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EFFECT OF SS 316 WIRE MESH AND SiC_P CERAMIC PARTICLES ON EXPLOSIVE CLADDING OF DISSIMILAR ALUMINIUM Al 5052 AND Al 1100 PLATES SUBJECTED TO VARIED LOADING RATIOS

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ABSTRACT

In this study, dissimilar grade aluminium plates (Al 5052, Al 1100) are explosively cladded with the aid of chemical explosive, by placing a stainless steel (SS 316) wire mesh and silicon carbide (SiCp) ceramic particle in between, at varied loading ratios (mass of explosive/mass of flyer plate). Interfacial microstructure of the explosive clad reveals the transformation of straight to wavy morphological interface as the loading ratio is enhanced. Vickers hardness value of the explosive clad increases with loading ratios and the maximum hardness is witnessed at the wire mesh. Ram tensile and shear strengths of the wire mesh – SiCp reinforced dissimilar aluminum clad are higher than the base alloys. Further a welding window - an analytical estimation - is formulated and correlated with the experimental results.

Keywords*: Explosive cladding, Aluminium composite, Wire mesh, Ceramic particle, Mechanical Strength and Welding window.*

1. Introduction

Aluminium based composites are stronger, lighter and less expensive, and attract major applications ranging from predominantly aerospace and automobile to defense, marine, sports and recreation industries [1]. Joining of dissimilar grade aluminium by conventional joining techniques is complex due to the non-availability of relevant filler metals to adopt with the solidification mode. In addition, oxide formation in the molten stage results in brittle intermetallic compounds which weakens the clad strength and inhibit atoms from diffusing across the interface and results in a poor metallurgical bond [2]. Explosive cladding is a solid state process and a reliable alternative with a shorter processing time, wherein controlled explosion impose two or more metals to join together. The energy derived from a chemical explosive is used to accelerate flyer plate across a predetermined standoff-distance over the base plate to be hard-pressed together to form a clad [3-5].

Acarer et al. [6] investigated the effects of process parameters on microhardness and shear bond strength of the dissimilar explosive clad, however they failed to adopt the design of experiment (DOE), which Raghukandan [7] adopted to evaluate the effects of process parameters viz., flyer plate thickness, explosive loading ratio (*R*), angle of inclination (α) and standoff distance on the tensile and shear properties of Cu-low carbon steel explosive clads. The analysis of shear strength of multilayer explosive cladding is reported by Mousavi et al [8]. Durgutlu et al. [9], from his experiments in explosively welded copper and stainless steel, showed that the wavelength and amplitude of the interfacial waves increases with stand-off distance. Likewise, Dyja et al. [10] performed microstructural and mechanical studies on dissimilar explosive clad Al-Cu bars in a cylindrical configuration. The production of fiber reinforced Al-SS-Al composite by explosive cladding was reported by Raghukandan et al [11].

Though numerous studies related to the effect of process parameters on explosive cladding of dissimilar metals are reported, limited literature are available on the production of composite plates by explosive cladding and hence is attempted. However, studies on wire mesh and ceramic particles positioned between participant metals have not been investigated. The goal of the study was to manufacture composite plates by explosive cladding.

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To this aim, microstructural and mechanical properties of the wire mesh and ceramic particles reinforced with aluminium explosive clads are determined as per relevant standards and the results are reported.

Table 1 Mechanical Properties of participant materials

Material Property	Al 5052 (flyer plate)	Al 1100 (base plate)	SS 316 (Wire Mesh)
Density, (Kg/m^3)	2680	2730	8000
Vickers hardness, (H_v)	68	52	129
Young's modulus, (GPa)	70.3	68	193
Bulk sound velocity, (m/s)	6300	6300	5800
Ultimate tensile strength, (MPa)	228	175	580
Tensile yield strength, (MPa)	193	148	290
Shear strength, (MPa)	138	108	238

2. Experimental Procedure

The explosive cladding experiments were conducted with a stainless steel wire mesh (Wire mesh orientation {WMO} 45^o, mesh size-0.704 mm, wire diameter-0.34 mm) and SiCp ceramic particles 105 µm to 125 µm size with a weight percentage of 1.5 as reinforcements between the flyer (Al 5052) and base plate (Al 1100) as shown in Fig. 1.

