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Fusion welding studies using laser on Ti–SS dissimilar combination

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ABSTRACT

Laser welding investigations were carried out on dissimilar Ti–SS combination. The study is aimed to improve the weld strength and ductility by minimizing harmful intermetallics and taking advantage of high cooling rates in laser welding. Results of continuous wave 3.5 kW CO_2 laser welding of totally dissimilar combination of Titanium and stainless steel (304) have been discussed. Bead on plate welding experiments were conducted to identify the laser welding parameters using depth of penetration as criteria. The welding of dissimilar combination has been attempted both autogenously and with interlayers such as Vanadium (V) and Tantalum (Ta) in the form of laser cladding as well as strip. Autogenous welds were carried out by varying the laser power, welding speed and position of the laser beam with respect to the joint centre. The resultant welds are characterized by macrostructure analysis, SEM/EDAX and XRD and as welded tensile test in UTM. The autogenous welds have exhibited extensive cracking even when welded at high speeds or by manipulating the beam position with respect to the joint. Similarly Vandaium as interlayer could not achieve crack free joint. A joint with 40 MPa strength could be made with Ta as interlayer. Results and analysis of these variants of laser welded joints are reported and discussed.

1. Introduction

Joining of dissimilar materials finds applications in variety of fields such as thermal power station, nuclear industries, petrochemical industries, cryogenic vessels, micro electronics, medical, etc. due to the need to tailor the location of materials according to design/performance. However, the difference in thermo physical properties of materials being joined can increase the residual stress on one side of the joint making the heat affected zone (HAZ) of low expansion material weaker and the difference in chemistry can lead to formation of brittle intermetallic phases.

The difficulty in joining increases with increase in dissimilarity. For example, the boiler heat exchanger tubes require joining of austenitic to ferritic grade of steels. The materials are not differing in chemistry and metallurgy much but there are thermal properties mismatch which can result in cracking during high temperature service. Similarly, there are applications requiring totally different materials to be joined like Al–Steel, Titanium–stainless steel, etc. for variety of applications which differ both in metallurgy and thermo physical properties. One such dissimilar combination of Ti–SS is applied in nuclear industries, cryogenic vessels, etc. Fusion welding of this totally dissimilar combination will require careful considerations of the difference in properties. However, it is understood that if the size of the intermetallics can be maintained below 10 μm [1,2], the intermetallics will not embrittle the weld. Such a control in size should be feasible with processes which give high cooling rates.

Wang et al. [3] studied the feasibility of electron beam welding of TA15 Ti alloy to SS using a Cu interlayer. They have found that with dual pass electron beam welding with first welding between Ti and Cu sheet and second welding between Cu and SS sheet, cracking could be avoided. However, the intermetallics could not be avoided completely which has led to brittle fracture when stretched. Mousavi and Sartangi [4] have arrived at a suitable parametric window both analytically and experimentally for explosive welding of CP Ti–SS 304. They have found that explosive load had a severe impact on both the interface morphology and intermetallic formation and concluded that at low loads formation of intermetallics could be totally avoided. Cola et al. [5] studied the microstructural features of inertial friction welded Ti–316L SS joint using Nb as interlayer and were able to achieve the desired microstructure and strength for cryogenic application. Kamachi Mudali et al. [6] studied the corrosion and bend ductility of joint between Ti dissolver and 304L SS tubing by friction and explosive welding. They have found out that friction welded joints have poor bend ductility but good corrosion resistance and vice versa in explosive bonded joints. Kaharaman et al. [7] have studied the explosive bonding of Ti to SS with respect to explosive ratio concentrating on the interface appearance. Lee and Jung [8] has attempted friction welding of Ti–SS321 and they were able to achieve a joint strength of 400 MPa by altering the

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microstructure by varying the friction force. Fuji et al. [9] were able to increase the bend ductility of friction welded joints by stress relieving by PWHT at 500 °C and rapid cooling. Vollertsen and Grupp [10] were able to braze a thin sheet of titanium to stainless steel using laser. Still, there is no known or prior report on laser fusion welding of Ti–SS combination. High power density laser welding will enable welding at high speeds with a cooling rate $>1000^{\circ}$ C/s creating favorable conditions in dissimilar materials joining through reduction in number and sizes of inter metallic phases in the fusion zone.

In this paper some of the results of CW CO_2 laser welding of titanium (Ti) to AISI 304 stainless steel (SS 304) of 3 mm thickness have been presented. In order to evaluate the efficacy of laser fusion welding at high speeds, investigations have been undertaken to join 3 mm thick Ti plate to similar thickness SS304 after identifying the usable laser power and welding speed through bead on plate studies on stainless steel (bead on plate studies on Ti were not done as fusion depth etc. are likely to be more than SS 304 for the same welding conditions). The results of laser welding in both autogenous mode and with interlayers are discussed.

