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ScienceDirect
Trans. Nonferrous Met. Soc. China 24(2014) 697−704
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effect of heat treatment on microstructure and mechanical property of Ti−steel explosive-rolling clad plate

Hai-tao JIANG[1], Xiao-qian YAN[1], Ji-xiong LIU[2], Xiao-ge DUAN[1]

1. National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing, Beijing 100083, China;
2. Baoti Group Co., Ltd., Baoji 721014, China

Received 27 February 2013; accepted 6 June 2013

Abstract: The effect of heat treatment on microstructure and mechanical properties of the Ti−steel explosive-rolling clad plate was elaborated by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), transmission electron microscopy (TEM), micro-hardness test and shear test. The composites were subjected to heat treatment at temperature of 650−950 °C for 60 min. The results show that the heat treatment process results in a great enhancement of diffusion and microstructural transformation. The shear strength decreases as the treatment temperature increases. Heated at 850 °C or below, their shear strength decreases slowly as a result of the formation of TiC in the diffusion interaction layer; while at the temperature of 850 °C or above, the shear strength decreases obviously, which is the consequence of a large amount of Ti−Fe intermetallics (Fe_2Ti/FeTi) along with some TiC distributing continuously at diffusion reaction layer.
Key words: Ti−steel explosive-rolling clad plate; heat treatment; diffusion; mechanical properties

1 Introduction

Titanium and titanium alloys are principally applied as materials for chemical reactors and heat exchangers due to their excellent capability of anti-corrosion. However, the cost of titanium and its alloys is very high, especially for structural parts. Partly replacing titanium and its alloys with steel to meet the strength requirements can reduce the production cost to a large degree. Ti−steel clad plate, on one hand, makes full use of the capability of anti-corrosion of titanium and the high strength of steel; on the other hand, it reduces the material cost. Thus, it has been widely used in chemical industry, seawater desalination, and flue gas desulfurization (FGD) in power plant [1−7]. However, the degradation of mechanical properties due to the formation of brittle compounds such as TiC and Fe−Ti intermetallics on the interface may occur, so it is difficult for titanium and steel to combine directly. At present, the explosive cladding method is mostly embraced to produce Ti−steel clad plate, for it ensures higher bonding strength and conjoint ratio of the plates. Nevertheless, it is not available for the production of large-size and thin Ti−steel clad plates. Based on explosive cladding [8], the rolling bonding method can produce large-size and thin Ti−steel clad plate without the loss of bonding strength and conjoint ratio.

Currently, more studies have focused on the diffusion behavior of the explosive clad plate during heat treatment process. YAN et al [9] studied the effect of heat treatment on the properties of explosive clad plate. Their results showed that, at 850 °C or above, the shear and peeling strength decreased with the increasing of the heat treatment temperature. AKBARI and SARTANGI [10] studied the composition and thickness of the intermetallic which was formed on the interface of Ti−steel explosive clad plate after different processes of heat treatment. Moreover, some scholars [11−15] indicated that TiC was formed on the interface during the heat treatment processes and had an effect on the formation of Ti−Fe intermetallics.

At present, more attentions have been paid to the research on the production process and properties of explosive clad plate. A few researches have been done in the area of microstructure and properties by different production processes [16,17]. Less researches have paid attention to Ti−steel explosive-rolling clad plate and the

Corresponding author: Xiao-qian YAN; Tel: +86-10-62332598; E-mail: huazhimeng123@126.com
DOI: 10.1016/S1003-6326(14)63113-7

distribution of the interfacial compounds. In this work, the effect of diffusion reaction on the microstructural transformation and mechanical properties of explosive-rolling clad plate during different heat treatment processes is studied.