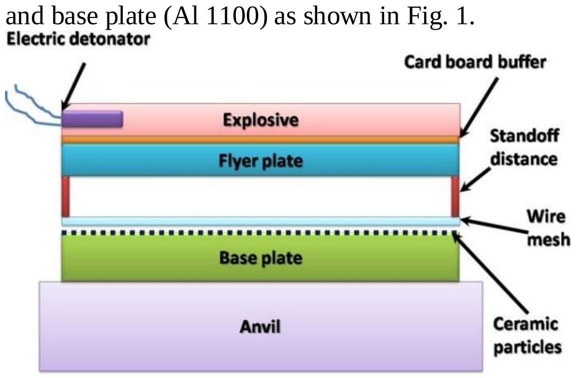

Fig. 1 Parallel configuration Explosive Cladding.

Aluminium 5052 (size of 80 mm x 60 mm x 2 mm) and Al 1100 (80 mm x 60 mm x 5 mm) were used as flyer and base plates respectively. The mechanical properties of the participant metals are tabulated in Table 1.

Slurry chemical explosive (SUN 90) (detonation velocity, V_d - 4500 m/s and density, ρ - 1.2 g/cm^3) was the energy generator, detonated by an electric detonator. Experiments were conducted with varied loading ratios, *R*, (0.6, 0.75 and 0.9) and with a constant standoff distance of 6.5 mm.

Explosively cladded specimens were sectioned parallel to the detonation direction for examining the nature of interface and the samples were prepared through standard metallographic practice. The specimens were analyzed with Optical Microscope (VERSAMAT-3) equipped with Clemex image analyzing system. Vickers hardness was measured across the interface in a HMV-2T Vickers hardness tester by applying a 100 g load at uniform intervals. Ram tensile test specimens (Fig: 2) were prepared in the direction of detonation as per MIL-J-24445A standard and shear test samples (Fig: 3) were fabricated as per ASTM B898-99 standard. Both tests were conducted in UNITEK-94100 Universal Testing Machine by applying uni-axial compressive force on explosive clads.

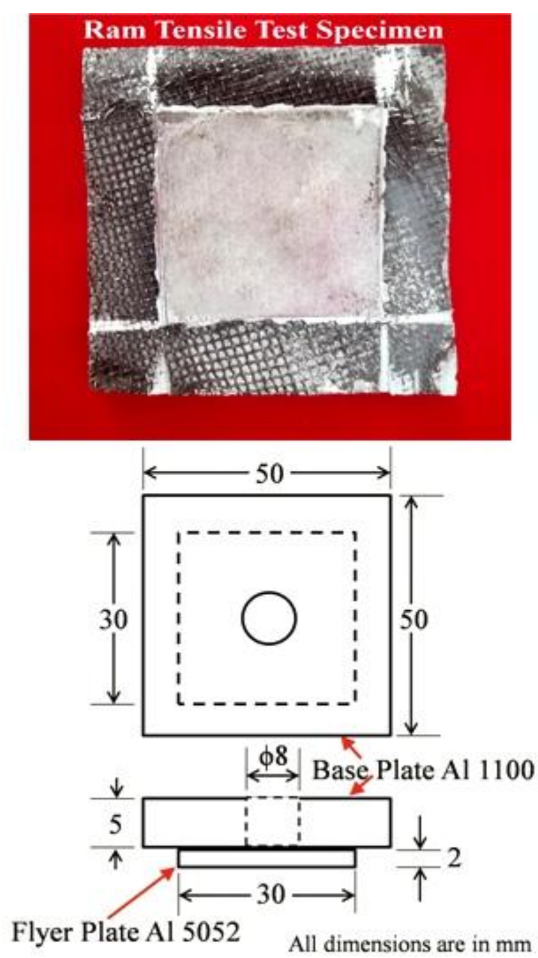

Fig: 2 Ram Tensile Test Specimen with dimensions.

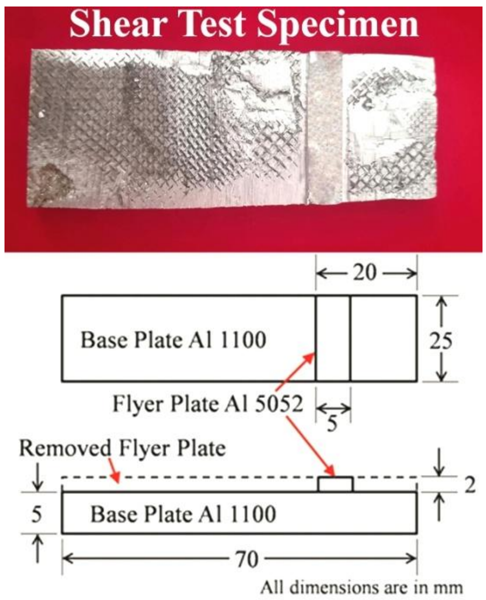

Fig: 3 ASTM Side Shear Test Specimen with dimensions.

