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Microstructural and Mechanical Properties of Al 5052-SS 316 Explosive Clads with Different Interlayer

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Abstract. This study focuses on the effect different interlayer viz., copper, aluminium and stainless steel interlayer on the explosive cladding of aluminum alloy (Al 5052) - stainless steel (SS 316) plates subjected to varied process parameters viz., standoff distance, loading ratio (mass of explosive/mass of flyer plate) and inclination angle. The interface transforms from straight to wavy, while increasing the standoff distance and loading ratio. Moreover, increase in loading ratio enhances the wave length and the amplitude of interfacial wave. Mechanical testing viz., Vickers micro-hardness, Ram tensile and side shear test were conducted on Al 5052-SS 316 explosive clads and the results are reported. The maximum hardness is obtained for Al-SS 304-SS 316 explosive clads, while the tensile and shear strength of aluminum-SS 316 explosive clads with copper interlayer exhibit an acceptable joint strength.

1. Introduction

Aluminium - steel bimetals are employed in ship building and as high speed transition joints owing to light weight and good corrosion resistance [1]. Aluminium - steel clad plates replace solid aluminium or steel in structural, thermal expansion management and corrosion resistant applications. The reason for using aluminium - steel composite part instead of single metal is to lower cost with better corrosion resistance and improved strength. Welding of aluminium-steel plates by conventional methods is not viable due to the formation of undesirable intermetallic compounds, which weakens the clad strength and results in a poor metallurgical bond. Whereas, explosive cladding offer a feasible alternative to clad aluminium-steel plates devoid of intermetallic compounds at minimum cost. The quality of explosive clad is dictated by the proper selection of process parameter viz., standoff distance, loading ratio and inclination angle [2-4].

Acarer et al. investigated the effects of process parameters (explosive rate, anvil, stand -off distance) on microhardness and shear strength of the dissimilar explosive clad [5]. In another study, Raghukandan [6] adopted Response Surface Methodology to evaluate the effect of process parameters viz., flyer thickness, explosive loading ratio (R), angle of inclination and standoff distance on the tensile and shear properties of Cu-low carbon steel explosive clads. The effect of heat treatment on the aluminium-steel clad strength was reported by Mousavi et al [7]. Recently, Saravanan et al. employed different layer in Al-Cu explosive cladding and reported the significance of kinetic energy utilization on the nature of interface and strength [8]. Similarly, Tamilchelvan et al. cladded titanium-steel at varied loading ratios and standoff distances and who reported the significance of kinetic energy dissipation [9]. Though numerous attempts were made by earlier researchers to explosively clad dissimilar metals, the studies on the effect of different interlayer on Al-steel explosive cladding is limited, and attempted herein. In addition, the mechanical strength of Al-SS 316 explosive clads with different interlayer is determined experimentally, as per the relevant standards, and the results are reported.

2. Experimental Procedure

Inclined explosive cladding configuration reported elsewhere [10] was attempted with aluminum 5052 (50 mm × 100 mm × 2 mm and SS 316 (50 mm × 100 mm × 6 mm) as flyer and base plate respectively. The interlayers viz. Copper (chemical composition in wt%: Mn-0.0002, Si-0.0004, Mg-0.0001, Zn-0.00042, Fe-0.032, Al-0.001, Cu-Bal.), aluminium (chemical composition in wt%: Cu-0.0292, Mn-0.017, Si-0.101, Mg-0.0169, Zn-0.0158, Fe-0.479, Al-Bal) and SS 304 (chemical composition in wt%: Cr-18, Ni-8, Cu-0.05, C-.08, Si-0.34, Mo-0.05, Mn-2, P-0.04,S-0.03, Fe-Bal.) are positioned as interlayer between flyer and base plates. The flyer-interlayer and interlayer-base plates are separated by 10 mm, which allow the flyer plate to reach its terminal velocity. A constant loading ratio and inclination angle (R-1.0 &A-10°) are maintained and the detailed experimental conditions are given in Table 1. The chemical explosive (detonation velocity 4,000 m/s, density 1.2 g/cm^3) was packed above the flyer plate, and the detonator was positioned on one corner. The mating surfaces were mechanically polished and thoroughly cleaned by acetone, prior to experiments.

