1 Mechanical tests

The friction welded joint between Ti and 304 SS reveals the formation of flash (Fig. 2) that is a typical characteristic of friction welded joints. The flash contains predominantly Ti, which is due to the relatively lower flow stress of Ti at higher temperature compared to that of 304 SS. At higher temperature, Ti undergoes allotropic transformation at 1155K from hexagonal close packed alpha phase to low strength body centred cubic _ phase and experienced major deformation. The heat generated by friction welding process makes Ti softer and it starts flowing as a flash variation of yield strength of Ti and SS with temperature.

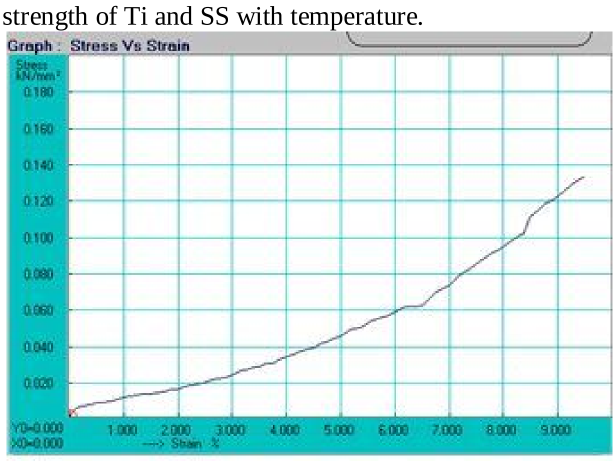

Fig. 3 Tensile tested weld sample Ti and SS

Table 4: Mechanical properties

	YS (MPa)	UTS (MPa)	% Elongation	Hardness (VHN)
Ti grade5 and 304SS	78	134	9.1	288

Table 4 shows the variation in the ultimate tensile strength (UTS) of the joint and the fracture locations for various combinations of friction welding pressure and burn-off length. The weld joints made with 100MPa friction pressure and 1mm burn-off length failed in weldment.

3.2 Microstructure analysis

Fig.4. Optical micrograph of Titanium base material

Magnification 150X & 250X
Etchant: Kroll's Reagent Soln.

Fig. 4 shows the microstructure of the Titanium alloy which is alpha and beta alloy. The microstructure shows fine alpha grains and beta acicular grains showing that they have been normalized. Fig 4 shows the microstructure of titanium alloy. The higher magnification has resolved the alpha grain and the beta grain considerably. The alpha grains are acicular and the alpha grain is at the grain boundaries of beta grains which are black in color.

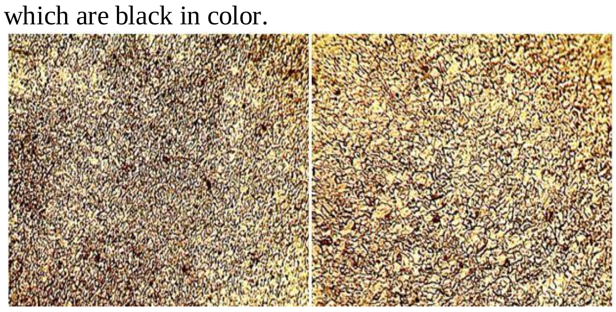

Fig. 5 Optical micrograph of 304 SS

Magnification 150X & 250X
Etchant: Aqua Regia Soln.

Fig. 5 shows the austenite grain that is very fine throughout h matrix of the wrought 304 grade austenitic stain less steel. The higher magnification is observed for the Stainless Steel metal matrix. The grain of austenite is resolved and the grain boundaries are clearly visible. The grain boundaries and the matrix are free from carbide precipitation.

Fig. 6 shows the zone where both the metal are in close proximity but lack fusion. Clear surface of separation is observed.

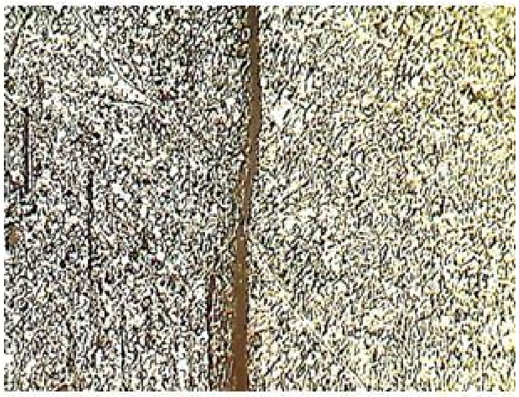

Fig. 6 Optical micrograph of Ti and S.S interface

The microstructure of the titanium is elongated alpha and beta grain along the direction of the flow.

3.3 Micro hardness test

The micro hardness (VHN) test was performed on the etched transverse cross-section of the weld zone using a load of 0.5 kg, which was applied for duration of 20 s. five measurements in each weld zone. The hardness values were measured 0.2 mm below the upper surface and the 0.2 mm above the lower surface.

Table 5.Hardness in the weld

Distance in mm	VHN in 0.5 kg load
0.2-1.0	260
1.0-2.0	262
2.0-3.0	231
3.0-4.0	357

3.4 Macrostructure analysis

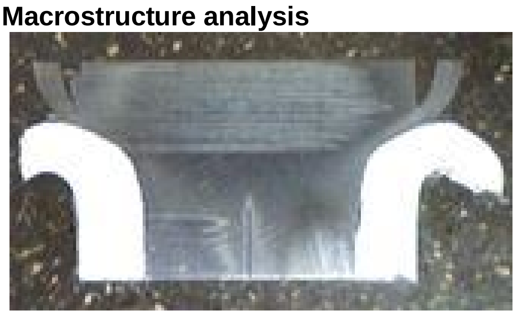

Fig 7. Macro graph of Ti and 304 SS

Fig. 7 shows the macro-photo of the joint. It was observed that the obvious upset collars (flashes) were formed around the weld interface on both the sides. The weld bandwidth was found to be very narrow in all welds.

4. Conclusions

1. Friction welding parameters were optimized to produce joints that are stronger than the Ti base material as confirmed by tensile tests, and tensile failure occurred in the weld region.

2. The weld metal hardness values are higher than the base metal. This is due to considerable differences in the Ti-SS proportion in all weld zones. The increase of the hardness in the weld zone depends on the grain sizes of Ti and SS phases in the weld.

3. Shows the characteristic grain flow of the titanium alloy which has showed good ductility and plastic flow at the friction zone. The direction of the flow of the grain has changed normal to the up-set pressure applied. The grains have elongated due to the deformation at high temperature.

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