3. Results and Discussion

3.1. Microstructure

Microstructural observation of the explosive clads shows both straight and wavy morphologies {Fig. 4(a-c)}. Flyer (Al 5052) and base plates (Al 1100) are identified by the lighter and darker grey texture respectively. The influence of loading ratio, R, on the interface microstructure is revealed in Fig. 4(a-c). White oval and elongated white streaks shows the longitudinal and transverse sections of the wire mesh at the interface. Ceramic particles (SiCp) are visible as black spots around the wire mesh. Increase in the loading ratio shows the transition from a straight to wavy morphology, following high kinetic energy dissipation at the interface. The shear deformation together with the momentum of the flyer plate forms a hump that deflects the jet upwards and completely blocks off the jet which induce the formation of 'Trapped jet' and is observed for a higher loading ratio (R-0.9).

The interfacial microstructure for a lower loading ratio (R-0.6), reveals a straighter interface with minimal amplitude (30 µm) as observed in Fig. 4(a). At the lower loading ratio, the flyer plate velocity, V_p, and kinetic energy spent at the interface is minimum, leading to the formation of straight interface with lower amplitude at the lower explosive mass. This is in agreement with Saravanan et al. [12] who cladded dissimilar metal combinations (Aluminum-Low carbon steel, Copper-Stainless steel, and Aluminum-Copper). When the explosive loading ratio, *R*, is increased to 0.75, the metal flow around the collision point becomes uneven and indecisive due to the enhanced kinetic energy available to create a wavy interface with higher interfacial amplitude (75 µm) as observed in Fig. 4 (b)

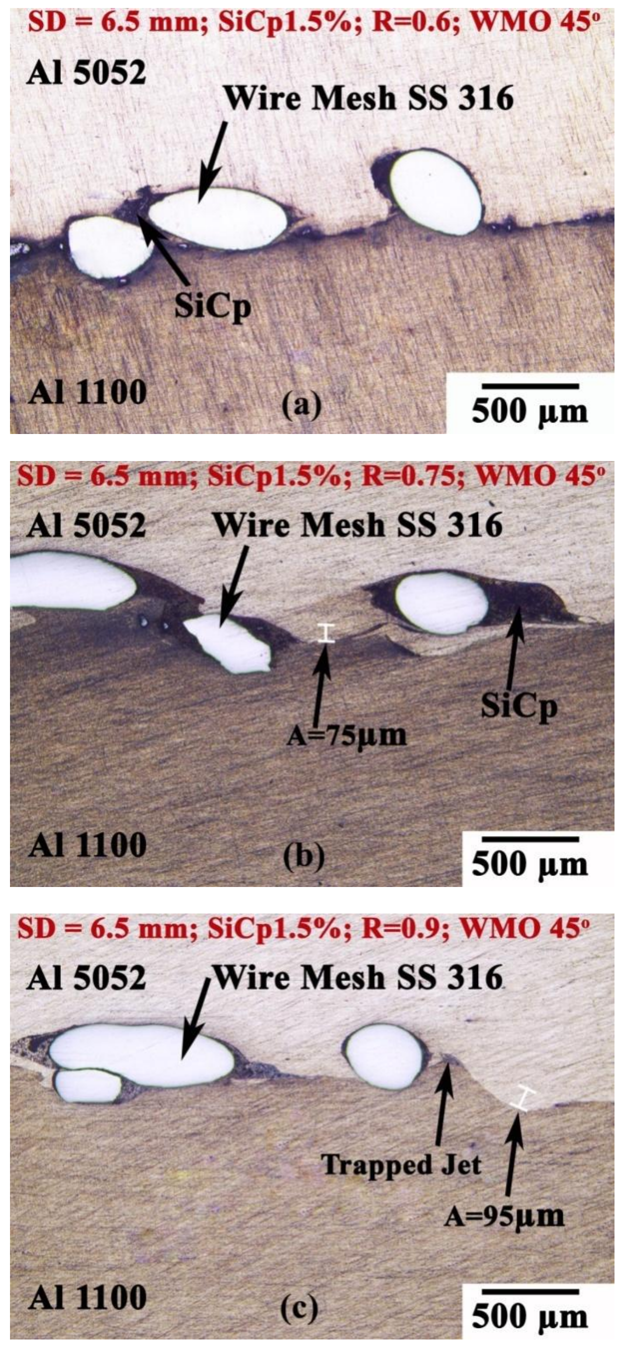

Fig. 4 Microstructure of Al-Al explosive clad.