Post cladding, the clads were sectioned parallel to the detonation direction for examining the nature of interface, and the samples were prepared through standard metallographic practice. Vickers micro-hardness was measured based on ASTM E 384 standard [11] on a ZWICK micro-hardness tester with a load of 4.9 N and a dwelling period of 0.5 mm/min. The averages of three hardness values are values are presented. Ram tensile test specimens for each experimental conditions were prepared in the direction of detonation (MIL-J-24445A standard) and shear test specimens were fabricated as per ASTM B898-99 standard. Both the tests were performed in a servo controlled universal testing machine (UNITEK-94100) by applying uni-axial compressive force on the explosive clads and the results are reported.

Table 1 – Experimental conditions

No	Inter layer	Standoff distance, SD, mm	Loading ratio, R	Inclination angle, A degree	Kinetic energy loss,ΔKE, MJm^{-2}
1	Cu	10	1.0	10	0.76
2	Al	10	1.0	10	0.82
3	SS 304	10	1.0	10	0.82

3. Results and Discussion

3.1 Microstructural Characterization

The interface microstructure of Al 5052-SS 316 explosive clad with copper, aluminium and stainless steel (SS 304) interlayers (Fig. 1a-c) show wavy morphologies as reported by earlier researchers [12, 13]. Formation of straight interface is observed on the similar metal sides, whereas, they transform into a wavy interface on the dissimilar side. The undulating interfaces, a noticeable characteristic of explosive cladding process, provide a better interlocking mechanism as the interfacial morphologies are designed and regulated by the system parameters viz., collision angle, collision velocity, preset angle, nature of explosive, standoff distance and properties of participant metals.

The Al 5052-Cu-SS 316 (Fig. 1a) microstructure display a wavy interface devoid of defects, viz., cracks, trapped jet and molten layered zone. When copper is introduced as interlayer between Al-5052 and SS 316 clad, the interfacial waves (amplitude-27µm) are more pronounced on the first interface (flyer-interlayer), whereas the amplitude of interfacial waves (20 µm) declines on the second interface (interlayer-base).

The Al5052-SS316 clad with aluminium interlayer display a straight interface with devoid of crakes, trapped jet and molten layer. When aluminium interlayer is introduced, the

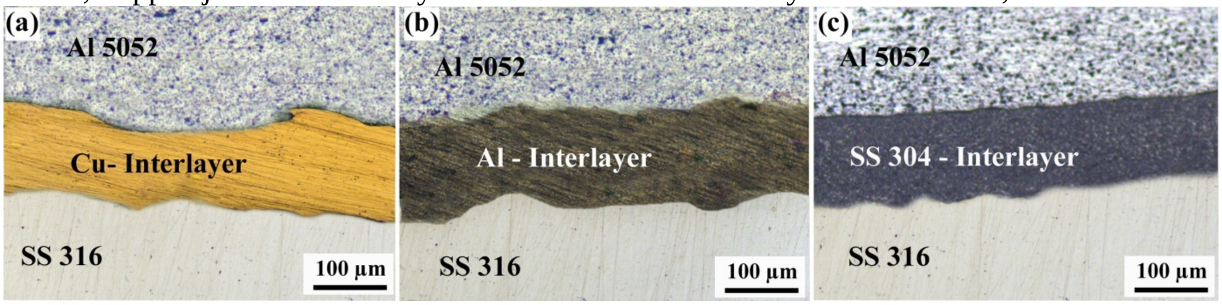

Fig. 1 (a-c) Microstructure of the Al-Steel explosive clad
(a) Cu interlayer (b) Al interlayer (c) SS 304 interlayer

available kinetic energy (0.82MJm^{-2}) increases, thereby metal flow around the collision point becomes unstable and oscillates, creating a wavy interface with a higher amplitude (Fig. 1b: 32 µm) consistent with the report of Somasundaram et al[14]. The kinetic energy spent during collision in explosive cladding with interlayer is given by an empirical relation [8]

$$\Delta KE = \frac{m_f m_b V_p^2}{2(m_{f+m_i})} + \frac{M m_b V_{p1}^2}{2(M_+ m_b)} \qquad (1)$$

Where 'm_f' is the mass of flyer plate per unit area, 'm_i' is the mass of interlayer per unit area, 'm_b' is the mass of base plate per unit area,' V_{p1}' is the flyer plate velocity and M is the combined mass of flyer plate and interlayer. The flyer plate velocity (V_{p1}) after the first impact is calculated by

$$V_{p1} = 2V_d \sin(\beta/2) \qquad (2)$$

where 'β' is the dynamic bend angle, calculated by

$$\beta = \left(\sqrt{\frac{k+1}{k-1}} - 1\right) . \frac{\pi}{2} . \frac{R}{(r + 2.71 + 0.184 t_e/SD)} \qquad (3)$$

Where R is the loading ratio, 'te' is the thickness of explosive and 'SD' is the standoff distance. K is a constant varies from 1.96 to 2.8 depends on the thickness of the explosive.

