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Nature of the interface between AA7072 alloy explosively clad to AA8090 aluminium alloy

P. MALLESHAM
MVSR Engineering College, Hyderabad, India

A. A. GOKHALE*
Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500058, India
E-mail: amolhina@rediffmail.com

V. S. R. MURTI
Osmania University, Hyderabad, India

Aluminium-lithium based alloy plates were explosively clad with Al-1 wt% Zn alloy sheets. Clad plates were evaluated for bond continuity, interface shape, microstructure, variation of elemental concentrations across the bond interface, and bond strength. Comparisons of selected characteristics were made with roll clad sheets developed earlier.

Ultrasonic tests revealed the bond to be continuous at all locations except over 50 mm wide edges of the plates. Both straight and wavy shaped interfaces were observed, often alternating arbitrarily. Microstructures on each side of the interface were distinct and characteristic of the individual alloys bonded. No localized melting was observed in the interface regions. Elemental concentration varied sharply across the bond line in the as-clad condition, later changing to a smooth profile after heat treatment. The diffusion widths, when expressed as a percentage of the cladding thickness, were much smaller than the corresponding values of previously studied roll clad sheets.

'Tensile shear strength' of the clad samples exceeded the shear strength of monolithic Al-1%Zn alloy, thus indicating good bonding. The bond strength values were marginally lower than those of roll clad sheets. These differences could, perhaps, be due to the differences in the extent of elemental diffusion across the bond interface between the two techniques.

1. Introduction

In explosive cladding, a jet produced by high velocity oblique impact between two components being clad leaves two virgin and clean surfaces, which are pressed together to form a strong bond [1]. The rapid time scale of events and the presence of considerable bulk of the metal ensure minimum rise in the overall temperature of the metals. Consequently, no significant change in the chemical composition or properties (such as corrosion resistance) of the clad material takes place after cladding [2, 3].

Two fundamental variables in explosive cladding are: impact velocity and collision angle [4]. These variables, in turn, depend on process variables like detonation velocity, thickness and confinement of the charge, thickness of the flyer plate and buffer, standoff distance and static angle [1, 4]. In general, explosive welding exhibits great latitude in operating parameters and still produce acceptable bond quality. However, very low collision energy may lead to lack of bonding, and excessive collsion energy may produce large volumes of melt causing formation of brittle intermetallic compounds [5]. A wavy bond interface is usually present in explosive cladding, particularly when materials with similar densities are clad, though straight interfaces are also observed. No significant difference in the bond strength is found between these two types of interfaces [3]. Correlations between process parameters and interface shape characteristics have been proposed [6].

In the present investigation, sheets of Al-1%Zn alloy equivalent to alloy AA7072 were explosively clad to plates of Al-Li based alloy equivalent to AA8090. Such and other high strength aluminium alloys used in aeronautical applications are usually roll clad by pure Al or by Al-1Zn alloy [7]. The clad plates were characterised by a variety of techniques and compared, in some respects, to previously studied roll clad sheets of the same combination of alloys [8].

2. Experimental details

Al-Li-Cu-Mg-Zr (henceforth referred simply as Al-Li or the base alloy) and Al-Zn alloys (also referred as

*Author to whom all correspondence should be addressed.

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TABLE I Explosive cladding parameters

1	Stand off distance (distance between parent and cladding/flyer plate)	3 mm
2	Type of explosive	High explosive NaCl:TNT = 25:75
3	Density of explosive	2.3 g/cm^2
4	Initial angle of inclination	0°
5	Detonation velocity[a]	2500 m/s
6	Detonation angle[a]	5°
7	Flyer plate velocity[a]	218 m/s

[a]These parameters were estimated by M/s IDL based on their previous experience.

the cladding alloy) were melted in medium frequency induction furnace, and cast in mild steel moulds as plates of size 310 × 225 × 45 mm. The plate compositions were found to be: Al-2.42Li-1.22Cu-0.97Mg-0.06Zr and Al-1.0Zn (all wt%), with Fe and Si contents of 0.08 and 0.02% in both the alloys. These compositions correspond to AA8090 and AA7072 specifications, respectively. The Al-Li alloy plate was homogenized at 540°C for 40 h. Both the plates were skin machined to remove oxide scales, soaked at 475°C for 2 h and hot rolled to 24 and 4 mm thickness, respectively, at 10–20% reduction per pass. Both the alloys were annealed at 400°C for 2 h and air-cooled.

