Corrosion Resistant Dissimilar Joints between AISI Type 304L SS and Titanium

■ EXECUTIVE SUMMARY

To link titanium and zirconium metal based (Ti, Zr-2, Ti–5%Ta, Ti–5%Ta–1.8Nb) dissolver vessels containing highly radioactive and concentrated corrosive nitric acid solution to other nuclear fuel reprocessing plant components made of AISI type 304L stainless steel (SS), high integrity and corrosion resistant dissimilar joints between them are necessary. Fusion welding processes produce secondary precipitates which dissolve in nitric acid, and hence solid-state processes are proposed. Among various dissimilar joining processes available for producing titanium-304L SS joints with adequate strength, ductility and corrosion resistance, explosive joining has been found to produce corrosion resistant joints with acceptable corrosion rates and bend ductility. Based on the results, dissimilar joint produced by the explosive joining process was adopted for CORAL plant application.

■ OUTLINE

The fabrication and qualification of DMW joint between titanium and AISI type 304L SS is crucial in the reprocessing plant especially because of zero failure requirements due to corrosion. Fusion welding processes produce secondary precipitates which dissolve in nitric acid and hence, solid-state processes are proposed for joining titanium and AISI type 304L. In Japanese reprocessing plants, both explosive bonded and diffusion bonded sections are used. A direct bonding between titanium and type 304L could be achieved by vacuum diffusion bonding with the pre-cleaning of the surfaces using ion sputtering. High corrosion resistance in severely corrosive nitric acid with adequate mechanical strength and bend ductility are the minimum requirements for this purpose. Solid-state welding processes, viz. explosive bonding, diffusion bonding and friction welding were considered for fabricating this DMW joint to achieve adequate mechanical properties and corrosion resistance. The friction-welded and explosive-bonded pipe joints were subjected to detailed investigations including non-destructive examinations such as liquid penetrant, radiography and ultrasonic testing. The joints passed all the NDT tests as per the acceptance standards (Table 1).

The explosive bonding process produces a bonding by high velocity impact of the work pieces caused by a controlled explosion/detonation. The bonding is produced within a fraction of a second. The important interrelated variables in explosive bonding are (1) collision velocity (2000–5000 m/s), (2) collision angle (3) flyer plate velocity and (4) nature of explosive. Smooth surface finish of titanium and type 304L SS are obtained in order to create a better interface after explosive joining operation. The cladded plate was subjected to a stress-relieving heat treatment at 540°C for 1.5 h.

Three-phase corrosion tests were conducted in 11.5 N boiling nitric acid for both friction welded and explosive-bonded pipe joints. It was observed that for both the joints, the corrosion rate in the condensate phase is markedly higher than in the liquid and vapour phases. Detailed optical and scanning electron microscopy examinations of the specimens exposed to the condensate phase indicated severe corrosion attack of the friction-welded joints with wide opening at the interface (Fig. 1(a) and (b)). In the case of the explosively welded joint, the interface was free from corrosion, but corrosion attack at the 'vortex' region of the AISI type 304 L SS was noticed. In general, the average corrosion rate of the friction-welded joint in vapour and condensate phases was marginally lower than the explosively welded joint. The corrosion rate of the friction-welded joint could be attributed to the selective loss of material at the 'trench' formed at the joint interface, an unacceptable situation for structural integrity considerations. Thus, explosively welded joints showed better performance as compared to friction-welded joints from corrosion point of view.

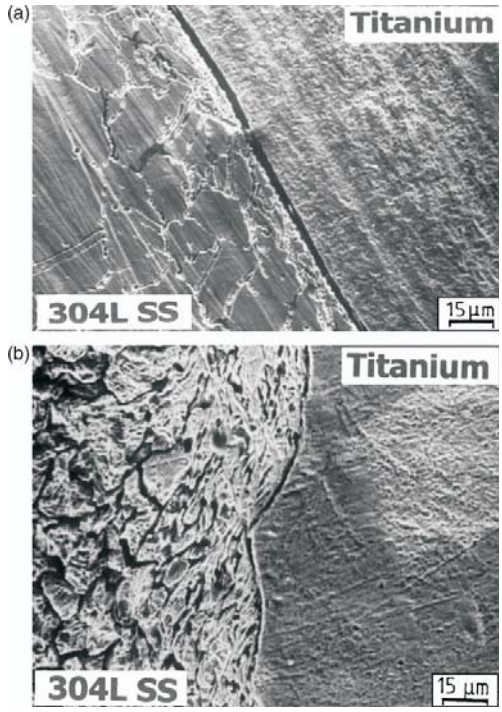

Fig. 1: SEM micrographs showing severe corrosion attack of the friction-welded joint (a) with wide opening at the interface compared to (b) smooth interface of explosive joint

