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Effect of explosive ratio on explosive welding quality of copper to aluminium

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Abstract

The goal of this research is to study the influence of the ratio of an explosive composed of 80% ANFO and 20% matrix on the quality of dissimilar explosive welds of Cu-DHP copper to aluminium alloy 5083-H11, in flat configuration. It is analysed the influence of four explosive ratios (1.4, 1.8, 2.3 and 2.6) on the microstructure and mechanical properties of welds. It was observed that the increase in the explosive ratio gives rise to an increase of the collision point velocity (Vc) and the impact velocity (Vp) and consequently reduces the thickness of the flying plate after welding as well as produces wavy interfaces of greater amplitude. Microstructural analysis showed the formation of hard and brittle intermetallic compounds in the interface region, more obvious in welds made with higher ratio of explosive.

Keywords: Explosive welding; explosive ratio; copper; aluminium; intermetallic phases.

1. Introduction

New applications in the areas of power generation, aerospace, automotive, defence, electronics, created the need for joining multifunctional materials and hybrid structures of dissimilar materials [1,2]. The aluminium-copper joining, for example, has increased its use in electronic applications, power transmission systems, heat exchangers, etc. The joining of these materials by fusion welding is considered not feasible due to mismatch of physical properties, especially the melting temperature, and the formation of brittle intermetallic phases in the weld [3]. Since the main thermodynamic variables for the formation of brittle intermetallic phases during the welding process are temperature, pressure and time, solid state welding processes are an alternative to fusion welding processes. Friction stir welding is a solid state process that, although promising in solving these problems because temperatures involved are lower than in fusion welding, causes also the formation of brittle intermetallic phases (CuAl, $CuAl_2$ and Cu_9Al_4) very detrimental to the mechanical properties of welds, as shown by one of the authors of the current study [4,5]. The restriction on the formation of brittle intermetallic phases in the weld can be achieved by reducing the temperature and time of interaction between the materials involved during the welding process. Explosive welding is considered a cold process because no external heat is provided; heat is generated by the almost instant impact between the plates together, showing the welds no heat affected zones, unlike fusion welds [6]. In this process a flying plate is accelerated due to the thrust promoted by the expansion of detonation gas, against a slightly spaced stationary plate, generating high pressure and causing

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considerable plastic deformation of plates and jetting of melted materials at the interface, resulting in a solid connection (Fig. 1).

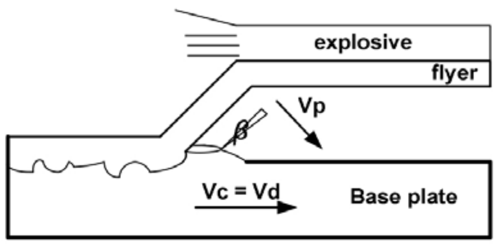

Fig. 1. Schematic representation of the explosive welding process. Vc - Collision point velocity, Vd - Detonation velocity, Vp - Impact velocity and β - Collision angle.

The detonation speed of the explosive controls the collision point velocity (Vc) of the plates along the interface, i.e., the welding speed.
The impact of the flying plate on the base plate promotes the formation of waves at the weld interface, but there is no consensus about their formation mechanism [7,8]. Quality of the joints is strongly dependent on process parameters such as type of explosive and explosive ratio, thickness and material type of plates to be welded and standoff distance [8,9].

2. Experimental Procedure

Dissimilar welds were made by explosive welding in flat configuration using a flying plate of copper Cu-DHP with 200x90x1 mm and as base plate the aluminium alloy 5083-H111 with 185x72x30 mm size. Before welding, plates were cleaned and abraded so as to remove impurities and imperfections from surfaces. An explosive consisting of a mixture of 80% ANFO (94% ammonium nitrate and 6% fuel oil) and 20% matrix (aqueous solution of ammonium nitrate) was used in different proportions controlled by the explosive ratio (1.4, 1.8, 2.3 and 2.6). The explosive ratio is given by the ratio between the mass of explosive and the mass of flyer plate under the explosive. Welds were referenced by letters SE, then the thickness of the flying plate and the height of the explosive used; SE1_20 means the explosive welding performed with a flying plate of 1 mm thick and 20 mm high of explosive. The SE1_20 and SE1_30 welds were made on a sand base while SE1_15 and SE1_25 on a steel base.
Measurement of detonation velocity (Vd) was based on the record of time of explosion propagation, using ionization probes, in a digital oscilloscope *LeCroy WaveJet 352*. Specimens for metallographic study were removed parallel to welding direction, ground and polished according to conventional procedures. Etching of copper was done using a mixture of 5 mL of H_2O_2 and 50 mL of NH_4OH. It was not possible to etch the aluminium alloy although several chemical reagents have been used. The hardness measurements were taken on a line transverse to the copper-aluminium bonding interface with a load of 200 gf for 15 seconds. In the case of intermetallic compounds, it was used a load of 50 gf due to their small size. The analysis of the intermetallic compounds was carried out through an electronic scanning microscope (SEM) provided with energy dispersive X-ray spectroscopy (EDS) *Philips XL30 SE*.

3. Results

The increase in the explosive ratio promotes increased detonation velocity (Vd), impact velocity (Vp) and small increase in collision angle (β), as shown in Table 1. Detonation velocity was measured, as mentioned above, while the other variables were computed according to the procedure described in Ribeiro *et al.* [10].

Table 1. Detonation results.

	SE1_15	SE1_20	SE1_25	SE1_30
R	1.4	1.8	2.3	2.6
Vc (m/s)	1712	1854	2013	2149
Vp (m/s)	660	755	830	885
β (º)	22.2	23.5	23.8	23.8

R - Explosive ratio, Vc - Collision point velocity, Vd - Detonation velocity and β - Collision angle.

Based on experimental conditions used, a weldability window was constructed, which defines the set of parameters from the domain providing welds with good quality; based on the calculated values, it was inserted in this area the point corresponding to each weld, as illustrated in Fig. 2. Looking at the figure, it is found that welding with the lowest ratio of explosive (SE1_15) is outside the weldability window to the left of the left edge which delimits the formation of waves in the weld interface. The SE_20 and SE_25 welds are within the weldability window and SE_30 welding is on the upper limit which delimits the possible formation of excessive molten zones.
According to this weldability window, it is expected that the weld SE_1_15 presents a flat interface without any wave, while the weld SE_1_30 should provide broad melted zones.