MECHANICAL AND METALLURGICAL PROPERTIES OF ALUMINUM-STAINLESS STEEL EXPLOSIVE CLADS WITH ALUMINIUM INTERLAYER

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Abstract

In explosive cladding, intensive deformation due to high pressure and temperature emanating from chemical explosive is used to join similar and dissimilar metals. In this study, the interface morphology and tensile behavior of aluminum-stainless steel explosive clads were evaluated with multiple aluminum interlayers. The Al-SS304 explosive clads show straight and wavy interfaces depending on the kinetic energy available on the interface. A smooth interface devoid of intermetallics resulted when employing interlayer. Tensile test of Al-SS04 clads showed an acceptable bonding strength as per ASTM-E8 standard.

Keywords: *Explosive Cladding, dissimilar metals, interlayer, microstructure, strength*

1. Introduction

Explosive cladding is a solid state bonding technique used to craft a metallurgical bond between two metals by high velocity oblique impact, aided by controlled detonation of an explosive charge [1]. At elevated temperatures aluminum tends to form intermetallic compounds with other metals which complicate the production of their bimetals. Explosive cladding offers a reliable solution as the process is completed in few microseconds (about 50 µs). Aluminum-stainless steel is one of the popular bimetallic combination employed as transition joints in cryogenic heat exchanger, cryogenic liquid transport vehicles and as hull materials for ship building as they exhibit good corrosion resistance and shock bearing capacity. The microstructural behavior of the interface is concerned with the plastic deformation developed by the kinetic energy loss at the interface. Hence formation of intermetallic compounds at interface can be controlled by reducing the kinetic energy loss spent for plastic deformation [2]. Manikandan et al.[3] while cladding Ti-Steel employed a thin interlayer and reported good bonding strength due to reduction of kinetic energy loss to ambience. Banker [4] showed that an interlayer is beneficial in Tantalum-Steel clads for achieving good shear and tensile strength. The studies on the effect of multiple interlayer are limited and is attempted herein. Tensile tests were on Al-SS304 explosive clads as per ASTM-E8 and the results are reported.

2. Experimental Procedure

Fig.1 illustrates the explosive cladding process. Aluminum plates of 120 mm × 50 mm × 3 mm dimensions and stainless steel 304 of 120 mm × 50 mm × 6 mm dimensions were employed as flyer and base plates respectively. Aluminum with dimensions of 120 mm × 50 mm × 0.3 mm was employed as interlayer. All the plates were polished both mechanically and chemically to obtain a clean surface before cladding. Sun 90 explosive (density, ρ = 1.2 gm/cm^3, detonation velocity, V_d = 4000 m/s) was packed above the flyer plate and the detonator was positioned on one corner of the flyer plate as shown in Fig 1. The experimental conditions and chemical compositions of the participating metals are given in Tables 1 and 2 respectively. Inclined plate setup with preset angle of 15° and standoff distanve of 5mm was adopted.

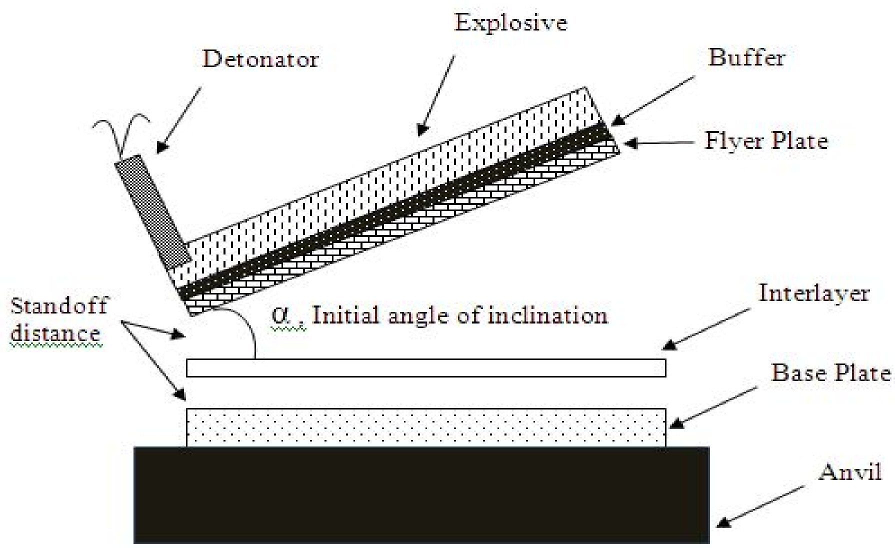


Fig.1. Inclined explosive cladding setup

Table 1. Experimental conditions and parameters

Experiment No.	Combination	No. of interlayer	Loading ratio, R	Standoff distance, S (mm)	Initial inclination angle, α (degrees)	Tensile strength (MPa)	
						Aluminum	Stainless steel
1	Al-SS304	0	1.0	5	15	274	505
2	Al-SS304	1	1.0	5	15		
3	Al-SS304	2	1.0	5	15		