2 Experimental

Explosion welding is an efficient alternative to conventional joining in this case. It works by accelerating the clad plate (here: titanium) to a very high velocity towards the base plate (here: steel) through the ignition of an explosive coating on its surface. Three external process parameters mainly control the jet expansion between the plates and the collision, namely, the explosive mass, collision angle and stand-off distance, as shown in Fig. 1. By introducing rolling technique into explosive clad plate, Ti−steel clad plate becomes thinner and larger. Ti−steel explosive-rolling cladding plate used in this study was manufactured by Xi'an Tianli Clad Metal Materials Co., Ltd., China. The thickness of the composite is 1.2 mm (cp-Ti)+10 mm (low carbon steel). Their chemical compositions are given in Table 1. And their mechanical properties are given in Table 2. The

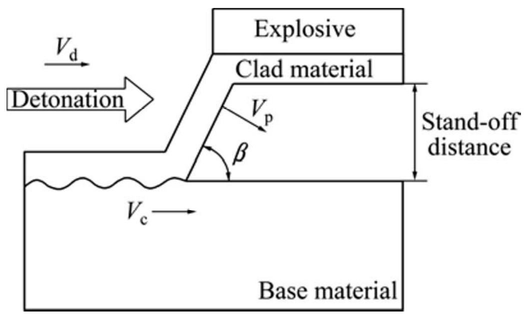

Fig. 1 Schematic of experimental setup of explosive welding process

Table 1 Chemical composition of TA2 and Q235B (mass fraction, %)

Alloy	Fe	Ti	C	Mn	Si
TA2	0.031	Bal.	0.009	−	−
Q235B	Bal.	−	0.16	0.50	0.15
Alloy	P	S	N	H	O
TA2	−	−	0.012	0.002	0.06
Q235B	0.011	0.010	−	−	−

Table 2 Mechanical properties of TA2 and Q235B

Alloy	Yield strength/MPa	Tensile strength/MPa	Elongation/%
TA2	321	440	32
Q235B	260	445	31

shear strength of Ti−steel explosive-rolling clad plate is 192.9 MPa.

Ti-steel explosive-rolling clad plate was cut into several equal parts (10 mm×70 mm×11.2 mm) and then these specimens were heat treated in the furnace for about 60 min at temperatures of 650 °C, 750 °C, 850 °C and 950 °C respectively, and air cooled to room temperature.

Specimens for microstructure examination were extracted from the central part of the joint in a plane parallel to the rolling. The cross-sections of specimens were ground with emery papers up to No. 2000 and polished to 1 μm followed by etching in 4% nital solution. Microstructure evolution due to the heat treatment was examined by optical microscope (OM, ZEISS AX10), and the thickness of interaction layer and distribution of constituent element across the interface were examined by a scanning electron microscope (SEM, ZEISS ULTRA 55) equipped with an energy-dispersive X-ray spectrometer (EDS). Fractured structure and interfacial compounds were analyzed by an X-ray diffractometer (12 kW rotating anode, D/MAX-RB). Specimens for transmission electron microscopy (TEM) observation were prepared from slices that were cut parallel to the rolling direction and mechanically ground to a thickness of ~0.05 mm. Disks of 3 mm in diameter containing the bonding interface were spark cut and polished using an argon ion beam milling machine (Model 691.CS) to obtain an observed area. TEM observation and analysis of electron diffraction patterns were carried out in a Tecnai F 30 microscope operated at 300 kV. The interfacial bonding strength was tested by a digital micro-hardness meter (HXD−1000TM/LCD).

The shear strength was obtained by tension−shear test in accordance with the specifications set in GB/T 8546−2006 (Titanium clad steel plate) and GB/T 6396−2008 (Clad steel plates—Mechanical and technological test). Shear strength test was carried out on the Instron−1185 instrument in the compression direction. The shearing speed of the machine was 0.5 mm/min. Three samples were tested for each welding and the average values were reported.

3 Results and discussion

3.1 Microstructure transformation of steel side during heat treatment process

Figure 2 shows the microstructure transformation of steel side during the heat treatment process. Figure 2(a) shows the as-received structure of the specimen. The intermetallic sinter which was formed in the explosive cladding process broke into pieces under the rolling pressures, with the previous wavy interface becoming straight. At the same time, the ferrite and pearlite at the steel side deformed and tended to form banded structure.

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