Al-Zn alloy sheets of 4.0 mm thickness were clad to 24 mm thick Al-Li alloy plates at M/s IDL, Ltd. The important explosive cladding parameters are listed in Table I. Samples were evaluated for (i) macroscopic nature of the interface, (ii) microscopic nature of the interface, (iii) elemental distribution across the interface before and after heat treatment (530°C for 1 h, water quenched and aged 170°C/24 h) and (iv) bond strength by shear test. 50 mm wide edge portions were excluded from further investigations, since ultrasonic tests carried out by the cladding agency revealed incomplete bonding in these regions. Elemental line scan data from previous studies [8] on roll clad samples of 4 mm total thickness and 0.24 mm cladding thickness was used for comparison.

Rectangular samples of size 65 × 15 mm with 2 mm wide slots on either side of the bond interface were used for the tensile shear tests (Fig. 1). Though the samples are pulled in tension, the slots on either side of the interface restrict the deformation to take place along the interface between the slots. Bond strength is calculated as the failure load divided by the interface area undergoing deformation. The base metal portion of the clad samples was milled to make its thickness equal to that of the cladding (4 mm).

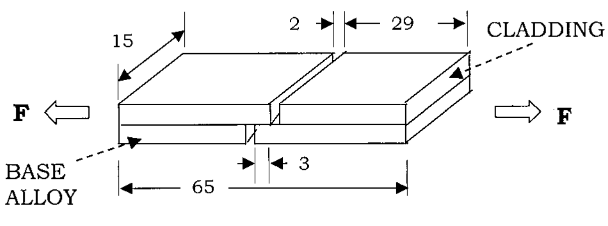


Figure 1 Tensile shear test piece for bond strength determination [4].

The results of the bond shear tests were interpreted as follows. Bonds having shear strength greater than that of the cladding alloy (weaker among the two alloys) were considered to be of acceptable quality [9]. For this purpose, shear strength of rolled and annealed cladding alloy sheet (from the same lot used for cladding) was determined using the same type of test used to evaluate bond strength. The samples were tested in Instron 1185 UTM at a crosshead speed of 1 mm/min. Bond strengths of previously produced [8] roll clad samples having ∼2 mm thickness of each alloy were used for comparison.

3. Results and discussion

Macroscopic observations of polished and etched samples revealed both straight and wavy type of interfaces, even occurring next to each other (Fig. 2). There were no systematic changes in the nature of the interface with reference to locations in the plates.

It is generally pointed in the literature [1, 4] that the transition from straight to wavy interface occurs when the collision velocity during cladding exceeds a critical value. Variations in the collision angle are also known to affect the nature of the interface. Since the collision angle is not expected to change during the progress of cladding (except during beginning and end), the variations in the collision point velocity must be responsible in the present case for the changes in the straightness of the interface. This, in turn, could be due to inadvertent local changes in the area density of the explosive material. In no case, signs of local melting (identified as a typical as cast structure) or pockets of parent metal entrapped in clad material (or vice versa) were noticed. These observations indicate that the collision point velocities must be lower than the critical velocity required for fusion to occur, and further, must be near the critical velocity required for straight-to-wavy transition in the interface to occur.

The interfaces were further examined at higher magnifications in the heat treated samples (Fig. 3), and were found to be continuous. No pores or line discontinuities were observed. Coarse intermetallics, sometimes reported in dissimilar element cladding [3], were also not seen in the interface region. Recrystallisation occurred in both the alloys, showing finer grain size in the base alloy and coarser grain size in the cladding sheet. The finer recrystallisation structure of the base alloy is related to the presence of Zr in the alloy.