2. Experimental details

The welding experiments were carried out on 3 mm thick CP Ti and SS 304. The base material composition and the strength characteristics of the material are given in Table 1.

Laser welding experiments were carried out using a 3.5 kW CW CO_2 (Rofin Sinar DC035) laser. This laser has a very high beam quality ($K>0.9$) enabling it to be focused to a very fine spot of 180 μm using a focusing mirror of 300 mm focal length. All the experiments were carried out using argon shielding at a flow rate of 30 l/min for both plasma suppression and shielding, in trailing configuration. Before welding the surfaces to be joined were cleaned using acetone to remove any dirt, oil, grease, etc. Initially bead on plate (BOP) experiments were conducted on 3 mm thick SS 304 to identify welding parameters to get full penetration. BOP experiments were not conducted on titanium as the fusion characteristics such as depth of penetration is more for titanium. Autogenous welding has been carried out using optimized parameters in both continuous wave (CW) and pulsed mode to obtain higher cooling rates in the fusion zone. Welding experiment in CW mode is also carried out with 0.15 mm beam offset towards the titanium side and the welding head being tilted 15° towards titanium side. Butt welding has also been attempted with interlayers. The methodology and the interlayers adopted are

I. Welding with V strip of 0.7 mm thickness as interlayer with laser power of 3.5 kW, speed of 3 m/min and donut mode (360 μm spot size) to melt both the edges along with the interlayer.
II. Welding experiments carried out by cladding the abutting surfaces of SS and Ti with tantalum which was subsequently polished using a rough emery sheet to have a smooth surface for welding and then the butt welding has been carried out using the optimized parameter obtained from BOP. The cladding was done by preplacing the tantalum powder on both SS and titanium with PVA as the binder. This was executed with 2 kW power at a speed of 1 m/min and a defocus of 125 mm. EDS has been done on samples after cladding and polishing to check the level of dilution.
III. Butt welding with Ta interlayer in the form of a strip with 3.5 kW, 6 m/min and gauss mode. The welding was carried out in two steps due to the thickness of the Ta (0.5 mm) interlayer. First the Ta strip was placed and welded to titanium and then the surface was polished and cleaned and again it was welded to SS employing the same parameter.

The butt welded joints with interlayers have been subjected to dye penetration testing (DPT) and tensile testing in the as welded condition by pulling it in a UTM. The fractured surfaces were subjected to EDS and XRD to analyze the type of fracture and composition of the fractured surface of welds.

3. Results and discussion

3.1. Bead on plate experiments

The beads on plate experiments were conducted to optimize the parameter for the maximum cooling rate possible for the required depth of penetration of 3 mm. The results have shown that the laser power of 3.5 kW and welding speeds of 5 and 6 m/min (Fig. 1) have yielded the weld with minimum melting for the required depth of penetration. The high speed could be achieved because of the very high beam quality ($K>0.9$) of the laser. Hence, the same parameter has been frozen for carrying out butt welding.

3.2. Autogenous butt joints

3.2.1. Autogenous joints with CW output

The autogenous butt joints carried out with CW laser at 3.5 kW and 6 m/min have resulted in extensive cracking. The formed joint broke even while taking the pieces from the welding fixture. The resultant fractured surface has been analyzed by XRD for the

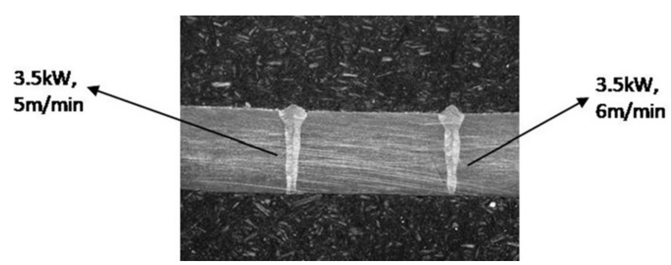

Fig. 1. BOP results on SS304.

Table 1
Chemical composition and mechanical properties of base materials.

Material	O_2	N_2	H_2	C	Fe	Others	Ti	YS (MPa)	UTS (MPa)	% El
Cp Ti	0.25	0.028	0.01	0.08	0.25	0.1	Bal	335–545	510–605	21–29
Material	**Cr**	**Ni**	**Mn**	**C**	**Si**	**S**	**Fe**	**YS (MPa)**	**UTS (MPa)**	**% El**
304	19	9	1.8	0.08	<0.045	0.03	Bal	210	515	40