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EXPLOSIVE CLADDING OF ALUMINIUM 5052-STAINLESS STEEL 304

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ABSTRACT

This study addresses the effect of process parameters viz., loading ratio (mass of explosive/mass of flyer plate) and preset angle on dynamic bend angle, collision velocity and flyer plate velocity in dissimilar explosive cladding. In addition, the variation in interfacial microstructure and mechanical strength of aluminium 5052-stainless steel 304 explosive clads is reported. The interface exhibits a characteristic undulating interface with a continuous molten layer formation. The interfacial amplitude increases with the loading ratio and preset angle. Maximum hardness is observed at regions closer to the interface.

Keywords: *Explosive cladding, Aluminium, Stainless Steel, Microstructure and Hardness.*

1. INTRODUCTION

Aluminium-steel bimetals are employed as super structure material in ship building and as high speed transition joints in industrial requirements, owing to light weight and good corrosion resistance. The aluminium-steel clad is preferred than solid aluminium/steel to attain better corrosion resistance, enhanced strength accompanied with reduced cost [1]. Welding of aluminium-steel by traditional methodologies leads to poor metallurgical bonding, due to the formation of detrimental intermetallic compounds at the interface, which weakens the mechanical behaviour of the clad [1]. In this context, explosive cladding, a solid state metal joining technique, provides a reliable alternate for cladding aluminium-steel plates, free from intermetallic compounds [2]. In explosive cladding, the unique undulating nature and the consequent mechanical properties of the explosive clad is dictated by the appropriate selection of process parameter viz., properties of the explosive, flyer plate thickness, distance of separation, loading ratio and initial angle [3]. Numerous researchers cladded dissimilar metals by altering the process parameters and studied their effect on interface microstructure and strength [4,5]. However, the studies related to study the effect of process parameters in explosive cladding of Al 5052-SS 304 is limited, and hence attempted. In this study, aluminium and stainless steel sheets are cladded at varied loading ratios and preset angles, and the variation in interface microstructure and mechanical strength are reported.

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2. EXPERIMENTAL PROCEDURE

Parallel and inclined explosive cladding configuration reported elsewhere [6], was attempted with aluminium 5052 (50 mm × 100 mm × 2 mm) and SS 304 (50 mm × 100 mm × 6 mm) plates as flyer and base plate respectively. The flyer and base plates are initially separated by 5 mm (standoff distance), which allows the flyer plate to reach its terminal velocity. The mating surfaces were mechanically polished and thoroughly cleaned by acetone, prior to experiments. The chemical explosive (density, ρ = 1.2 gm/cm^3, detonation velocity, Vd= 4000-4200 m/s) was packed above the flyer plate and detonated by an electric detonator, positioned at one corner. The loading ratio, R, was varied from 0.8 to 1.0, while the preset angle was varied from 0 to 5. The detailed experimental conditions are given in Table 1

Table 1. Experimental conditions

S. No	Loading ratio, R	Standoff distance, S (mm)	Preset angle, A (degree)	Dynamic bend angle, β (degree)	Collision velocity, V_c, (m/s)	Flyer plate velocity, V_p (m/s)
1	0.8	5	0	10.03	4000	699.4
2	0.9	5	0	10.89	4000	759.7
3	1.0	5	0	11.7	4000	816
4	0.8	5	3	13.03	3071.7	699.4
5	0.9	5	5	15.89	2728.8	759.7

Subsequent to cladding, samples for the microstructural observation under a VERSAMET optical microscope, were sectioned in the mid-section of the clad, parallel to the detonation direction. Specimens were polished with 600-1500 grades of emery papers, for 1 µm finish. Al 5052 was etched with kellers reagent, while SS 316 was etched with 2 % nital solution. The micro-hardness test was performed in a ZWICK micro-hardness tester with 4.9 N load and dwell time of 20 s. The average of three measurements, for each reading, was recorded.

3. THEORETICAL

In explosive cladding, the influencing parameters are determined by the following empirical expressions. The dynamic bend angle, β, is analytically determined by [2]

$$\beta = 2\sin^{-1}\frac{V_p}{V_d} \quad (1)$$

Where V_d is the detonation of the explosive and V_p is the flyer plate velocity, calculated by

$$V_p = 2V_d Sin\frac{\beta}{2} \quad (2)$$

The flyer plate collides with the base plate at collision velocity , V_c, is estimated by [2]

$$V_c = V_d\frac{\sin\beta}{\sin\alpha} \quad (3)$$

Where 'α' is the preset angle.

