Journal of Manufacturing Engineering, June 2011, Vol. 6, Issue 2, pp 112-115

TRIAXIAL WELDABILITY WINDOWS ON EXPLOSIVE CLADDING OF DISSIMILAR METALS

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ABSTRACT

Explosive Cladding is a unique combination of explosive and metallurgical technologies. By detonating an explosive charge on top of a plate, the plate can be bonded with an underlying plate. The explosive detonation provides the energy to form a jet between the plates that cleans the surfaces and subsequently bonds the two plates metallurgically. An attempt is made to generate three dimensional welding window using empirical relations. Aluminium to Low carbon steel sheets is explosively cladded and the experimental results were found to be in accordance with the generated weldability window. The increase in hardness near the interface is also reported.

Keywords: *Explosive Cladding, Dissimilar Metals, Weldability Window, Microstructure and Microhardness.*

1. Introduction

Explosive cladding is one example of a constructive application of explosives in which the energy produced by the detonating explosive is used to accelerate a metal plate (flyer plate) across a predetermined distance (stand-off distance) into contact with another metal plate (base plate) to achieve a solid state joining [1]. Due to high pressure and associated strain rates, "jetting" occurs and removes the oxide layer present at the weld surface of the plates, leaving behind perfectly clean surfaces. Under the high pressures generated by the colliding plates, the ultra clean surfaces are forced into intimate contact and a metallurgical bond is formed [2]. Aluminium is used as a super structure material in ship building to avoid crevice corrosion. Low carbon steel provides good strength at low cost. The reason for using a composite part instead of single material is to lower cost while effecting better corrosion resistance, acceptable strength and improved electrical properties. The strength of the explosive clad is always greater than the weaker of the mating metals [2].

Explosive cladding provides a viable alternative to weld Aluminium- Low carbon steel dissimilar combination which is not possible by other conventional methods. Due to their desirable properties as a combination, Aluminium has been employed as flyer plate whereas low carbon steel was employed as the base plate. The quality of bonds strongly depends on judicial control of process parameters which include surface preparation, stand off distance, explosive mass, detonation energy and detonation velocity [3]. Considerable progress has been made to establish the optimum operational parameters which are required to produce an acceptable weld. Consequently welding windows of various parameters such as collision velocity-impact angle or flyer plate velocity-impact angle were proposed by various authors [4, 5]. The welding window enables the analytical condition for the formation of wavy and straight interface. This study was conducted to generate a triaxial welding window and to optimize ideal parameters for welding within the window. Aluminium-Low carbon steel plates were explosively cladded by both inclined and parallel geometries keeping the welding conditions similar. For examining the interfacial characterization, the clad plates were cut parallel to detonation direction and the samples were prepared with standard metallographic route. Micro hardness testing was carried out using a zwick microhardness tester with a 500 g load and the results are reported.

2. Experimental Procedure

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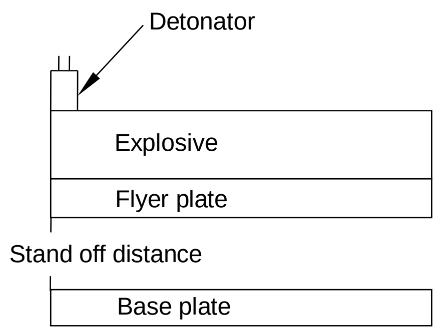

Fig. 1 Parallel Configuration

Figs. 1 and 2 illustrate the two basic geometric configurations of the explosive cladding which are commonly used.

(i) Angle bonding and (ii) Parallel bonding [6]. Upon detonation of the explosives, the flyer plate collapses on to the parent plate and a metallic jet is formed at the impingement line between two plates [6]. Low carbon steel plates of 50mmX90mmX5mm were used as base plates, while aluminium plates (50mmX90mmX2.5mm) were used as flyer plates. Commercial, Neogel 90 explosive with a detonation velocity of 4500m/s was the energy generator. The initial angle was 0 and 3 degrees.