Distribution of the alloying elements Cu, Mg and Zn across the bond interface was studied by Electron Probe Microanalysis (EPMA) line scan method. Li distribution could not be measured due to the limitation of the EPMA technique. Elemental line scans for these elements in the as-clad and heat treated conditions were recorded for both straight and wavy interfaces, but presented only for the straight interface (Fig. 4a, b). The approximate diffusion widths were measured along the elemental line scans, as the distance over which the X-ray intensity varies from high to low value, and given in Table II.

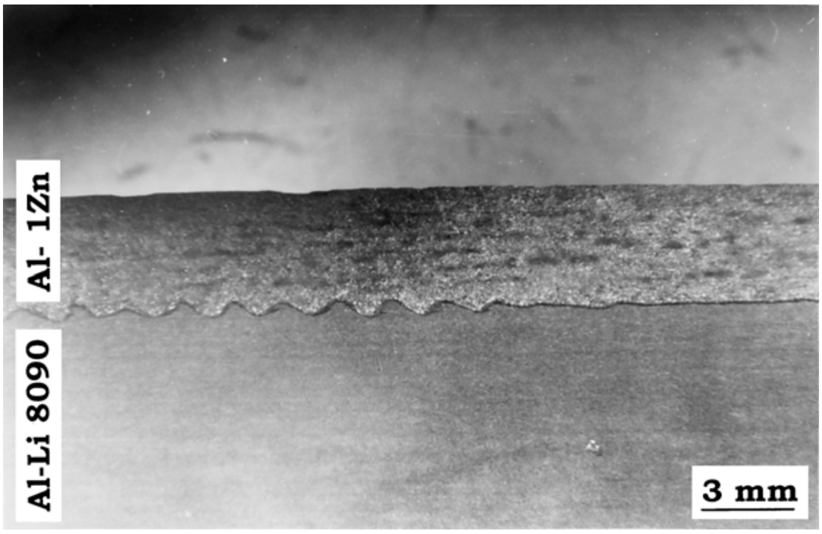


Figure 2 Macroscopic views of explosive clad interface showing combination of straight and wavy geometry.