Table 2. Chemical compositions of participant metals (wt %)

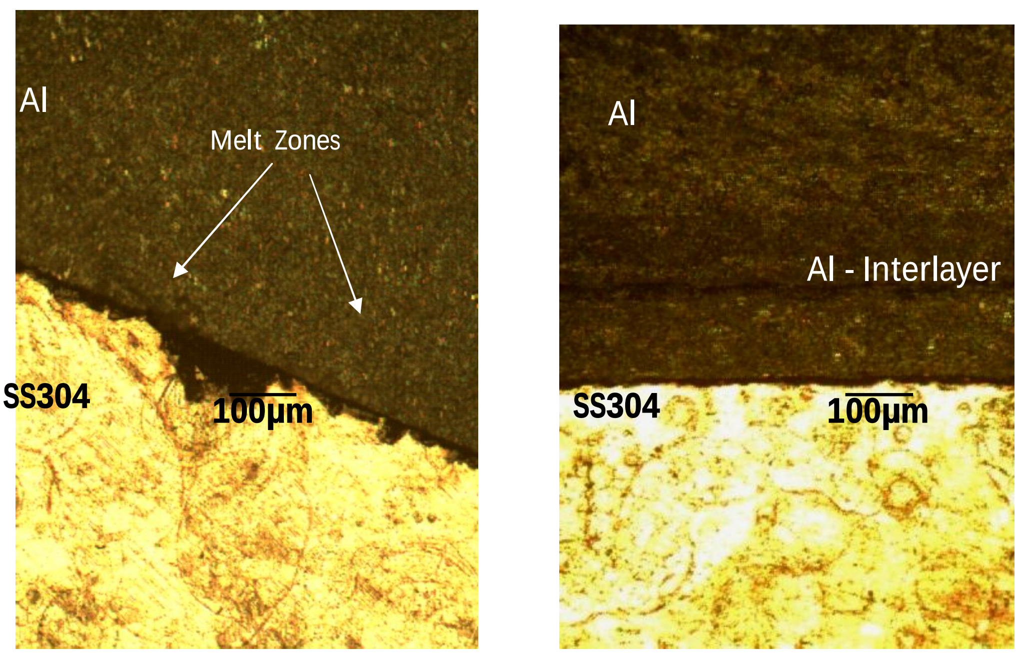
Elements	Cr	Ni	Mn	C	Si	Al	Cu	Fe	Mg	Zn
Al	-	-	0.0177	-	0.101	Bal.	0.0292	0.479	0.0169	0.0158
SS304	18.91	8.44	1.79	0.015	0.483	-	0.043	Bal.	-	-

After explosive cladding process, the interface microstructure was examined by optical microscopy following standard procedures. Tensile tests were carried out on Al-SS clads as per ASTM E8-04 on UNITEK-94100 universal testing machine.

