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Effect of heat treatment on bonding interface in explosive welded copper/stainless steel

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ABSTRACT

In this investigation, explosive welding and heat treatment processes provided an effective method for manufacturing high-strength and high-ductility copper/ austenitic stainless steel couple. In order to improve diffusion in the interface of copper/stainless steel, first the tensile samples were provided from the welded part, then they were subjected to annealing at 300 °C (below recrystallization temperature) for 8–32 h with 8 h intervals and then samples were cooled in the furnace. Optical microscopy (OM), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were utilized to evaluate the possibility of diffusion in the joints. Moreover, in order to measure the hardness of the samples, microhardness test was performed. Microstructural evaluations showed that the stainless steel 304L had a wavy interface. Furthermore, the post heat treatment process resulted in great enhancement of diffusion. Microhardness measurements showed that the hardness of the sample near to the interface is greatly higher than other parts; this is due to plastic deformation and work hardening of copper and stainless steel 304L in these regions. The interface of samples with and without the post heat treatment was exhibited ductile and brittle fracture, respectively.

1. Introduction

The challenge of developing materials for advanced structural applications is gradually shifting from the optimization of novel bulk materials to the synthesis of compounds that contain metallurgical joints. This means that the design of modern metallic compounds must be built on a detailed microstructure-oriented understanding and property optimization of the underlying interfaces at the joints between dissimilar bulk metals [1,2].

Dissimilar joints to bind two discrete materials with completely various physical and mechanical features can be produced by either fusion or solid state welding [3]. General occupied dissimilar joining processes are roll bonding, pressure welding, friction welding, ultrasonic welding, diffusion bonding, laser forming and explosive welding [4].

Explosive welding is a welding method that welds two or more plates with each other with high pressure coming from explosion. Explosive welding, also known as explosive bonding, occurs as a result of an inclined crash between two metallic plates. In spite of the occurrence of heat during the explosion, a heat transfer is not observed from one plate to another due to the lack of time [5,6].

The bonding interface in explosive welding, presents three morphologies: wavy, straight and melted layer. These morphologies have received a lot of attention and discussions [4–9]. For technical purposes, these morphologies depend on the impact velocity and angle. The interface developed is related to two important phenomena that take place during bonding: rarefaction wave interaction and mechanical friction. The propagation of compressive and tension waves inside the material due to the impact and shock induced by the detonation, as well as their interaction, is responsible for the first phenomena. Sliding due to the acceleration of the flyer plate onto base plate, as well as the jet formation and its interaction with both flyer and base plates is responsible for the second one. These phenomena could introduce several metallurgical property changes [9].

The quality of the bonds strongly depends on careful control of the process parameters. These include material surface preparation, plate separation or stand-off distance, explosive load or explosive ratio, detonation energy and detonation velocity. The selection of parameters is based upon the mechanical properties, density and shear wave velocity of each component [6,10,11]. Considerable progress has been made to establish the optimum operational parameters which are required to produce an acceptable bond

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Table 1
The chemical composition of stainless steel 304L and copper.

Elements (wt.%)	Cr	Ni	Mn	C	Si	S	Al	Cu	Fe
AISI 304L (base plate)	18.91	8.44	1.79	0.015	0.483	0.03	–	0.043	Balanced
Copper (flyer plate)	0.03	0.03	–	–	–	–	0.155	Balanced	0.05

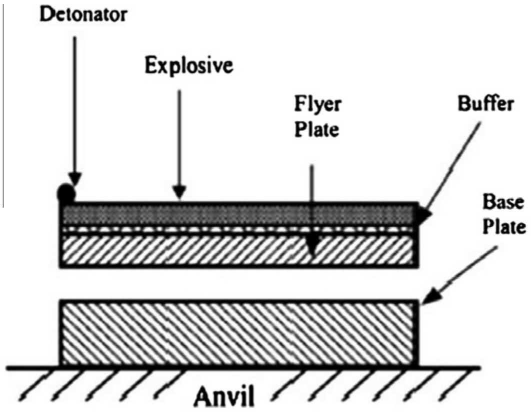

Fig. 1. Display of experimental set up of explosive welding process [6,7].