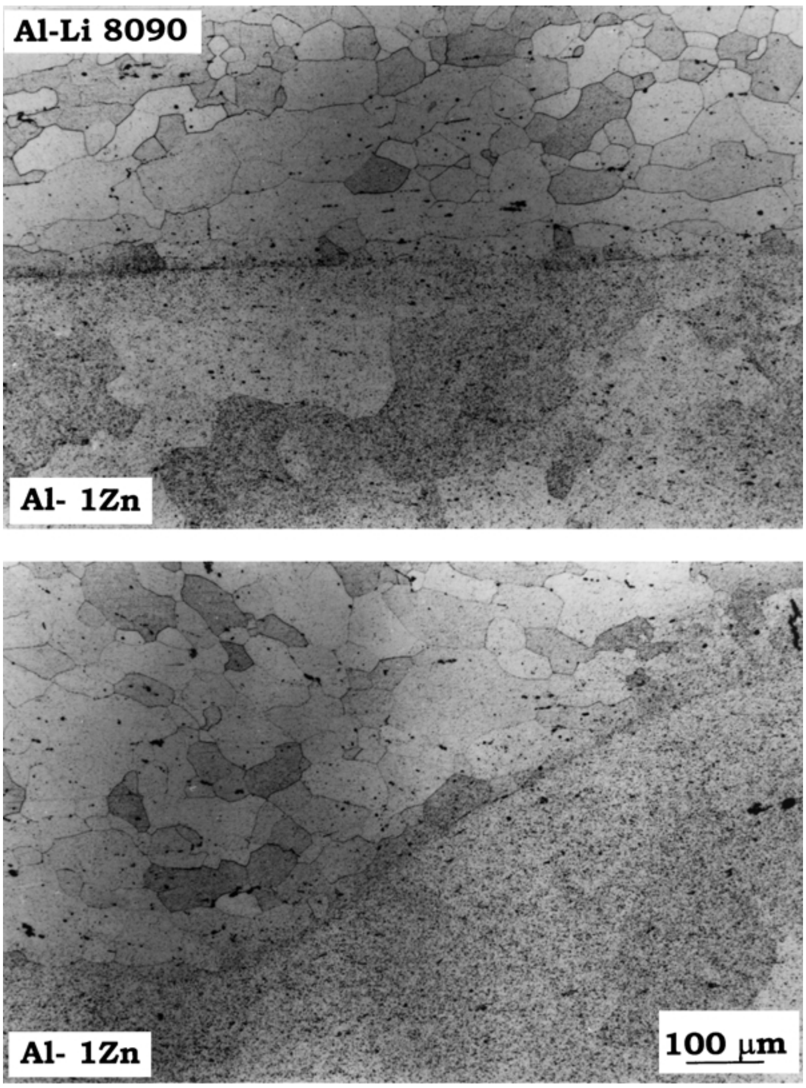
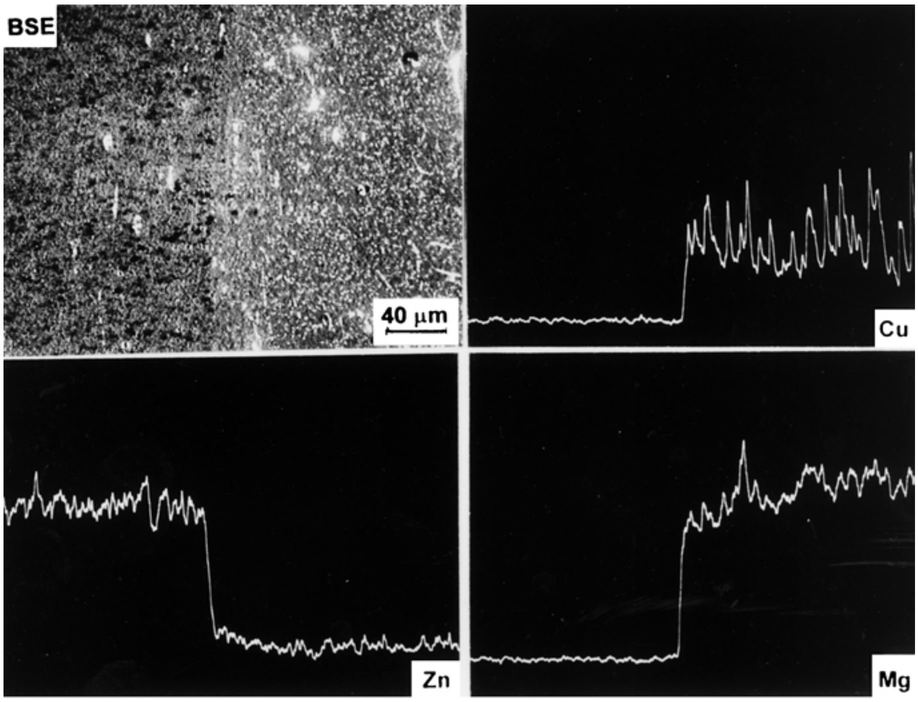
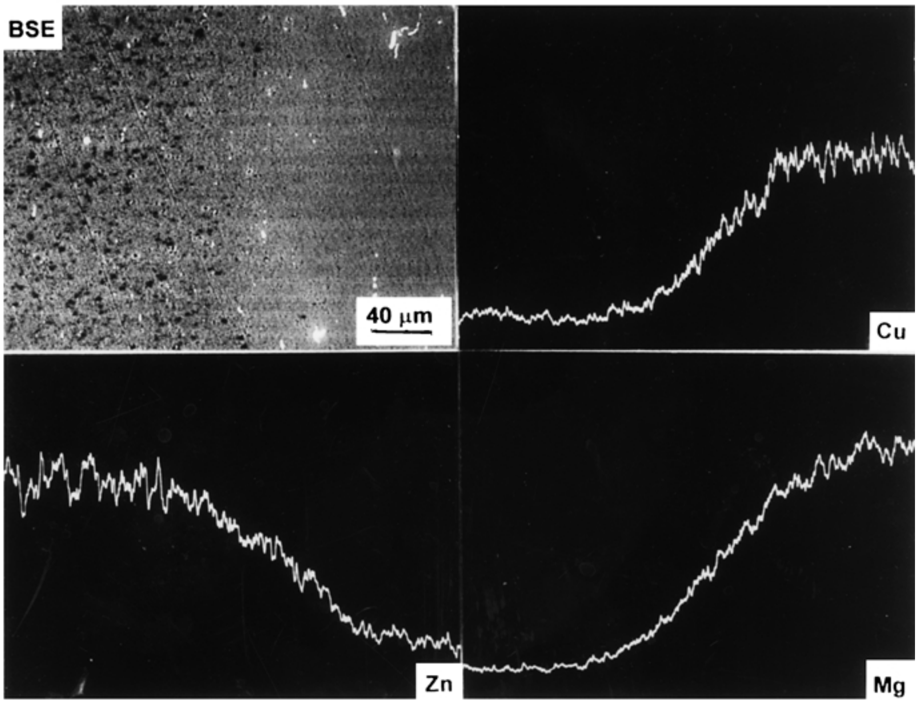


