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DEVELOPMENT OF WELDING WINDOW FOR UNDERWATER AL – STEEL EXPLOSIVE CLADDING

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Abstract

This study attempted analytical estimation of the welding domain for underwater explosive cladding of aluminium (Al 5052) - stainless steel (SS304). A welding window, an analytical estimation, can ascertain whether the interface is wavy-like or otherwise. The welding window's lower, upper, left, and right boundaries were constructed using empirical relations suggested by peer researchers. The soundness of the dissimilar clads relates to their closeness to the lower boundary. The interface microstructure is in concurrence with the analytical outcomes.

Keywords: *Explosive Cladding, Dissimilar metals, Welding window, Microstructure.*

1. Introduction

Hybrid composites are used in many engineering applications due to their adaptable characteristics, such as being lightweight, having a high strength-to-weight ratio, low cost, and ease of structure formation [1]. Aluminium alloys are mainly used as superstructure material in shipbuilding due to their high specific strength, excellent corrosion resistance and low cost. However, the concern about the overall mechanical strength is remarkably achieved by cladding with other metals [2]. For manufacturing hybrid composite plates, techniques such as Laser welding [3], Friction stir welding [4], Diffusion bonding [5] and Explosive cladding [6] are attempted.

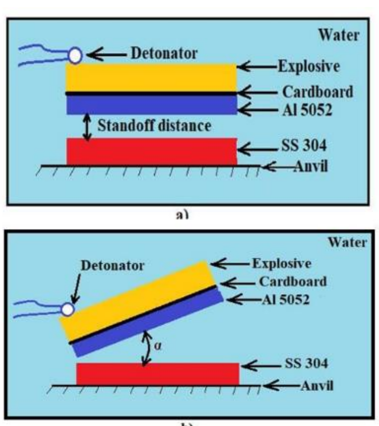

Fig. 1 Underwater Explosive cladding (a) Parallel setup (b) Inclined setup

From the above techniques, underwater explosive cladding (Fig.1) is superior because of its ability to join multi-layers of similar or dissimilar metals and alloys that cannot be bonded through any other traditional manufacturing method [7].

In underwater explosive cladding, the controlled detonation of chemical explosives promotes metallurgical bonding, owing to localised plastic deformation at the bonding interface [8]. The quality of explosive cladding strongly depends upon judicial control of process parameters, including surface preparation, stand-off distance, explosive mass, detonation energy, and detonation velocity [9]. The collision parameters can be determined to provide an explosive clad of high strength, which can be attained through a welding window. In this aspect, earlier researchers have made considerable progress in establishing the optimum operational parameters. Consequently, welding window parameters, such as collision velocity - bend angle or flyer plate velocity – bend angle, are proposed [8]. The welding window enables the analytical condition for forming a wave or straight interface. This study attempts to generate a welding domain for an underwater aluminium-stainless steel dissimilar combination.

2. Theoretical

When an explosive detonation occurs, the pressure wave accelerates the flyer plate rapidly before impacting the base plate to form a clad. The flyer plate loses a portion of its kinetic energy during a collision, which leads to plastic deformation at the point of impact. The following expression yields the plate velocity (V_p) and dynamic bend angle (β) [10].

$$V_p = 2V_d sin\left(\frac{\beta}{2}\right) \quad (1)$$

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$$\beta = \left(\sqrt{\frac{k+1}{k-1}} - 1\right) \cdot \frac{\pi}{2} \cdot \frac{r}{r+2.71+0.184t_e/s} \quad (2)$$

At which flyer plate collides with the base plate, i.e. Collision velocity (Vc) calculated using [8],

$$V_c = V_p \cdot \frac{\cos\left(\frac{\beta-\alpha}{2}\right)}{\sin\beta} \quad (3)$$