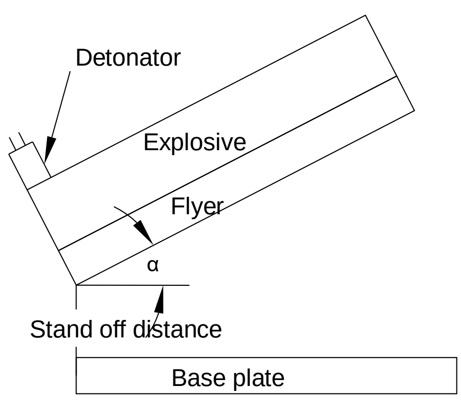

Fig. 2 Inclined Configuration

The stand off distance between flyer and base plate was maintained at 5 mm. The welding conditions were estimated based on the empirical equations explained in the following section.

3. Estimation of Welding Conditions

3.1 Parallel geometry

In parallel arrangement the welding velocity is equal to detonation velocity of the explosive [6]. The flyer plate velocity V_p was calculated by Gurney equation [6] which predicts the terminal velocity.

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

Where V_d is the detonation velocity of explosive and β is the dynamic bend angle. The dynamic bend angle β can be calculated using the following relation [7].

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

Where r is the loading ratio (mass of explosive for unit mass of flyer plate) and s is stand off distance and t_e is thickness of explosive. The value of k in equation (2) ranges from 1.96 to 2.6 depending on thickness of explosive. [7, 8].

3.2 Inclined geometry

The flyer plate velocity V_p can be calculated using Gurney equation [6].

$$V_p = \sqrt{2E} \left(\frac{(1 + 2/R)^3 + 1}{6(1 + 1/R)} + \frac{1}{R}\right)^{-1/2} \qquad (3)$$

Where R is the loading ratio, √2E is the Gurney energy, which is experimentally known for common explosives. The dynamic bend angle β, collision angle γ and welding velocity Vc were calculated from Birkhoff equation [6].

$$V_c = V_P \cdot \frac{\cos\left(\frac{\beta - \alpha}{2}\right)}{\sin \beta} \qquad (4)$$

Where α is the initial angle, V_p is the plate velocity. Known values of α, β, V_p, V_d, V_w and the properties of the materials enable the design of the weldability window.

4. Results and Discussion

4.1 Weldability Window

Attempts to evaluate the set of parameters for satisfactory explosive welding had to rely either on empirical relations or trial experiments. The objective of this present study was to determine the right parameters for providing the smoothest interface. The development of a theoretical model which is capable of predicting the mechanism by which waves are produced was attempted. The wavy or transition bond without any apparent inter metallic layer yields the most desirable properties. Various authors have studied jet formation, critical impact pressure, maximum impact velocity and wavy smooth transition velocity. Witmann et al [4] and Deribas et al [5] developed an explosive welding window in which collision angle β is plotted in ordinates and welding velocity Vc in abscissa. Saravanan and Raghukandan [9] developed a triaxial welding window having the plate velocity, collision velocity and dynamic bend angle as their coordinates. In this study, an attempt has been made to develop a three dimensional weldability window having the same parameters as shown in Fig. 3. The lower boundary refers the condition to achieve fluid like conditions at the collision point so that jetting occurs. The lower limit of welding window can be calculated using [6].

$$\beta = K_1\sqrt{\frac{H_V}{\rho V_C^2}} \qquad (5)$$

Where H_v is the Vickers hardness number in N/mm^2 and ρ is density in kg/m^3 of flyer plate. The value of k_1 is 0.6 for high quality pre cleaning of surfaces, 1.2 for imperfectly cleaned surfaces and 0.85 for general cases. Conditions closer to lower limit of the window possesses lower collision angle and minimum plate velocity results in an interface free from intermetallics and defects. This study focuses on the lower limit of the welding domain. Vaidyanathan et al stated that experimental conditions closer to the lowest corner of the lower limit are preferable [10] which is in accordance with this study. A welding window gives an idea about collision conditions so that we can achieve an interface free from interfacial melting, defects and flyer damage. Welding with a wavy interface is assumed to be strong in nature, though a straight interface can produce a strong joint as well [6]. Any point within the window would mean successful welding with a wavy interface. The accurate boundaries of the window are difficult to be defined as it involves various assumptions and constants during the formulation of window. The properties of flyer plate are more influential in formulating the window. The microstructure of the experimental condition falls within the window shows a wavy morphology as shown in Fig 4. Flyer plate velocity is inversely proportional to welding velocity and at higher dynamic angles an explosive dent is formed and the degree of dent increases with welding velocities.

