CHOSEN PROPERTIES OF SANDWICH MATERIAL Ti-304 STAINLESS STEEL AFTER EXPLOSIVE WELDING

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Resume

The work deals with evaluation of joint of stainless steel 304 SS (sheet) and commercially pure Ti both after welding explosion and followed-up annealing at 600°C/1.5h/air. The bonding line shows sinusoidal character with curls in crest unlike the trough of the sine curve. The heat treatment does not change the character of the interface. In work amplitude, wave length and the interface thickness were measured. Thickness of compressed cladded matrix of Ti was measured in area of crests and troughs. In crest of joint melted zones were studied, where complex oxides and intermetallic phases were revealed

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1. Introduction

Explosive welding enables to joint directly a wide variety of similar or quite different metals that cannot be joined using any other welding or bonding technique [1-4]. The bonded materials show increased strength, resistance to abrasion and corrosion, or toughness in the applied surface layer of material, whereas the whole product need not be made from the same one. Bonding method significantly also reduces material costs. In numerous papers an attention has been paid to explosive welding. In the work [5] Zimmerly presented the join of nickel-titanium alloy to low carbon steel by explosive welding and characterised the quality of the resulting bimetal tandem being integral part of investigation of erosion protection. The microstructure and mechanical properties of some explosively welded metals and alloys combinations have been studies by several authors, as well. In the work [6] characterization of the as clad and stress relieved studied titanium-steel bond was showed. Similar material was studied in paper [7], too. However, the primary interest was focused on hardness and microstructure after welding. The work [8] reports investigation results of the microstructure-properties relationship in explosively welded duplex stainless steel and steel on the as clad condition. Just few information about the 304 stainless steel-titanium sandwich is why the presented work is focused on some metallographic parameters, intermetallic phases and parameters of bonding line after explosion, respectively after follow-up heat treatment (HT). The mentioned bimetal find application in heavy chemical industry.

2. Experimental approach

For study the 304 stainless steel (304 SS) and titanium (Ti) matrix welded by explosion were used. Titanium was of commercial pure with detected impurities (wt. %): 0.01C, 0.05Fe, 0,05O, 0.005N, 0.006H. The 304 SS had followed chemical composition (wt. %): 0.04C, 0.45Si, 1.96Mn, 18.42Cr, 9.74Ni, 0.0065P and 0.011S. In EXPLOMET-Opole both materials were explosively welded and subsequently the clad plate was subjected for ultrasonic testing. Before welding the plates were polished. Followed mechanical properties were as welded condition and were given by Explomet Opole. Tensile tests were curried out according to the standard EN 10002-1 (MTS machine) at ambient temperature. After bonding the bimetal showed yield stress on the level of 410 MPa, tensile strength was 561 MPa and elongation 38 %. Impact energy (CVN - conventional V-notch of Charpy specimens) of bimetal at 20°C and -11°C corresponded to 233 and 216 J. According EN 10045-1 tests were carried out by use of PSW 300 AF machine with maximal capacity of 300 J. The samples of 304 SS steel and Ti sandwich were machined by mechanical cutting to avoid any change in microstructure. The thickness of the 304 SS and the Ti layer corresponded to 110 mm and to 6 mm (given in sequence). Plate was a square cross about a 2600 x 2600 mm. For metallographic evaluation of microstructures, including micro-joints in the welded area, samples of dimension 20 x 20 x 40 mm were made. Five samples were used for the follow-up HT: annealing at 600°C/1.5 hour/air. The HT makes the microstructure more homogeneous and fiver. Specimens for micro-structural examination were prepared by standard metallographic techniques. The bimetal was etched in nitric acid and fluorhydric one and in water solution of hydrochloride and nitric acid.

For both material types metallographic evaluation included the wave amplitude and wave length, thickness of the weld, thickness of the deformed Ti matrix near the crest and the trough of the interface, and analysis of formed phases (in-homogeneities) in close proximity of the weld line. The light microscope Olympus X70 and the electron microscope SEM JEOL JSM-6490 LV equipped with energy dispersion analyser (EDA) OXFORD INCA Energy 350 were used.

3. Description of achieved results

At lower magnification micrograph of the as bonded 304 SS - Ti sandwich shows wavy interface in nature as the Fig. 1 demonstrates. The Ti matrix is situated above. In comparison with the length of the sample (including 6 waves) the average total length of the interface showed difference of 14.2 % as the Fig. 1 demonstrates.

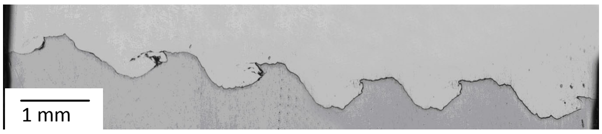

Fig. 1. Wave line of joint (Ti matrix is situated above)

On average, the amplitude corresponded to 287 μm and the wave length to 1690 μm. After the HT there was no change in the type of interface.