4. RESULTS AND DISCUSSION

4.1 Microstructure

The effect of varied loading ratio and preset angle on the unique undulating Al-steel explosive clad microstructure is shown in Fig.1. Interfacial melting is witnessed at few regions of the crest of the wave for all attempted conditions, due to enhanced temperature at specific locations. Further, grains across the periphery are finer and oriented towards the detonation direction.

The interface microstructure of Al 5052-SS 304 explosive clad, for a loading ratio, R of 0.8 and preset angle 0, show a wavy interface, having minimum interfacial amplitude and formation of a continuous strip of molten diffusion layer (Fig.1.a).

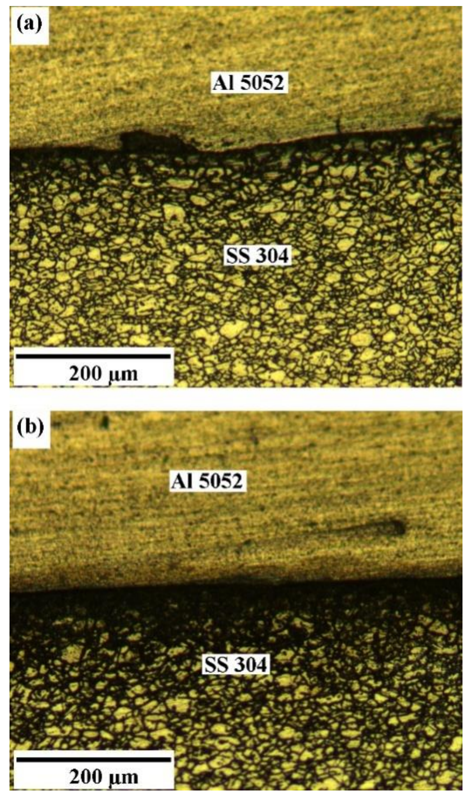

Fig. 1 Microstructure of the Al 5052- SS 304 explosive clad (a) R-0.8 A-0 (b) R-0.9 A-5

The molten layer, probable weaker locations in the clads, are formed due to the dissipation of the available kinetic energy at the interface. The kinetic energy dissipated (ΔKE) is represented by [7]

$$\Delta KE = \frac{1}{2}\frac{m_f m_b V_p^2}{(m_f + m_b)} \quad (4)$$

Where 'm_f' and 'm_b' denote the mass of flyer and base plate per unit area respectively and 'V_p' is the velocity of flyer plate. Bataev et al. opined that the molten layer formation at the interface is probable if the dissipated kinetic energy is utilized for melting the participant metals, instead of creating an undulating interface [8]. However, for a loading ratio, R-0.9 and preset angle 5 degree (Exp.5), flyer plate velocity and collision velocity are higher (Table 1), leading to the formation of additional molten layers are witnessed (Fig.1.b) at the interface. Further, the accumulated high temperature at the vicinity, during the high velocity impact, supports the formation of intermetallic compounds as well. Formation of intermetallic compounds at higher energetic conditions is consistent with the reports of earlier researchers [9,10]. Hence it is concluded that the kinetic energy dissipation characterizes the nature of interface.

4.2 Micro-hardness

Vickers micro-hardness of the pre clad Al 5052 and SS304 metals are 107 and 130 HV respectively. The harness value increases with loading ratio and the maximum hardness is witnessed at regions closer the interface for all attempted conditions, Post cladding, the hardness of Al 5052 increases by 25 to 30 percent, while SS 304 shows a 40 to 50 percent increases, consistent with Durgutlu et al [11]. The increase in hardness near the interface is due to impulse shock received by the participant metals and the high speed collision. The gradual decrease in hardness away from the interface is due to the subsequent reduction in plastic deformation.

5. CONCLUSION

The experimental study on explosive cladding of aluminium 5052-stainless steel 304 leads to the following salient conclusions.

1. The process parameters loading ratio and preset angle significantly influences the nature of Al-SS explosive clads.
2. The nature of interface is dictated by the kinetic energy available at the interface.
3. Thickness of intermetallic layer increases with loading ratio and preset angle.
4. Maximum hardness is witnessed at the vicinity of the interface.

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