3. Welding window

The upper, bottom, left and right boundaries, transition, maximum and minimum bend angles, and critical jetting angles are straight and curved boundaries that make up the welding window, drawn between two parameters. Wittmann et al. [11] and Deribas et al. [12] created an explosive welding window where collision velocity Vc is plotted in abscissa and dynamic bend angle, and β is plotted in ordinates. The lower boundary is particularly relevant because it provides minimal impact velocity. The transition (Vf) Velocity from laminar to turbulent flow was defined by Cowan using the fluid hypothesis as follows:

$$R = \frac{(\rho_F+\rho_P)V_F^2}{2\,(H_F+H_P)} \quad (4)$$

At the point of transition, the Reynolds number is 10.045. The sonic velocity of the flyer plate, or 120% of bulk sound velocity, is the right boundary [13]. However, it is visible from the literature that experimental conditions closer to the upper boundary restrict the choice of the process parameters. Bahrani and Crossland [14] conducted experiments to identify the upper & lower boundaries of the dynamic angle and proposed a lower value of 2 -3° and a maximum of 31°. The maximum & minimum initial angle in an inclined configuration is recommended between 18° and 3°, respectively. The equation was proposed by Deribas et al. [12] as the lower boundary,

$$\beta = K\sqrt{\frac{Hv}{\rho V_C^2}} \quad (5)$$

Deribas proposed a relationship for finding the welding upper boundary beyond which the flyer gets damaged and is given by

$$\sin\frac{\beta}{2} = \frac{K_3}{(t^{0.25}.V_C^{1.25})} \quad (6)$$

4. Results and discussion

4.1. Formulation of welding window

The welding window for aluminium–stainless steel dissimilar combination is shown in Figure 2. Researchers opined that the experimental conditions prevailing between the upper and lower boundaries result in successful clad. However, the regions closer to the lower boundary and close to the left corner are critical in attaining a defect-free clad [15, 16, 17]. It is inferred from Figure 2 that a successful explosive clad is acquired when the bend angle is between 5° and 15° and a collision velocity of 2500-3500 m/s. The position of experimental conditions depends on the nature and detonation velocity of the chemical explosive used. The interface microstructure obtained from the experimental conditions prevailing inside the welding window is shown in Figure 3 and detailed in the next section.

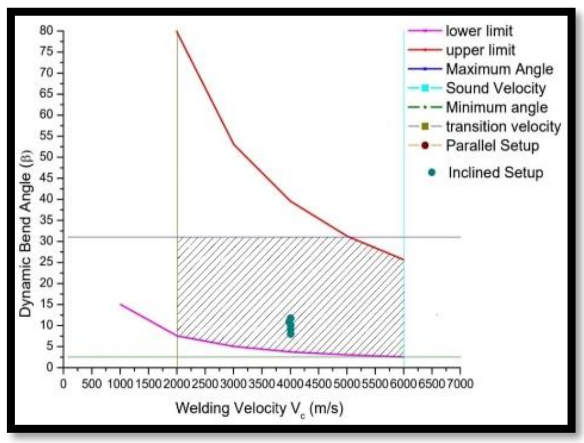

Fig. 2 Welding window for underwater aluminium – stainless steel explosive cladding

The interface microstructure of an aluminium-steel explosive clad is crucial for assessing the joint's mechanical properties, including strength, toughness, and corrosion resistance. The microstructural features vary based on the alloys used and welding parameters. The explosive clad typically exhibits a layered structure with distinct layers of aluminium and steel. A wavy pattern characterises the interface, often called a "Morse code" pattern, indicating dynamic plastic deformation. The interface between aluminium and steel experiences extreme plastic deformation and high strain rates during the explosive welding process. Metallurgical bonding occurs at the atomic level due to the intimate contact between the materials. On the aluminium side, there is evidence of severe plastic deformation, grain elongation, and alignment in the direction of the explosive force. Due to the high energy input during the explosive welding, localised melting and subsequent rapid solidification occur at the interface. The solidification process leads to the formation of fine-grained structures in the melted regions.

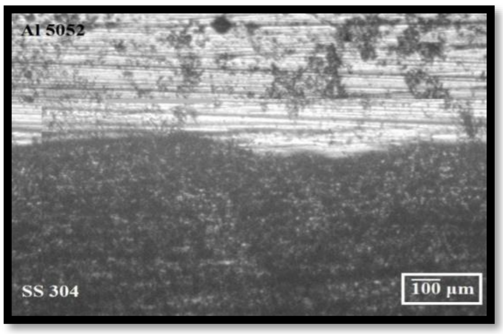

Fig. 3 Microstructure of the Al-Steel explosive clad

5. Conclusion

1. Aluminum – Stainless steel underwater explosive clad with a wavy interface emerges for a dynamic bend angle range of 5° to 15° and collision velocity between 2500 – 3500 m/s.
2. Experimental conditions closer to the lower boundary of the underwater welding window are recommended.
3. The aluminium-steel explosive clad exhibits a layered structure with a distinct interface.

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