Ceramic particles with reduced size are spread around the intersecting points of the woven wire mesh. When the loading ratio is further amplified to 0.9, amplitude increases (95 μm) owing to the maximum or largest kinetic energy spent at the interface to result in the highest interfacial amplitude. The increase in kinetic energy forces the ceramic particles away from the interface which reduces the mechanical strength and detailed in the next section. In addition, trapped jet formation contributes to the reduction in mechanical strength as well. It is evident from the micrographs that the experimental condition with loading ratio, R, of 0.75 is favorable. By raising the loading ratio R, the flyer metal flow over and around the wire mesh and SiCp to form a very good strength.

3.2. Microhardness

Fig. 5 illustrates the measured microhardness values across the interface of explosive clad specimens at different loading ratios. It is evident that a substantial increase in hardness is observed near the interface due to plastic deformation of plates, presence of wire mesh and ceramic particles. Maximum hardness values are observed at the interface for a higher loading ratio (*R*-0.9), while minimum is recorded for a loading ratio of 0.6 and the results are consistent with the earlier researchers [12-15]. Moreover, a 7.5 % boost in hardness is observed in the interface by escalating the loading ratio R, from 0.6 to 0.75. Further raise in the loading ratio, R from 0.75 to 0.9 leads to a 0.8 % increase in hardness, as the ceramic particles are expelled from the interface as discussed in the previous section. In addition, the enhance in hardness is due to the cold plastic deformation experienced adjacent to the interface during the collision while explosive cladding is carried out as discussed by Prabhat et al [14].

The tensile and shear strength increase with the loading ratio, R from 0.6 to 0.75 (Fig. 6). Further raise in loading ratio (R-0.9) leads to a marginal decrease in strength due to the formation of ‘Trapped Jet’ as observed in earlier section. During explosive cladding, the induced stress due to collision increases, leading to higher deformation as reported by Saravanan et al [13]. Straight interface observed for a loading ratio, R-0.6 leads to better strength than the base alloys, due to the presence of ceramic particles trapped between the wire mesh and the base plate. Further, formation of wavy interface and the presence of ceramic particles (SiCp), contributes to the improved bond strength for a loading ratio R-0.75.

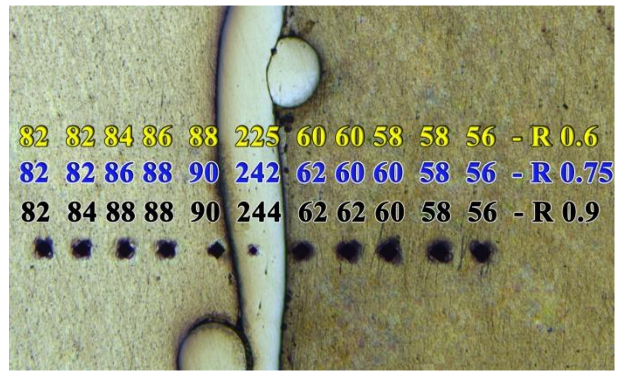

Fig. 5 Vickers Hardness variation across the interface

3.3. Composite Bond strength

While the loading ratio is further amplified (R-0.9), a slight shrink in bond strength is witnessed, due to the absence of ceramic particles and Jet trapping at the interface. It is concluded that a strong Al-Al explosive clad with good microstructural and mechanical properties is attained for a loading ratio of 0.75.

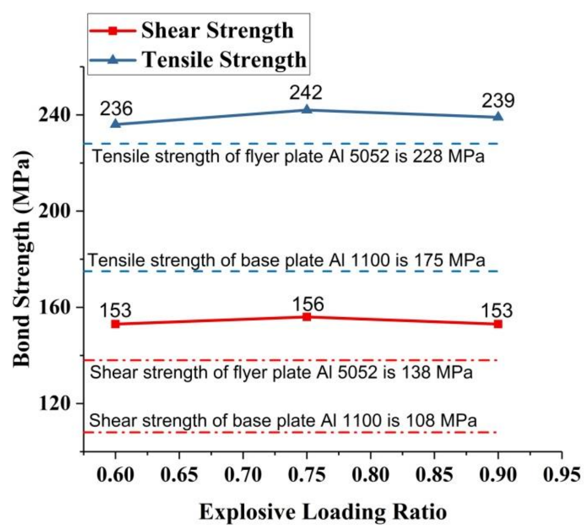

Fig. 6 Bond strength of explosively cladded plates measured by the tensile and shear test.