Figure 3 Microscopic views of explosively clad interfaces in straight and wavy regions in heat treated condition.

It was observed that, in the as-clad condition, the diffusion widths were slightly larger for the wavy interface than for the straight interface. This could be due to local heating, related to vortex formation and entrapment of kinetic energy (which manifests as wavy interface). However, it was found that the diffusion widths were much lower than those corresponding to roll clad alloys (Table II). This indicates that diffusion plays a larger role in hot roll cladding than in explosive cladding.



(a)



(b)

Figure 4 EPMA back scattered electron (BSE) image of the interface and elemental line scans across the straight interface. Alloy 7072 is on the left and alloy 8090 on the right side of the interface (a) as-clad condition and (b) heat treated condition.

After heat treatment, the diffusion width (measured at the inflection points of the wavy interface) was found to be greater in straight interface than in wavy interface. This could be related to the convergence of the elemental concentration gradients expected across the wavy interface where the line scans were taken (Fig. 5), reducing the diffusion flux. Once again, the diffusion widths were lower than in roll cladding (Table II). However, it is seen that heat treatment reduces the ratio of the diffusion widths (roll cladding:explosive cladding) corresponding to the two processes. In the heat treated condition, the diffusion widths increased for the different elements in the order Cu < Mg < Zn. This is in qualitative agreement with increasing diffusion coefficients of these elements in the same order [7].

Table III gives the bond strengths of the clad as well as monolithic alloys. It is seen from Table III that the average bond shear strength of the clad plate exceeded the strength of the Al-1Zn alloy sheet, indicating that the bonds were of good quality. The bond strength was marginally lower, but less scattered, than that of roll clad sheets [8]. These differences cannot be fully explained

TABLE II Diffusion widths for various elements across the clad interfaces

Element	Condition	Explosive cladding, straight interface: Actual (μm)	Explosive cladding, straight interface: % of the cladding thickness	Explosive cladding, wavy interface: Actual (μm)	Explosive cladding, wavy interface: % of the cladding thickness	Roll bond interface [5] % of the cladding thickness
Cu	As-clad	10	0.25	40	1.0	12.5
	Heat treated	130	3.25	120	3.0	40.4
Mg	As-clad	10	0.25	48	1.2	15.4
	Heat treated	180	4.5	150	3.75	51.7
Zn	As-clad	10	0.25	80	2.0	22.9
	Heat treated	220	5.5	200	5.0	52.9

Total thickness: 32 mm (explosive cladding) and 4 mm (roll cladding); Cladding thickness: 4 mm (explosive cladding) and 0.24 mm (roll cladding).