[6]. It was reported in the literature that in explosive welding, a hard and brittle intermetallic is formed during the welding and this intermetallic affects the bonding quality with a negative manner [12].

The microstructural characteristics and mechanical properties of the explosively welded various metals and their alloys have been studied by several investigators. Recent applications of explosively welded copper/stainless steel in corrosion environment prompted the present investigation. Although, there are articles about copper/stainless steel produced by explosive welding technique in literature [9,12,13], there are no report about the effect of post heat treatment on bonding interfaces in explosively welded copper/stainless steel 304L. Therefore, the goal of this study is to investigate the effect of post heat treatment on the bonding interface properties to derive optimized conditions of explosively welded copper/stainless steel 304L.

2. Experimental procedure

The chemical compositions of the copper and austenitic stainless steel 304L are given in Table 1. The parallel preparation was used for experimental set up for explosive welding as schematically revealed in Fig. 1. Due to the mechanical and corrosion properties of stainless steel, this metal was chosen as base plate while, copper was obtained as overlay plate (flyer plate) for to their high application in the vessel industry [13]. Copper and stainless steel plates were designed with dimensions of 420 × 520 × 1 mm^3 and 400 × 500 × 1 mm^3, respectively. The amatol (TNT 10% and ammonium nitrate 90%) was chosen as explosive material. The initial gap between two metal plates was chosen to be about 3 mm. The matching surfaces were carefully cleaned by polishing and degreaser. After welding, the tensile samples were prepared according to ASTM: E8/E8M-11 (Fig. 2) and post heat treatment process was performed at 300 °C, to avoid formation of $Cr_{23}C_6$ in stainless steel (below recrystallization temperature of both metals) from 8 h to 32 h with 8 h intervals. After the heat treatment the samples were cooled in the furnace. The tensile tests were conducted at ambient temperature on a Hounsfield H50KS testing machine at an initial strain rate of 10 mm/min.

Samples for metallographic observations were cut as parallel to the explosion direction from the explosively welded plates and these were mounted in bakelite. Then, these samples were polished using 80–4000 grit water-proof SiC paper. Finally, the polishing was finished on a cloth using diamond paste of 3 μm and then the plates etched in etchant of 33 cc HCl, 33 cc HNO_3 and 34 cc H_2O. A Nikon EPIPHOT 300 optical microscopy (OM) was used for the microscopic examination of the etched samples. For investigation of the fracture surfaces, the scanning electron microscopy examinations were carried out on samples using Seron AIS-2100. Also, for investigation of diffused layer, the energy dispersive spectroscopy (EDS) analysis was performed. Microhardness testing was carried out on a Leitz Wetzlar using a 100 g load. For each sample, three different measurements were taken in the distance of 50, 100, 200, 400 and 600 μm from the interface and the average values are reported.

3. Results and discussion

3.1. Microstructural observation

Fig. 3 and 4 demonstrated the OM figures of copper/stainless steel joints before and after the heat treatment at different times, respectively. These figures indicated that bonding at the copper/stainless steel interface had wavy morphology. In other words, after explosive welding process, both copper and stainless steel had wavy welding interface. Total interface area increased as a result of wavy interface. Straight and wavy interfaces can be formed between explosively welded materials and wavy interface is

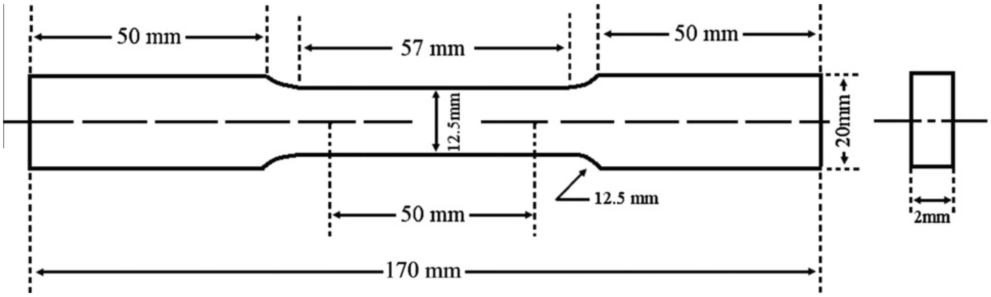

Fig. 2. Schematic representation of tensile test sample.