ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 563–568

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Improved microstructure and mechanical properties of dissimilar explosive cladding by means of interlayer technique

Somasundaram Saravanan [a,*], Krishnamurthy Raghukandan [b], Kazuyuki Hokamoto [c]

[a] Department of Mechanical Engineering, Annamalai University, Annamalai Nagar, Tamilnadu 608002, India
[b] Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar, Tamilnadu 608002, India
[c] Institute of Pulsed Power Science, Kumamoto University, Kumamoto 860 8555, Japan

ARTICLE INFO

Article history:
Received 22 October 2015
Accepted 21 March 2016
Available online

Keywords:
Explosive cladding
Interlayer
Kinetic energy
Microstructure
Strength

ABSTRACT

Aluminium and copper plates are explosively cladded with Al 5052, copper and SS 304 interlayers and the results are reported. While continuous molten layer is obtained in conventional explosive clads, a smooth interface, devoid of defects, is obtained in interlayer laced explosive clads. The mechanical properties of interlayer laced explosive clads confirm higher kinetic energy utilization leading to stronger clad. Ram tensile, shear strengths and Vickers microhardness of Al–Cu explosive clad with different interlayers are higher than conventional two layer clad.

1. Introduction

Explosive cladding, a solid state autogeneous metal joining technique, employs an explosive force to craft an electron sharing metallurgical bond between dissimilar metals [1,2]. Aluminium–copper clad plates replace solid aluminium 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 aluminium–copper plates by conventional methods is not viable due to the formation of undesirable intermetallic compounds, whereas, explosive cladding offers a feasible alternative to clad aluminium–copper plates devoid of intermetallic compounds at minimum cost [4].

On detonation of the chemical explosive pack, the flyer plate collides with the base plate to convert the available kinetic energy (due to the movement of flyer plate) into thermal energy to create a plastic interface [3]. As the process is very rapid (in μs), the judicial selection of process parameters viz., loading ratio, standoff distance, properties of explosive and flyer plate dictates the kinetic energy spent at the interface and restricts the intermetallic compounds formed [1]. Hokamoto et al. [5] emphasized the significance of kinetic energy spent at the interface and deduced an empirical relation which depends largely on the

* Corresponding author. Tel.: +91 9443676936.
E-mail address: ssvcdm@gmail.com (S. Saravanan).

http://dx.doi.org/10.1016/j.acme.2016.03.009

flyer plate velocity and the mass of participant metals and given by

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

where, 'm_f' and 'm_b' represents mass of flyer and base plate per unit area respectively, 'V_p' is the flyer plate velocity. Tamilchelvan et al. [6] while cladding titanium–steel, concluded that the formation of detrimental intermetallic compound is imminent, when the kinetic energy spent at the interface is high during conventional two layer cladding (without interlayer).

Alternatively, a strong clad devoid of intermetallic compounds between metallurgically incompatible metals is achieved by employing an interlayer, which bridges the wide difference in properties (coefficient of thermal expansion, thermal conductivity, yield strength, melting point, density or elastic modulus) and increases the mutual solid solubility of the mating metals. Han et al. [7] reported the use of pure aluminium interlayer for explosive cladding of aluminium alloy and steel whereas, Manikandan et al. [8] attempted stainless steel interlayer of different thickness (0.3–1 mm) between titanium and stainless steel and recommended 0.3 mm thickness interlayer for stronger clads. Although, few researchers introduced an interlayer between flyer and base plates, the studies on the effect of different interlayers on the interface microstructure and strength of aluminium–copper explosive clad is limited and therefore, attempted herein. Mechanical testing viz., Vickers microhardness, ram tensile, and shear tests were performed on the interlayered Al–Cu explosive clads and the results are presented.

2. Experimental procedure

A parallel explosive cladding set up, with and without interlayer reported elsewhere [9], is attempted with 0.3 mm thick aluminium 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), 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) and stainless steel 304 (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) interlayers positioned between aluminium (flyer: 50 mm × 90 mm × 2 mm) and copper (base plate: 50 mm × 90 mm × 6 mm). The chemical composition and the mechanical properties of participant metals are given in Tables 1 and 2 respectively.

The flyer–interlayer and interlayer–base plates are separated by 5 mm and 7 mm respectively to allow the flyer plate to reach its terminal velocity. A constant loading ratio (R-0.8), is maintained and the explosive (detonation velocity-4000 m/s, density-1.2 g/cm^3) was packed above the flyer plate with the detonator positioned on one corner of the pack. After cladding, the clad plates were sectioned parallel to the detonation direction for examining the interface 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 500 g load as per ASTM E 384 standard [10] and the results are presented. Ram tensile test specimens were prepared in the direction of detonation as per MIL-J-24445A [11] standard (Fig. 1a), and the tensile testing was conducted by compressing the ram into the annular space drilled out in the base in a UNITEK-94100 universal testing machine by applying uni-axial load. For each experimental condition, two samples were tested and the average values are reported. The shear test sample (Fig. 1b) is fabricated as per ASTM B898-99 [12] standard with a compressive force applied on the Al–Cu explosive clad.

Table 1 – Chemical composition of parent metals.

Material	Composition (wt.%)						
	Cu	Mn	Si	Mg	Zn	Fe	Al
Al	0.0292	0.0177	0.101	0.0169	0.0158	0.479	Bal
Copper	Bal	0.0002	0.0004	0.0001	0.00042	0.0032	0.001

Table 2 – Properties of participant metals.

Metal	Al (flyer)	Cu (base)	Al 5052 (interlayer)	SS 304 (interlayer)
Density (kg/m^3)	2700	8900	2860	7900
Melting point (°C)	660	1085	640	1400
Thermal conductivity (W/m K)	200	400	138	16
Tensile strength (MPa)	117	210	180	510
Shear strength (MPa)	75	126	100	303

3. Results and discussion

3.1. *Influence of interlayer on microstructure*

The interfacial micrographs of Al–Cu explosive clad, with and without interlayer (Fig. 2a–d) display regular and sinusoidal wavy topographies. 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, plate velocity, preset angle, nature of explosive, standoff distance and properties of participant metals.

A distinct variation, however, is seen between the clads with interlayer and clads without interlayer. A thin streak of molten layer (Fig. 2a) is observed in the vicinity adjoining the interface in the clad without interlayer. 'Molten layer zones' are formed when the available kinetic energy is completely dissipated at the interface and enhances material reactivity. Consequently, the temperature of molten pool increases and which is cooled by the surrounding metal. The molten layers are brittle and are weak spots in clads. The 'melting' and the subsequent 'molten layers' are restricted to the close proximity, adjacent to the interface, as this region experiences very high shear due to 'surface jetting' and consequently, the incidence of strong clad without intermetallics diminishes. Lysak and Kusmin [13] opined that the kinetic energy spent at the interface transforms into stress which results in strain (g) being converted into thermal energy. The formation of continuous molten layer, at higher energetic conditions,