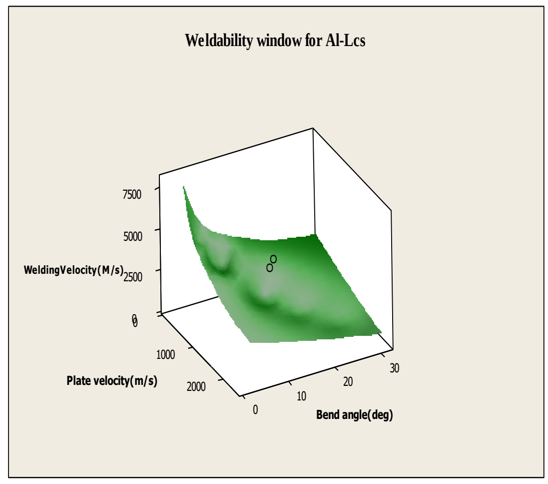

Fig. 3 Triaxial Weldability Window for Al-Lcs

4.2 Microstructural chracterization

Metallurgical problems encountered in the explosive cladding are not as severe as those associated with conventional fusion welding. Nevertheless, there are certain features uniquely associated with explosive cladding. In this process, the cladding plate is subjected to a high pressure shock wave emanating from the detonating explosive and the resulting collision with the base plate creates a high pressure shock wave. Microstructure examinations of the dynamic cladded Al-Lcs showed in Fig 4 reveals the characteristic feature of “undulating interfaces”. The weld is sound with an interface absence of any “molten layered zones”, with impact of the flyer with the base and as the detonation proceeds, wavy interfaces are formed. The microstructure shows elongated grains of ferrite and banded pearlite distributed throughout. Entrapments, as a result of the participating materials escaping from the “metallic jet” are not seen. Dynamic cladding produces peculiar deformation modes ‘Neumannbands’ which are otherwise mechanical twins appear in base plate, due to the sudden impact of flyer plate. Mechanical twinning is frequently observed in explosive welds as a result of the shock waves, the order of pressures required being different for different metals as reported by various researchers [11, 12].

Fig. 4 Al-Lcs Microstructure

4.3 Microhardness

The measured microhardness values of Al-Lcs are shown in Fig.4.The welded plates exhibited higher hardness than the starting plates because of cold deformation during explosion. Maximum hardness was obtained near the interface due to high level of plastic deformation adjacent to welded interface during collision. Interaction of a softening effect caused by the adiabatic temperature rise and the hardening effect or excess plastic deformation in the explosion area may be the reason for high reason for higher hardness at the interface. After being subjected to shock loading hardness found to be higher than the original materials where as away from the interface there is no significant increase. Turutnev et al [13] cladded aluminium with nickel, titanium and steel and reported that work hardening as the reason for having higher hardness at the interface. Kahraman [14] joined aluminium with steel at varied explosive mass and found that zones near the collision interface exhibits higher hardness at all explosive loads.

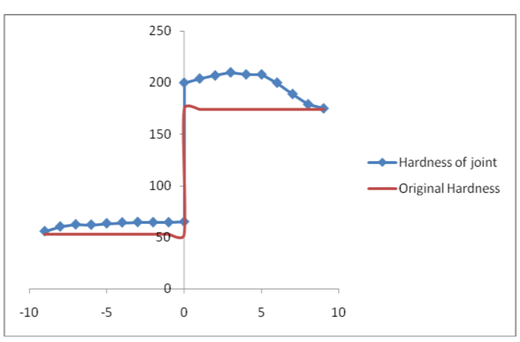

Fig. 5 Micro Hardness Values of the Al-Lcs Joints

5. Conclusion

The objective of this present study is to attain a wavy formation in the explosive welding of Aluminium-Low carbon steel combination. Weldability window for this combination was determined which is useful in tailoring welding conditions. The following conclusions were drawn from this study.

1. Weldability window is a very effective analytical procedure to determine the parameters for explosive welding.
2. Weldability window is helpful in determining the conditions for obtaining straight, wavy weld formation.
3. Points closer to the lower limits of welding window are preferable.
4. Microstructural characterization reveals an interface free from intermetallics and defects.
5. Microhardness values in the welded samples were higher than the original materials and maximum hardness was achieved near the interface due to high level of plastic deformation.

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