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Underwater Explosive Welding of Tin and Aluminium Plates

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Abstract. In the present study, underwater explosive welding of commercial pure Sn and Al plates was attempted. Distance between the explosive and the center of the sample was varied to change the pressure applied to the plates to be welded. Evolution of interfacial microstructures at the welded Sn/Al joints was assessed. An increase in the distance between explosive and the sample exhibited decrease in the formation of wavy morphology at the interface. Cross–sectional interfacial microstructures clearly indicated that, Sn and Al plates can be joined successfully using underwater explosive welding technique.

Introduction

The Explosive welding (EXW) is a solid state process used for the joining (metallurgical) of similar or dissimilar a metal which is regarded as one of the most widely employed materials processing technique [1]. The EXW is generally performed in an open atmosphere. However, it is reported that conventional explosive welding always poses a problem for welding of materials, particularly for thin metal plate (below 1mm thickness) as well as brittle materials such as amorphous ribbon/ceramics and fusing of tungsten (W)/Cu [2,3]. Literature suggested that by using underwater explosive welding a significant decrease in kinetic energy (K.E) loss at the interface of flyer plate and base plate can be achieved [4–6]. In this method, water acts as a pressure transmitting medium. The underwater shock waves prevent the distortion of the welded joint and ensure the integrity of the joints. Hence, underwater explosive welding is regarded as one of the best and novel welding techniques [7, 8]. It reported that, Al/Steel, Al/Cu, Sn/Cu and Cu/Stainless Steel combinations of materials are the most essential in the electrical engineering and among these Al/Cu joints are widely used as electrical connectors in many industries because of their good corrosion resistance and electrical conductivity [9]. Although numerous investigations on explosive welding of various metal combinations were conducted by the researchers [9–12] welding and cladding of Sn and Al using this technique have not been paid attention. Sn based solder alloys are electrically connected with metallic components (most notably the Cu conductors) in the electronic device. However there is no solder alloy in electronic applications which operates with Al in the same way that ordinary solders operate with copper. Because Al does not alloy readily with solders, moreover the Al surface is covered with a thin invisible coating of aluminium oxide. Thin oxide film makes it difficult to join dissimilar materials [13].

Thus, the aim of current study is to make an attempt to fusing of Sn and Al plates using underwater explosive welding method. Further, evolution of interfacial microstructures between welded Sn/Al joint is investigated.

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Experimental

The commercial high purity Sn (0.5 mm × 100 mm × 100 mm) and Al (5mm × 100 mm × 100 mm) plates procured from Nilaco corporation, Japan were used in the present study. The procured Sn plate was sectioned into small plates having a dimension of 0.5 mm thick × 50 mm length × 50 mm width and Al plate of 5mm × 50 mm × 50 mm. Underwater explosion welding experiments with an inclined setup were performed to weld Sn and Al plates. A stand–off distance (SOD) between the flyer plate Sn and base plate Al was set to 0.2 mm by placing 0.2 mm thick aluminium plate as spacer between the plates. The inclination angle ($\propto$) between the plates was set to $20^{\circ}$to control the collision angle and the velocity. A stainless steel (SUS 304, 0.1 mm ×50 mm× 50 mm) was used as cover plate above the flyer plate to eliminate cracks between the joints. An inclined layer of SEP explosive (detonation velocity of 7 km/s, density 1300 kg/m^3) was bonded to Polymethyl Methacrylate (PMMA) plate and positioned above the flyer plate. The SEP explosive was procured from Kayaku Japan Co, Ltd, Japan. The distance between explosive and the center of the sample (d) were set at 30 and 60 mm. A mild steel anvil was positioned below the sample to ensure the sample flatness and to adjust its height. Entire setup was kept inside PMMA container which contained water. Fig. 1 shows the schematic diagram of underwater shockwave explosion welding technique with weldable conditions.