The found thickness of the bonding line corresponded to 1.5-2.7 μm. On average it was 1.9 μm. After etching the thickness of the interface was lying in interval 2.5-7.9 μm as the case may be, or was 5.3 μm on average. Using the SEM and the EDA analyser located melted zones on the base of Ti-Cr-Fe-Ni, eventually with Mn and/or with Al and Si were revealed in close proximity of the 340 SS - Ti interface as it can be seen in Fig. 2 and Table 1.

According the analysis 4 (5) phase types were detected in melted zones. The C3-C4 zones contained Ti (about 70 at. %), Fe (approximately 20 at. %), Cr (about 4.5 at. %), and Ni (bal.). The phase marked as 2 showed Ti (about 79 at. %), Fe (approximately 15 at. %), Cr (4 at. %), Mn (under 1 at. %) and Ni (bal.). Phase 1 and 3 were on a complex oxides basis of the Fe-Ti-Cr type with Fe content in range of 15-50 at. %, the Ti corresponded to 8-11 at. %, while the Cr content was 2-21 at. %. The Mn one was 0-1 at. %, Al with Si did not go over 6.5 at. % and Ni was balanced.

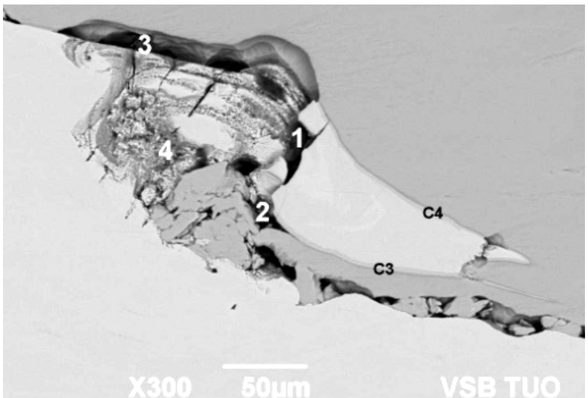

Fig. 2. Part of the wave line with detected zones

Table 1
Chemical composition of melt zones [at. %]

	1	2	3	4	C3	C4
O	43.72		50.79	11.64		
Al			6.47	1.36		
Si			2.67	0.36		
Ti	8.07	78.70	10.69	10.89	69.40	70.84
Cr	13.20	4.27	2.28	21.08	4.70	4.51
Mn		0.58		1.32		
Fe	32.43	14.72	25.45	49.80	22.15	20.50
Ni	2.58	1.73	1.10	3.55	3.75	4.15

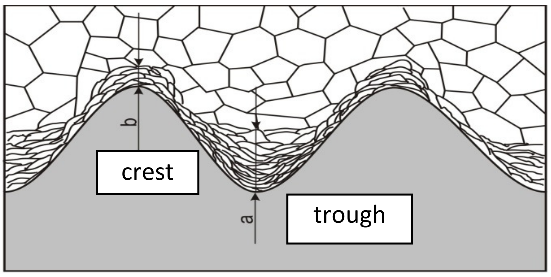

Fig. 3. Schema of evaluated thickness of deformed areas in Ti matrix

In frame of interface microstructure evaluation, the compressed Ti grains thickness was measured. The crest of wave represents parameter -b-, whereas the trough of wave the parameter -a- characterises as the Fig. 3 schematically shows. In the Ti matrix the average rate of b/a corresponds to 0.4 and represents differences in various wave level. The average thickness of deformed layer was 188.8 µm (b) in wave crest and 67.2 µm (a) in wave trough on average.

4. Conclusion

The line of interface of explosively welded stainless 304 SS and commercial Ti showed wavy character. It was not changed after annealing at 600°C/1.5 h/air. On average the amplitude corresponded to 287 µm and the wave length was 1690 µm. The thickness of bonding line was lying in interval of 1.5-2.7 µm.

In crest of wave the bonding line showed curls (see Fig. 1) unlike the trough of the sinusoidal wave. In curls various melted zones were detected. At collision process the kinetic energy dissipation is the reason of their formation. Chemical analyses complex oxides on the basis of Fe-Ti-Cr, eventually with Mn, Si and/or Al revealed. In melted zones intermetallic phase of Ti-Fe-Cr basis, eventually with very low Mn portion were also detected. Defects of un-joined materials type or voids were not found.

In vicinity of the wave interface evaluation of compressed Ti grains thickness showed the rate between crest and trough area on the average level of 0.4 (188.8/67.2). In Ti matrix none adiabatic shear bands and recrystallisation were revealed.

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