Table 1
Results of Non-destructive, mechanical and Corrosion Tests

Tests	Friction welded joint		Explosive bonded joint	
Non-destructive tests				
Liquid penetrant test	Passed		Passed	
Radiography	Passed		Passed	
Ultrasonic test	Passed		Passed	
Mechanical tests	***Test 1***	***Test 2***	***Test 1***	***Test 2***
Tensile tests				
Ultimate tensile streangth (MPa)	462	495	397	457
% Elongation	Negligible	Negligible	21.4	19.7
Bend tests				
Root bend (bend angle at failure)	<5°	<5°	60°	76°
Face bend (bend angle at failure)	<5°	<5°	80°	106°
Three-phase corrosion tests				
Liquid phase (avg. corrosion rate) (mpy)	0.48		0.44	
Vapour phase (avg. corrosion rate) (mpy)	0.72		1.5	
Condensate phase (avg. corrosion rate) (mpy)	10.07		12.03	

■ ADDITIONAL INFORMATION

A methodology was evolved for the erection of titanium dissolver equipment in containment box of the cell made of AISI type 304L SS as titanium cannot be welded directly to AISI type 304L SS. The welding of titanium equipment to stainless steel by appropriate design was a preferred one instead of mechanical fastening. A 6 mm Ti Grade 1 plate was clad with 12 mm 304L SS plate, and then it was machined and welded to the top flanges of the dissolver. It was essential that while welding the clad-ring to the dissolver flange at the bottom, it must be welded segment by segment (Fig. 2). In addition, cooling the welded segment to room temperature was practiced, in order to avoid over heating of the clad portion which other wise may lead to opening up of the bonded area.

■ GENERAL EXPLANATION RELATED TO THE DESCRIPTION

For fast reactor reprocessing plant facilities, titanium has been used for fabricating dissolver vessel in CORAL plant. The dissolver needs to be connected to the rest of the process vessels and piping made of AISI type 304L stainless steel. The fabrication and qualification of this dissimilar metal weld joint is crucial in the reprocessing plant. High integrity dissimilar joints with adequate corrosion resistance, mechanical strength and bend ductility are essential for uninterrupted operation of reprocessing plants. Several dissimilar joints were made by advanced fusion welding methods as they produce joints with poor corrosion resistance. Dissimilar joints of titanium to 304L SS prepared by solid state joining processes were considered as the best option. Commonly employed dissimilar joining processes are roll bonding, pressure welding, explosive welding, and diffusion bonding. Since no melting occurs at the interface, secondary precipitates are not formed by these processes and hence the corrosion resistance is not affected significantly during service. Development of dissimilar joints between titanium and stainless steel thus has been achieved by explosive joining processes with acceptable corrosion resistance.

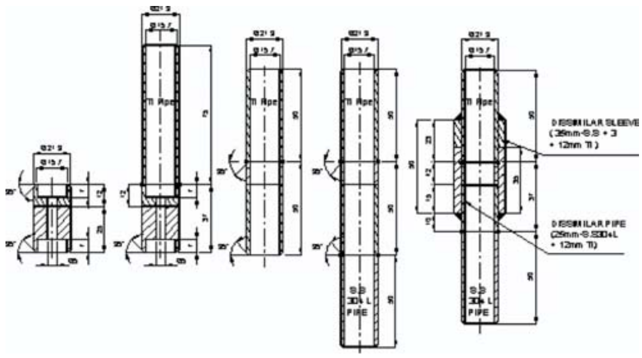

Fig. 2 : Design sequence of the dissimilar joining of titanium and type 304L SS

■ BRIEF DESCRIPTION OF THEORETICAL BACKGROUND

Dissimilar joints of titanium to 304L SS prepared by solid state joining processes are considered as the best option to provide good corrosion resistance. Commonly employed dissimilar joining processes are roll bonding, pressure welding, explosive welding, and diffusion bonding. Since no melting occurs at the interface, secondary precipitates are not formed by these processes and hence the corrosion resistance is not affected significantly during service. Thus explosive joining was considered as the best option based on mechanical, NDT and corrosion testing parameters to link between titanium and AISI Type 304L stainless steel.

■ ACHIEVEMENT

Corrosion resistant dissimilar joints of titanium and AISI type 304L stainless steel has been achieved for application in CORAL reprocessing plant through systematic R&D studies on corrosion and mechanical properties. The explosive joining parameters were initially established for optimising the micro-structural and corrosion aspects of the joints. A design sequence was achieved for plant applications.

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