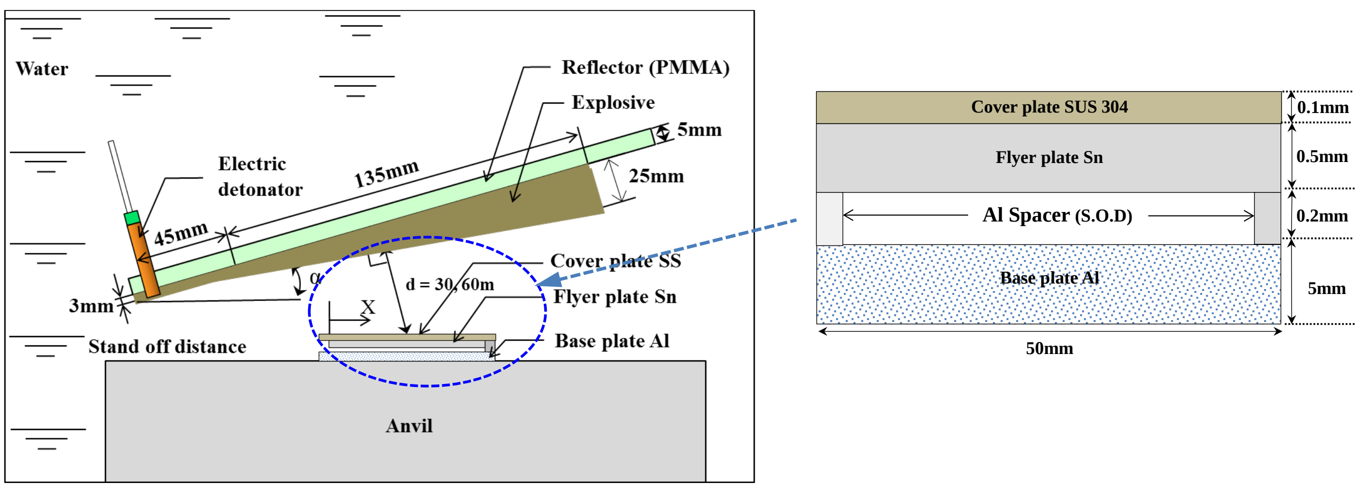

Fig. 1: Schematic outline of explosive welding using underwater shock wave technique.

Welded Sn/Al plates were sectioned along the direction of wave propagation using shear cutting machine (Aizawa, AST–612). Sectioned samples were polished using SiC papers of different grit sizes (400–2000 mesh number) using emery paper disc polishing machine (Velnus, Asahikase make). The final polishing was carried out on a disc polisher (Struers labpol – 1) using silica liquid lubricant. Interfacial region of Sn/Al joint cut at the center parallel to the detonation direction was micro–examined using an optical microscope (Nikon LM 2) and scanning electron microscope (JEOL JSM 6510A).

Results and discussion

Underwater explosive bonded Sn/Al plates at varied distance of the explosive from the center of the sample are shown in Fig. 2. As the detonation initiated, chemical reaction of explosive at high rate generated the shockwaves in the surrounding water. These shockwaves propagated through the water and accelerated the Sn plate (flyer) to impact the Al plate (base). Due to the collision (at higher rate), a strong metallurgical bond between Sn and Al was occurred.