The Al 5052-SS304-SS316 (Fig.1c) shows a straight interface devoid of intermetallic compounds and amplitude of explosive clad reduces to resemble a straight interface, when a lower thermal diffusivity stainless steel 304 (4.03 x 10^{-6} m^2/s) is used as interlayer. Though wavy interfaces are preferred, straight interface provides better strength as reported by Kahraman et al. [15]. Hence, it is consistent in this study. The nature of interface viz., wavy, straight or formation of intremetallic compounds is also established by the thermal diffusivity (α) of the interlayer and defined by

$$\alpha = \frac{k}{\rho c} \qquad (4)$$

Where, *k, ρ* and *c* denote thermal conductivity, density and specific heat capacity of metals respectively [4].

3.2 Mechanical Strength

3.2.1 Microhardness test

The Vicker microhardness of the explosively cladded Al5052-SS316 plates with different interlayer are measured at uniform interval. The Vickers hardness closer to the interface of interlayered clad is twice higher and (20%) more than the base metals. This is because of interface hardening owing to sudden deformation. The increase of hardness in the base plate closer to the interface is expressed and frequently discussed by earlier researchers [5,9, 10&16]. The hardness profile for Al5052-

SS316 explosive clads with different interlayer emphasizes the significance of higher density interlayer. The highest hardness is achieved in stainless steel (SS 304) interlayer following the higher collision velocity. This causes strong plastic deformation due to higher kinetic energy utilization. This enhancement in hardness is not significant at region away from interface following the reduction in plastic deformation.

3.2.2 Ram tensile test

Ram tensile strength of clads are higher than the weaker parent metal (Al5052-180MPa). The lowest tensile strength is obtained (263MPa) when aluminium is employed as interlayer however it is 20% higher than weaker parent metal. The introduction of higher density metals enhances the kinetic energy utilization and influences the mechanical strength of explosive clads. The highest tensile strength value is obtained for experimental condition involving stainless steel (SS 304) interlayer (278MPa) shown in Table 2. Mastanaiah et al. opined that ram tensile strength of explosive clads are invariably higher than the weaker of the participating metals, which is consistent with this study [17].

Table 2 – Tensile strength of explosive clads

No	Standoff Distance (mm)	Loading Ratio (R)	Inclination Angle (A^0)	Interlayer	Tensile strength (MPa)	Shear Strength (MPa)
1	10	1.0	10	Al	263	180
2	10	1.0	10	Cu	273	184
3	10	1.0	10	SS 304	278	186

3.2.3 ASTM side shear strength

The compressive force is applied on the explosive clad by measuring load with respect to displacement, until the sample fails on universal testing machine at 0.5 mm/min and the results are shown in Table 2. The shear fracture took place in the weaker metal (Al 5052) indicating the interface has higher strength than the weaker metal. This is in agreement with the results on Mousavi et al. who joined Ti-steel. [18]. The maximum shear strength is obtained at Al5052-SS304-SS316 explosive clad due to higher kinetic energy utilization at the interface. The shear strength of the clads are 60% - 67% higher than the aluminum and prevailing between the shear strengths of parent metals, which is consistent with the reports of Rao et al [19].

Conclusions

1. Introduction of interlayer significantly increases the kinetic energy utilization, and thereby, the formation of intermetallic compounds at the interface is inhibited.
2. Microhardness closer to the interface is higher owing to the sudden deformation experienced.
3. Al5052-SS316 explosive clad with stainless steel interlayer exhibit better mechanical strength.
4. Ram tensile strength and shear strengths is higher than that of Al 5052 indicating the bond is stronger than the parent metals

References

[1] Tricarico, R. Spina, D. Sorgente, M. Brandizzi, Effect of heat treatments on mechanical properties of Fe/Al explosion-welded structural transition joints, Mater. Des. 30 (2009) 2693-2700. https://doi.org/10.1016/j.matdes.2008.10.010
[2] S. Mroz, G, Stradomski, H. Dyja, Using the explosive cladding method for production of Mg-Al-bimetallic bars, Arch. Civ. Mech. Eng. 15(2) (2015) 317- 323. https://doi.org/10.1016/j.acme.2014.12.003

