Development of Weldability Window for Aluminum-Steel Explosive Cladding

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Abstract. This study addresses the development of biaxial and triaxial weldability window- an analytical estimation-for determining the nature of interface in aluminum 5052-stainless steel 304 dissimilar explosive cladding. The lower and upper boundaries of the biaxial weldability window are formulated using empirical relations proposed by earlier researchers. The process parameters -dynamic bend angle and collision velocity are chosen as ordinates and abscissa respectively. In addition, a triaxial weldability window, comprising of three process parameters viz., flyer plate velocity, collision velocity and dynamic bend angle is also developed. Explosive cladding experiments were conducted by varying the process parameters and the interface microstructure is correlated with the developed weldability windows.

1. Introduction

Development of bimetallic components drew the attention IN aerospace, ship building and automotive sectors, owing to their lightweight and good mechanical, thermal and corrosion resistance properties [1]. Aluminum clad steel is one such bimetallic component, used, as transition joint, in cryogenic pressure vessels and in power station cooling system. Numerous techniques are currently employed for cladding aluminum with steel such as hot rolling, hot pressing and diffusion bonding. However due to wide difference in density, melting point and coefficient of thermal expansion, bonding of aluminum to steel by conventional welding methods, is still a challenging one [2]. In this context, explosive cladding shows good potential to manufacture larger bimetallic clads and composite laminates without complications.

In explosive cladding, the quality of the clad depends on the judicial selection of process parameters viz., surface preparation, standoff distance, loading ratio, thickness of flyer plate and the properties of the chemical explosive [3]. Various researchers employed numerical simulation and weldability window-an analytical estimation for obtaining the optimum conditions-for an acceptable clad exhibiting microstructure free from defects and good strength [4-6]. In this study, an attempt is made to develop a triaxial weldability window in addition to the conventional biaxial one,for attaining optimum process parameters for a sucessful Al 5052-SS 304 explosive clad. The results show that the experimental conditions prevailing inside the boundaries of the window results in a successful clad with a wavy topography.

2. Experimental

Parallel and inclined explosive cladding configuration, shown in Fig.1 [7], with aluminum 5052 alloy (size: 90 mm × 50 mm × 2 mm) and SS 304 (size:90 mm × 50 mm × 6 mm) as flyer and base plates respectively was attempted.

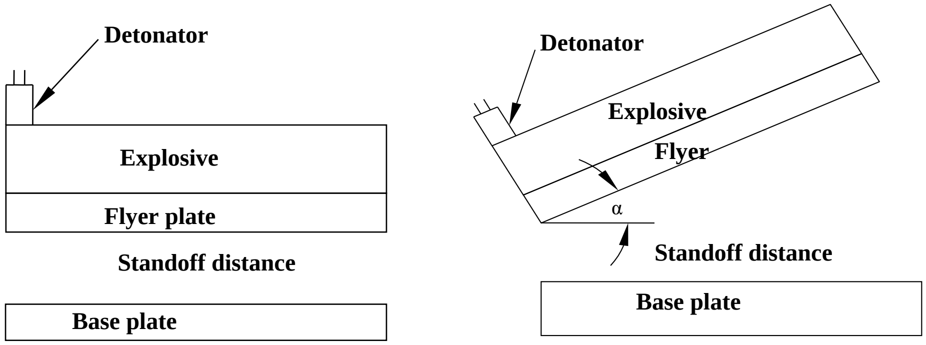

Fig.1 (a) Parallel configuration (b) Inclined configuration

The mating surfaces of the plates were mechanically polished and thoroughly cleaned prior to experiments. The explosive (detonation velocity of 4000 m/s), was positioned above the flyer plate and the preset angle between the flyer and base plate has varied from 0 to 5 degree. The loading ratio (mass of the explosive/mass of flyer plate) was varied from 0.8 to 1.0 and the detailed experimental conditions are tabulated in Table 1. Subsequent to cladding, samples were cut parallel to the detonation direction for microstructural examination. Microstructural features of the clad were observed under VERSAMET optical microscope and the results are reported.

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

3. Weldability window

The determination of precise boundaries in the construction of weldability window involves various assumptions and constants which are influential during the formulation.. The experimental conditions prevailing within the upper and lower boundaries of the window, results in a successful clad [8].. In explosive cladding, as the number of process parameters are more, weldability window is drawn between any two chosen influential process parameters. In this study, the biaxial weldability window is generated with welding velocity and dynamic bend angle as ordinate and abscissa respectively. In parallel configured explosive cladding, the welding velocity, V_c, is equal to detonation velocity (V_d) of the explosive [8]. The second chosen parameter dynamic bend angle, β, is analytically determined by

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

Where V_p is the flyer plate velocity determined by $V_p = 2V_d Sin\frac{\beta}{2}$ (2)

The lower boundary of the weldability window is determined by [4]

$$\beta = K \sqrt{\frac{H_V}{\rho V_C^2}} \quad (3)$$

Where, K is equal to 1.14, 'H_v' is the Vickers hardness and 'ρ' is the density of the flyer plate. The experimental conditions, superimposed on the biaxial weldability window, are falling closer to the lower boundary, as shown in Fig.2. The upper boundary of the weldability window is estimated by

$$\sin\frac{\beta}{2} = \frac{K_3}{\left(t^{0.25} . V_C^{\ 1.25}\right)} \quad (4)$$

Where $k_3 = C_f/2$, $C_f = \sqrt{K/\rho}$, K= E/3(1-2γ), Where C_f is compressive wave velocity, t is the thickness of flyer plate, V_c is the collision point velocity, k is the bulk modulus and E is the young's modulus.

