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Explosive Welding of Dissimilar Metals with a Wire Mesh Interlayer

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ABSTRACT

Explosive welding, a solid state welding process, employs a controlled energy of a chemical explosive to force two metals cladded at high pressure. In this study, aluminum and copper plates are explosively welded using stainless steel wire mesh as interlayer at varied loading ratios. Interfacial microstructure reveals a characteristic undulating interface, unique feature in explosive welding process. Maximum hardness is obtained at the interface following sudden impact. Corrosion rate is higher initially and tends to decrease over time, following the formation of layer over the surface. In addition, weldability window, an analytical estimation to predict the nature of interface is developed for Al-Cu explosive welding and the results are correlated with the experimental results.

Keywords- Explosive welding, microstructure, strength, weldability window, wire-mesh.

1. INTRODUCTION

Explosive welding is a solid state metal joining technique employs the energy stored in a chemical explosive to clad two or more similar or dissimilar metals method together [1]. As explosive welding process is complex, the quality of clad composite depends on the selection of process parameters viz., standoff distance, impact velocity, loading ratio and properties of explosive [2]. Aluminum-copper clad plates replace solid aluminum or copper in electrical, electronics and cookware applications due to their high thermal and electrical conductivity, superior heat dissipation, good soldering and electroplating properties [3]. Welding of aluminum-copper plates by conventional methods is not viable due to the formation of undesirable intermetallic compounds, whereas, explosive welding is very effective in welding aluminum-copper plates devoid of intermetallic compounds at minimum cost [4].

Various researchers [5-6] reported the metallurgical and mechanical properties of explosive welded dissimilar metals subjected to varied process parameters, whereas, Saravanan et al. [7] employed different interlayer between aluminum and copper to attain a satisfactory weld. However, studies on explosive cladding of aluminum-copper plates with a stainless steel wire mesh are scarce and attempted herein. The effect of loading ratio on microstructural and mechanical properties of wire mesh reinforced aluminum-copper explosive clad is presented. In addition, a weldability window for Al-Cu is developed to predict the nature of interface and correlated.

2. EXPERIMENTAL PROCEDURE

A parallel explosive cladding set up shown in Fig.1, with stainless steel wire mesh (chemical composition in wt%:Cr-18,Ni-8,Cu-0.05, C-0.08, Si-0.34, Mo-0.05, Mn-2,P-0.04,S-0.03,Fe-Bal) as interlayer was positioned between aluminum 5052 (chemical composition in wt %: Cu-0.1,Mn-0.4,Si-0.4,Mg-4.2,Zn-0.25,Fe-0.4,Ti-0.15,Cr-0.15,Al-Bal) and copper (chemical composition in wt %:Mn-0.0002,Si-0.0004,Mg-0.0001,Zn-0.0004,Fe-0.003,Al-0.001, Cu-Bal) plates of similar dimensions (80 mm x 60 mm). The thickness of flyer plate, base plate and interlayer are 2 mm, 6 mm and 0.5 mm respectively.

The flyer-interlayer and interlayer-base plate are separated by 5 mm respectively to allow the flyer plate to reach its terminal velocity. The chemical explosive (detonation velocity-4000 m/s, density-1.2 g/cm^3) was packed above the flyer plate at different loading ratios (R=0.7, 0.8, 0.9), with the detonator positioned on one corner of the pack. After cladding, the clad plates were sectioned parallel to the detonation direction for microscopic examination and the samples were prepared following standard metallographic practice. Vickers microhardness measurement across the explosive clads were carried out on a ZWICK microhardness tester applying 100 g load as per ASTM E 384 standard and the results are presented. To study the corrosion behavior, samples (15 mm X 15 mm) were placed in a glass of solution 3.5% NaCl-water solution for 24, 240 and 720 hours based on the reports of earlier researchers [2] and the variation in weight was observed in an electronic scale.

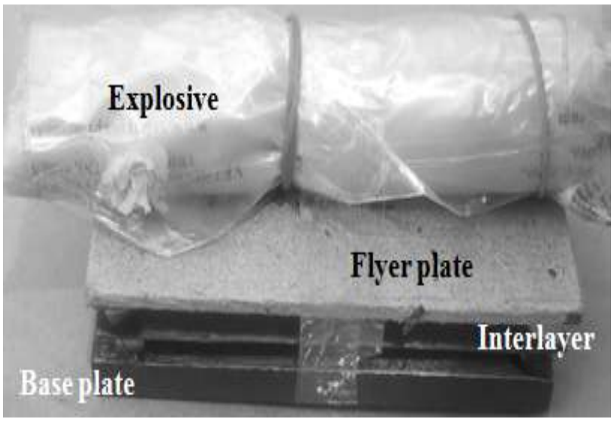

Fig. 1 Parallel explosive welding setup

3. RESULTS AND DISCUSSION

3.1 Microstructural Chracterization

The microstructural observation of the aluminium-copper explosive clads with wire mesh interlayer subjected to varied loading ratio show wavy morphologies as reported by earlier researchers [1, 2, 8]. When the loading ratio, R, increases, the interfacial waves are more pronounced. The Al-Cu explosive clads are sound, devoid of defects viz., cracks, trapping of jet and molten layered zones at lower energetic conditions, though formation of trapped jet and continuous molten layer are witnessed at higher loading ratio (R-0.9), because of higher kinetic energy dissipation and pressure developed.