TABLE III Tensile shear strengths of 8090/7072 claddings and monolithic 7072 alloy

Material/condition	Shear strength, actual (MPa)	Average (std. deviation) values (MPa)
Explosive cladding	57.5, 59.2, 58.0, 56.4, 56.2, 59.2, 48.9, 64.0	57.4 (4.2)
7072 alloy (prior to explosive cladding)	23, 27	–
Roll cladding (@ 475°C, 70% reduction in a single pass) [5]	90.1, 73.2, 90.8, 64.2, 81.3, 61.4	76.8 (12.6)
7072 alloy (rolled under similar conditions as in roll cladding) [5]	47, 48, 47.9	48.6 –

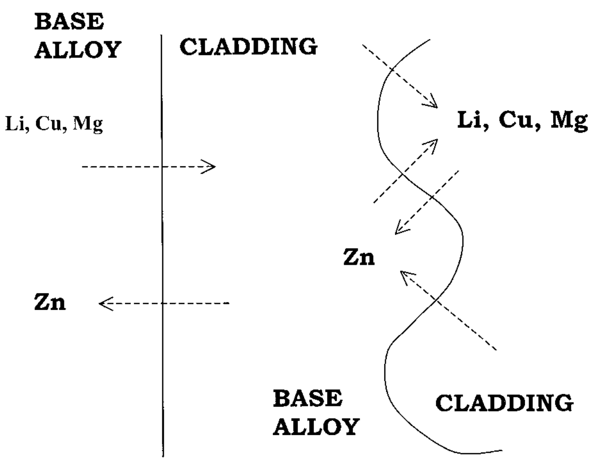


Figure 5 Schematic diagram depicting diffusion of alloying elements across straight and wavy interfaces. The arrows indicate directions of diffusive fluxes for the corresponding elements.

based on the available information, but could be related to less elemental diffusion across the interface and more efficient removal of oxides in explosive cladding than in roll cladding [8].

4. Summary

To summarise, Al-Li based alloy 8090 could be explosively clad to Al-Zn alloy 7072. The bonds were continuous, except near the edges of the plate, with no signs of local melting. Inter-diffusion of elements across the interface was negligible in the as clad condition, but increased after heat treatment. The bond strength exceeded the strength of Al-1Zn cladding alloy, indicating that the bonds were of good quality. The bond shear strength was marginally lower but less scattered in explosive cladding than in roll cladding.

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References

1. B. CROSSLAND, "Explosive Welding of Metals and its Applications" (Clarendon Press, Oxford Publ., 1982) p. 12.
2. A. NOBILI, *Stainless Steel World* **10**(1) (1998) 33.
3. M. GERLAND, H. N. PRESLES, J. P. GUIN and D. BERTHEAU, *Materials Science and Engineering* A **280** (2000) 311.
4. M. D. CHADWICK and P. W. JACKSON, "Explosive Welding, Forming and Compaction," edited by T. Z. Blazinski (Applied Science Publishers, New York, 1983) p. 219, 234 and 245.
5. V. D. LINSE and N. S. LALWANEY, *J. Metals* May (1984) 62.
6. V. BALASUBRAMANIAN, M. RATHINASABAPATHI and K. RAGHUKANDAN, *Journal of Materials Processing Technology* **63** (1997) 83.
7. J. POLMEAR, "Light Alloys," 3rd ed. (Arnold Publishers, London, 1995) p. 77.
8. P. MALLESHAM, PhD thesis, Osmania University, Hyderabad, India, 2000, p. 97.
9. H. KEARNS, "Welding Handbook," Vol. 3, 7th ed. (American Welding Society, 1984) p. 274.

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