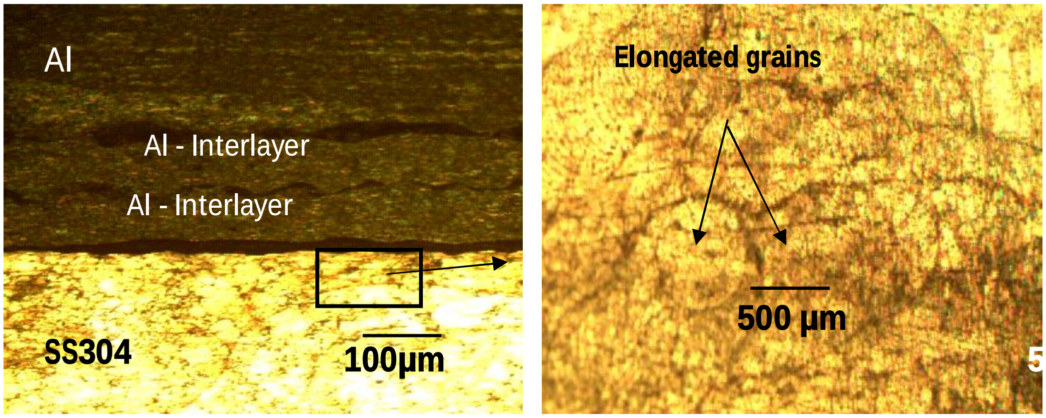
3. Results and Discussion

3.1 Microstructural studies:

Fig. 2 illustrates the interfacial microstructure of Al-SS304 explosive clads. The interfaces reveals characteristic wavy and straight morphologies as reported by earlier researchers[3-6]. In conventional two layer cladding, localized melt zones are observed (Fig.2.a) due to intense plastic deformation. When an interlayer is introduced, the kinetic energy spent at the interface reduces and consequently a straight interface devoid of intermetallic compounds resulted on both similar and dissimilar metal sides as reported by Han et al. [6]. When the flyer plate collides with interlayer part of the kinetic energy is utilized for plastic deformation at the first interface and the flyer-interlayer travels with the remaining energy to collide with base plate which resulted in straight interface. When multiple interlayers are employed, localized melting is seen at the vortex before or after each undulation between similar metals (Al-Al) whereas a thin



(a) (b)



(c) (d)

Figure 2. Microstructures of Al-SS304 explosive clads (a) without interlayer (b) with interlayer (c) with double interlayer (d)elongated grains continuous molten layer is obtained on the dissimilar metal side (Al-SS). In this case kinetic energy for plastic deformation is insufficient for diffusion of metals with neighboring metal. Hence, it is inferred that employing a single interlayer results in smooth interface than multiple interlayer. To notice the effects of plastic deformation over grains of participant metals, stainless steel microstructure at higher magnification was taken nearby interface. Stainless steel grains closer to the interface are elongated (Fig.2.d) parallel to the direction of explosion due to deformation caused by high speed collision. Raghukandan [7] reported that the grain structure in

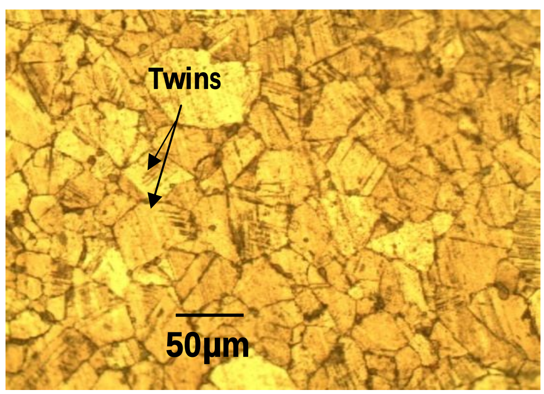


Figure 3. Microstructure of stainless steel 304

the immediate vicinity undergoes a tremendous amount of plastic deformation and is limited to a narrow region on each side of the interface. Microstructure composed of equiaxed austenite grains with mechanical or deformation twins are seen (Fig.3) due to high speed plastic deformation as reported by Saravanan and Raghukandan [8].

3.2 Tensile test

Tensile tests as per ASTM E8 were carried out at room temperatures. The experiments were conducted in a UTM applying a load of . Fractured sample after tensile test is shown in Fig 4. The tensile strength of Al-SS, Al-Al-SS, Al-Al-Al-SS clads were 302 MPa, 365 MPa, and 340 MPa respectively. These tensile strength of clads was lower than that of stainless steel, but it is higher than that of the weaker of the parent metals as reported by Acarer [9]. No separation at interface was observed after tensile test showing good bonding characteristics at interface. The Al-SS304 with a straight (exp.2) and wavy interfaces (exp.1 and 3) exhibit acceptable tensile strengths as reported by Durgutlu et al. [10].

Figure 4. Fractured Specimen after tensile test

5. Conclusion

1. Employing an interlayer controls the kinetic energy loss at the interface.
2. Single interlayer is suitable than double interlayer while employing high detonation velocity explosive.
3. Nature of interface is dictated by the kinetic energy spent during collision.
4. Grains near the interface were elongated in explosion direction owing to plastic deformation.
5. Tensile strength of the clads were higher than weaker of the parent metals**.**

6. References

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