4. Results and discussion

4.1 Biaxial weldability window

The biaxial weldability window for aluminium-steel, comprising of upper, lower boundaries and the experimental conditions (Table 1), is shown in Fig. 2. Researchers opined that the experimental conditions inside the upper and lower boundaries results in successful clad. However, the significance of regions near to lower boundary, and that too in close proximity to left corner in achieving a defect free clad is insisted by many earlier researchers [4,6,9]. Experimental conditions closer to the lower boundary indicate lower dynamic bend angle, collision velocity and plate velocity and which results in a defect free dissimilar clad (detailed in the section 4.3).

Fig.2 Biaxial weldability window (Al-SS 304)

4.2 Triaxial Weldability window

The lower boundary of the weldability window is generated in a three dimensional view, considering three parameters viz., bend angle, collision velocity and flyer plate velocity (Fig.3). A three dimensional lower boundary in a weldability window provides better understanding of the collision condition as the additional third parameter is considered as well.

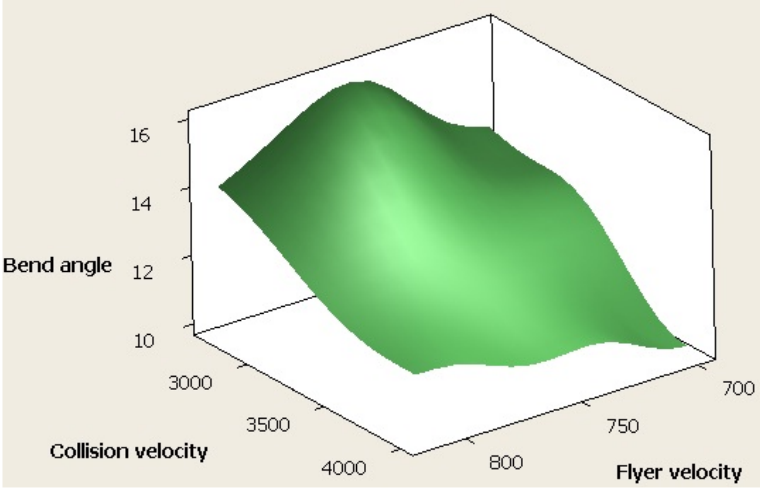

Fig.3 Triaxial weldability window (Al-Steel)

4.3 Microstructure

The interface highlights the difference in microstructure, from straight and sinusoidal topographies, and indicates the effect of explosive mass on the quantum of deformation work performed. Transformation of straight interface to an undulating interface, for an increase in loading ratio, is consistent with earlier researchers [10-12]. None the less, 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.

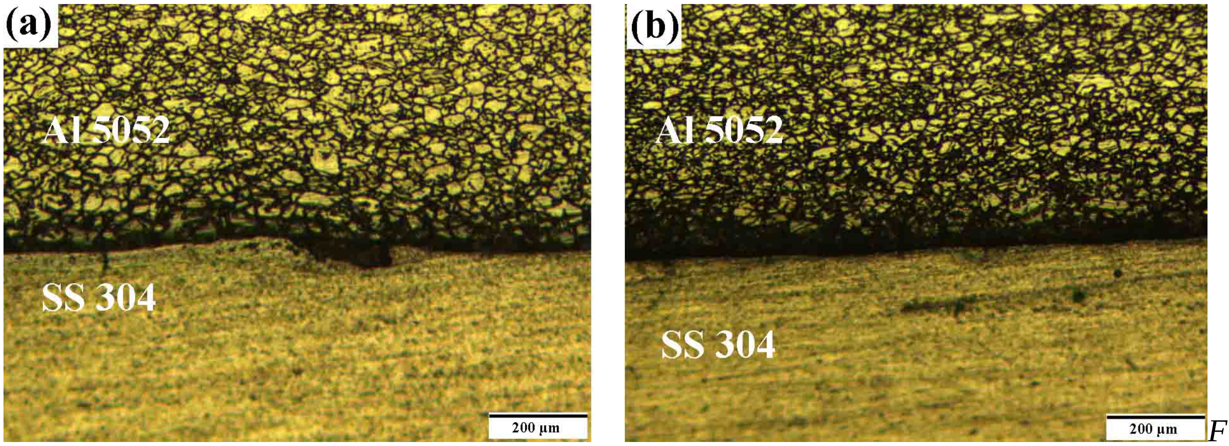

Fig. 4 Microstructure of the explosive clad (Al 5052-SS 304)

The interface microstructure of Al-SS 316 explosive clad, for a loading ratio, R of 0.8, show a straight interface with a continuous strip of molten diffusion layer (Fig.4.b). The molten layer, probable weaker locations in the clads, are formed due to the dissipation of the available kinetic energy at the interface. The microstructure of the aluminum 5052-stainless steel explosive clad at a loading ratio, R=1.0 (Fig.4.a) reveals the characteristic wavy interface with few intermetallic compounds on the vortices of the participant metals. The experimental conditions prevailing inside the weldability window results in a wavy interface.

Conclusion

1. Weldability window is a effective tool for selecting explosive cladding parameters.
2. The experimental conditions falling within the window produce a wavy interface.

3. Points closer to the lower limits of welding window are preferable.
4. Triaxial weldability window provides the influence of three process parameters, and hence advantageous.

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