3.4. Welding Window

The ability to predict either bonding or no bonding regions under different cladding conditions is very critical. Hence, the welding window - an analytical estimation - is implemented to predict the effects of process parameters on the nature of the interface [12-15]. Considerable progress is made by various researchers to establish the optimum operational parameters to produce a quality clad.

Mousavi and Sartangi [16] proposed a weldability criterion based on the flyer plate velocity and mechanical properties. Saravanan and Raghukandan [15] developed a tri-axial welding window with dynamic bend angle '*β*' welding velocity, V_C and flyer plate velocity V_P as ordinates.

In this study, the welding window for Al-Al is developed with dynamic bend angle and welding velocity as ordinate and abscissa respectively (Fig. 7), and the experimental results are correlated. The lower and upper boundaries of the window are critical, as it denotes the region of successful cladding with a wavy morphology. The lower boundary is determined by [15]

$$\beta = K_1 \sqrt{\frac{H_v}{\rho V_C^2}} \quad (1)$$

Where K_1 is a constant equal to 1.2, H_v and ρ represent hardness and density of the participant material.

The upper boundary of the window is determined by the empirical relation [15]

$$\beta = 2 \sin^{-1}\left(\frac{K_2}{t^{0.25} * V_C^{1.25}}\right) \quad (2)$$

Where $K_2 = C_f/2$, $C_f = K/\rho$, $K = E/3(1\text{-}2v)$, where C_f is compressive wave velocity, t is the thickness of flyer plate, V_c is the horizontal collision point velocity, K is the bulk modulus, E is the Young's modulus, and v is the Poisson's ratio of the parent metal.

The lower boundary of the window is more critical as it indicates the minimum collision velocity and dynamic bend angle. The experimental conditions closer to lower boundary is preferable because a lower collision angle results in small waves and lower plate velocity reduces interfacial layer and defects.

The experimental conditions falling within the lower and upper boundaries results in a successful clad. For a lower loading ratio, experimental condition falls closer to the lower boundary, resulting in a successful clad with a straight interface. However, for a higher loading ratio, experimental condition falls within the boundaries, leading to a smooth wavy interface. Hence the welding window can effectively be employed for predicting the nature of interface in Al-Al explosive clads.

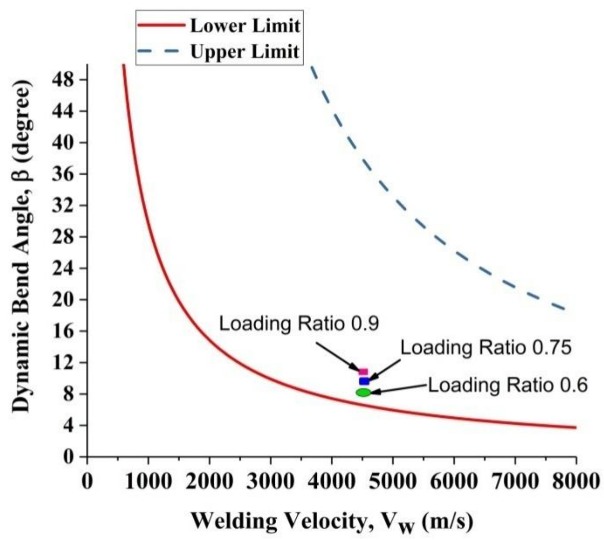

Fig. 7 Welding window for Al-Al-Explosive clads.

4. Conclusions

In this study, effect of wire mesh and ceramic particles on explosive cladding of dissimilar aluminium plates subjected to varied loading ratios is studied and the following conclusions are drawn:

The bond interface transforms from straight to wavy interface by increasing the loading ratio R, the flyer metal flow over and around the wire mesh and SiCp to form a very good strength.

The microhardness increase, near the welded interface, is due to the presence of ceramic particles, which ultimately enhances the hardness of the composite.

The highest shear bond strength of explosively welded joints is observed for wavy interface with respect to the loading ratio, R - 0.75. This may be attributed to the strong interlocking of parent and flyer plates with the wire mesh and ceramic particles at the interfacial bonding. However, at high explosive loading ratio (R - 0.9), the tensile and shear bond strength of aluminium composite reduces due to the formation of 'Trapped Jet' at the interface.

The experimental conditions attempted in the study are falling within the lower and upper boundaries of welding window.

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