The microstructures of Al-Cu explosive clad for a loading ratio of 0.7 is shown in Fig. 2.a. At lower energetic conditions, the flyer plate and collision velocities were diminutive and the energy spent for plastic deformation is just adequate enough to craft smaller waves to resemble like a straight interface with minimal amplitude and wavelength. When the explosive loading ratio, R, was increased to 0.8, the amplitude and wave length of weld increases to craft a wavy interface (Fig.2.b) as reported by Tamilchelvan et al. [9]. When the loading ratio increases to 0.9, the collision velocity, plate velocity and pressure developed increase further following higher kinetic energy spent at the interface to result in formation of jet trapping and molten layer at the interface (Fig.2.c). The formation of trapped jet at high kinetic energy conditions is concurrent with Saravanan and Raghukandan who joined dissimilar metals [10].

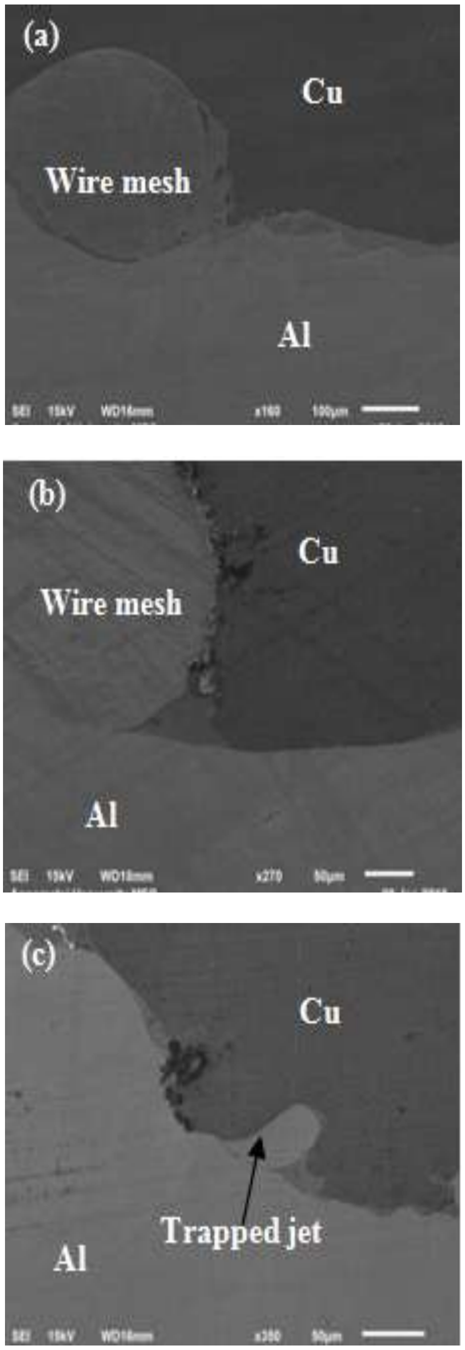

Fig. 2 Microstructure of Al-Cu explosive clad

(a) R-0.7 (b) R-0.8 (c) R-0.9

3.2 Microhardness

The Vickers microhardness of the explosive welded aluminum-copper with stainless steel wire mesh interlayer (Fig.3) is measured at uniform interval applying a load of 100 g. Post weld hardness is higher than base metal forming a typical curve. The maximum hardness (190 HV) is measured at the interface owing to the presence of higher strength stainless steel and sudden deformation as reported by Saravanan and Raghukandan [11]. There is no significant variation in hardness is observed away from the interface.