[3] A. Britto, R Sagai Francis, Edwin Raj and M. Carolin Mobel, Prediction of shear and tensile strength of the diffusion bonded AA5083 and AA7075 aluminium alloy using ANN, Mater. Sci. Eng., A 692 (2017) 1-8. https://doi.org/10.1016/j.msea.2017.03.056
[4] S.Saravanan, K. Raghukandan, Thermal kinetics in explosive cadding of dissimilar metals, Sci. Technol. Weld. Joining. 17(2) (2012) 99-103. https://doi.org/10.1179/1362171811y.0000000080
[5] M. Acarer, B. Gulenc, F. Findik, Investigation of explosive welding parameters and their effects on micrhardness and shear strength, Mater. Des. 24 980 (2003) 659-664. https://doi.org/10.1016/s0261-3069(03)00066-9
[6] K. Raghukandan, Analysis of the explosive cladding of cu-low carbon steel plates, J.Mater. Process. Technol. 139 (2003) 573-577. https://doi.org/10.1016/s0924-0136(03)00539-9
[7] S.A.A Akbari Mousavi, A.A Dashti , A. Halvaee, Effect of Operational Parameters and Heat treatments on the Aluminium-Steel Explosively Composite Plates, Adv. Mater. Res. 264-265 (2011) 223-228. https://doi.org/10.4028/www.scientific.net/amr.264-265.223
[8] S.Saravanan, K Raghukandan, Influence of interlayer in explosive cladding of dissimilar materials, J. Mater. Manuf. Process. 28(5) (2013) 589-594. https://doi.org/10.1080/10426914.2012.736665
[9] P. Tamilchelvan, K. Raghukandan , S. Saravanan, Kinetic energy dissipation in Ti-SS explosivecladding with multiloading ratios, Iran. J. Sci. Technol. Transactions of Mechanical Engineering 38 (M1) (2014) 91-96.
[10] M. Acarer, B. Demir, An investigation of mechanical and metallurgical properties of explosive welded aluminum-dual phase steel, Mater. Lett. 62(25) (2008) 4158-4160. https://doi.org/10.1016/j.matlet.2008.05.060
[11] ASTM E 384-99, Standard Test for Microindentation Hardness of Materials, ASTM international, 1999
[12] S.A.A.Mousavi, P.F Sartangi, Experimental investigation of explosive welding of cp-titanium/AISI 304 stainless steel, Mater. Des. 30(3) (2009) 459-468. https://doi.org/10.1016/j.matdes.2008.06.016
[13] E.Zanani ,G.H Liaghat, Explosive welding of stainless steel-carbon steel coaxial pipes, Mater. Sci. 47(2) (2012) 99-103. https://doi.org/10.1007/s10853-011-5841-9
[14] Somasundaram, Raghukandan Krishnmurthy, Hokamoto Kazuyuki, Effect of process parameters on microstructural and mechanical properties of Ti-SS 304L explosive cladding, J. Cen. South. Univ. 24 (2017) 1245-1251. https://doi.org/10.1007/s11771-017-3528-3
[15] Kahraman N, Gulence B,fndik A, Corrosion and mechanical-microstructural aspects of dissimilar joints if Ti-6Al-4V and Al plates, Int. J. Impact. Eng. 34(8) (2007) 1432-1432. https://doi.org/10.1016/j.ijimpeng.2006.08.003
[16] Y.B. Yan, Z.W. Zhang, W. Shen, J.H.Wang, L.K. Zhang, B.A. Cin, Microstructure and properties of magnesium AZ31B-aluminium 7075 explosively welded composite plate, Mater. Sci. Eng. A. 527 (2010) 2241-2245. https://doi.org/10.1016/j.msea.2009.12.007
[17] P. Mastananiah , G. Madhusudhan Reddy, K. Satya Prasad , C.V.S Murthy, An investigation on microstructures and mechanical properties of explosive cladding c103 niobium alloy over C263 nimonic alloy, J. Mater. Process. Technol. 214(11) (2014) 2316-2324. https://doi.org/10.1016/j.jmatprotec.2014.04.025
[18] S.A.A Akbari Mousavi, S.T.S Al-Hassani, A.G Atkins , Bond strength of explosively welded specimens, Mater. Des. 29(7) (2008) 1334-1352. https://doi.org/10.1016/j.matdes.2007.06.010
[19] V.N. Rao, M.G. Reddy, S. Nagarjun, Structure and properties of explosive clad HSLA steel with titanium, Trans. Indian. Inst. Met. 67(1) (2014) 67-77. https://doi.org/10.1007/s12666-013-0313-3