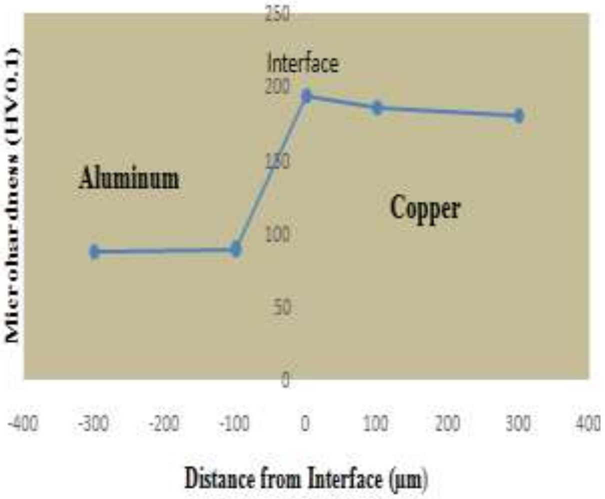

Fig. 3 Microhardness across the explosive clad

3.3 Corrosion

The specimens were recovered from the corrosive environment and cleaned as per EN ISO 7384 standards, weighed and the variation in weight per cm^2 surface area were determined. The weight of wire mesh interlayered Al-Cu explosive clad decreases for all conditions as corrosion affects the copper not on aluminum. The variation in weight (original weight-14.76 gm) after 24, 240 and 720 hours are given in Table.1. The corrosion rate is not significant maximum initially and tends to reduce over time and is consistant with Acarer [2] who cladded aluminum-copper. Hence it can be inferred that aluminum-copper explosive clads can safely be employed in corrisive environments.

Table 1 Corrosion test

Sl. No.	**Time** (Hrs)	**Wt. after testing** (gm)	**Wt. Reduction** (%)
1	24	14.72	0.2710
2	240	14.65	0.7452
3	720	14.58	1.2195

3.4 Weldability Window

Weldability window contains straight and curved boundaries comprising of lower limit,upper limit, right limit, left limit, transition, minimum and maximum bend angle and critical angle for jetting [12].Weldability window is drawn between dynamic bend angle and collision velocity. Weldability window for aluminum-copper explosive cladding is developed based on enperical relation reported by earlier researchers [12-14] and shown in Fig.4. The lower limit of weldability window can be calculated using

$$\beta = K_1 \sqrt{\frac{H_V}{\rho V_C^2}} \tag{1}$$

Where H_v is the Vickers hardness number in N/mm^2 V_c is the horizontal collision velocity (m/s) and ρ is density in kg/m^3 of flyer plate. The value of k_1 is 0.6 for high quality pre cleaning of surfaces, 1.2 for imperfectly cleaned surfaces and 0.85 for general cases. The upper limit of welding beyond which flyer gets damaged which depends on the thickness of flyer plate and is given by

$$\sin\frac{\beta}{2} = \frac{K_3}{\left(t^{0.25} . V_C^{1.25}\right)} \tag{2}$$

Where $k_3 = C_f/2$, $C_f = \sqrt{K / \rho}$, K= E/3(1-2γ), Where C_f is compressive wave velocity, t is the thickness of flyer plate, Vc is the horizontal collision point velocity, k is the bulk modulus and E is the young's modulus.

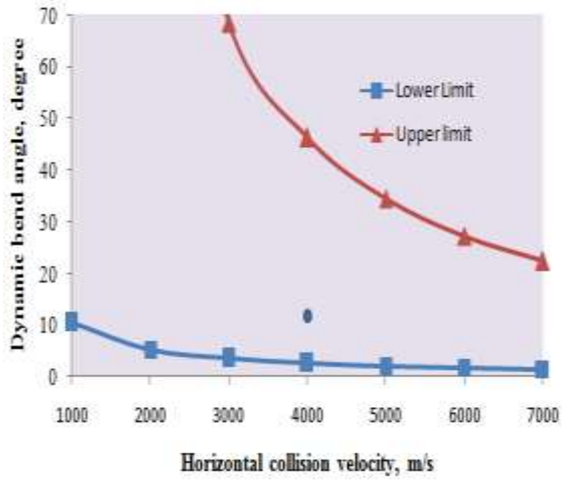

Fig. 4 Weldability window for Al-Cu explosive cladding

The accurate boundaries of the window are difficult to be defined as it involves various assumptions and constants during the formulation of window. The properties of flyer plate are more influential in formulating the window. Any point within the window would mean successful welding with a wavy interface which is characteristic of a strong weld. the experimental conditions attempted in this study falls within the weldability window results in wavy interface as detailed in previous section.

4. CONCLUSIONS

The objective of this present study is to determine the microstructural and mechanical properties of explosively cladded aluminum-copper plates with a wire mesh interlayer. The following conclusions were drawn from this study

a) The nature and properties of aluminum-copper explosive clad with stainless steel wire mesh was dictated by loading ratio.
b) Introduction of wire mesh significantly alters the interface microstructure.
c) Microhardness closer to the interface was higher due to the sudden impact followed by plastic deformation.
d) Corrosion studies confirm negligible reduction in material mass indicating, aluminum-copper explosive clad was very effective in corrosive environment.
e) Weldability window for Al-Cu explosive clad was developed and correlated with experimental conditions.

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