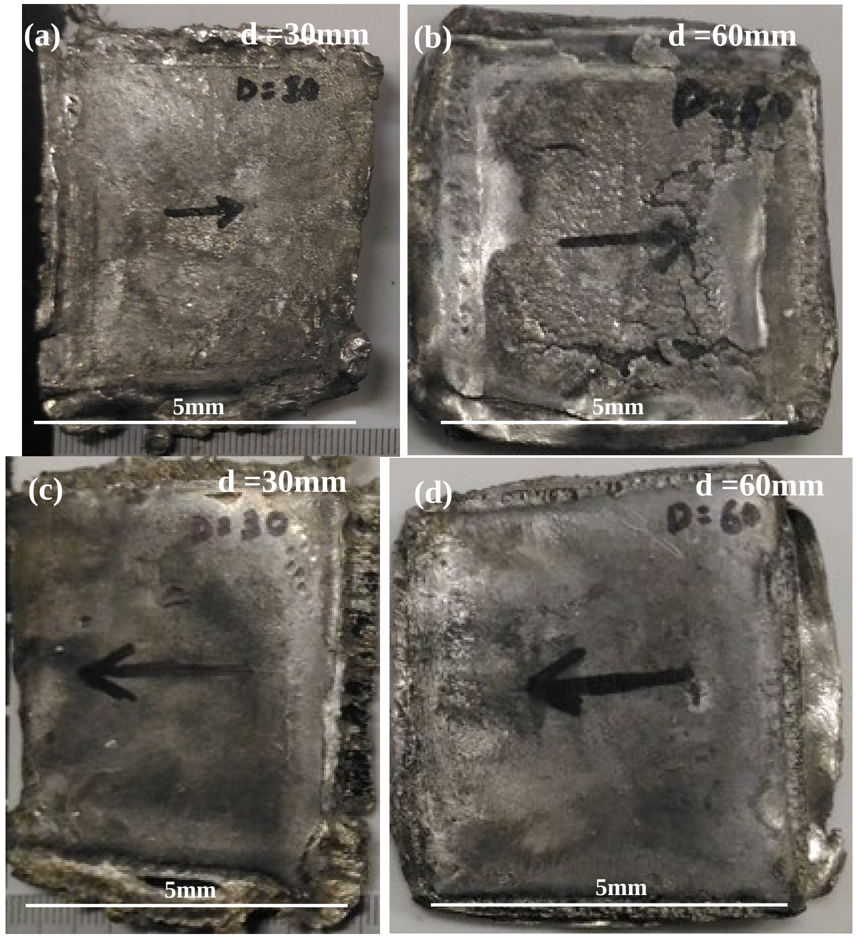

Fig. 2: Explosive welded (underwater) Sn/Alu samples at (a) d=30mm front view (c) d=30mm back view (b) d=60mm front view (d) d=60mm back view

If the distance between explosive and the center of the sample is kept low, collision takes place before the flyer Sn plate could reach the maximum velocity. Further, at higher distance of explosive from the sample, the velocity drops to a lower value at the time of collision [8,14]. The optical microstructures of cross section along welding direction (horizontal positions) for the samples welded at d = 30 mm and 60 mm are shown in Fig. 3 and 4.

Fig 3: Microstructures of cross section along the welding direction (horizontal positions) of welded Sn/Al plates at d = 30 mm.

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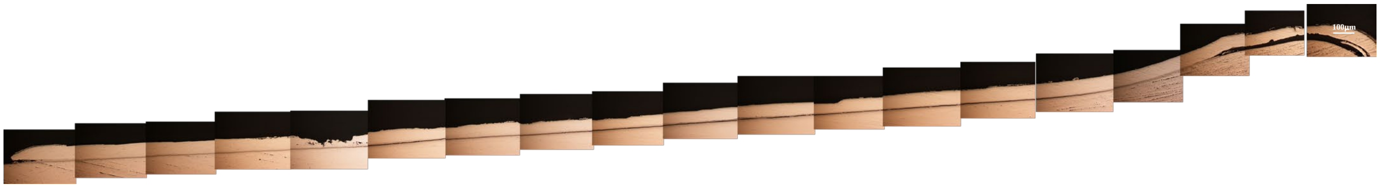

Fig 4 : Microstructures of cross section along the welding direction (horizontal positions) of welded Sn/ Al plates at d = 60 mm.

Interfacial microstructures (at higher magnification) of welded Sn/Al joints at varied water distance are shown in Fig. 5 and 6. Results indicated that pure Sn and Al can be successfully welded/joined using underwater explosive welding method. During explosive welding process, kinetic energy (K.E) of the flyer plate Sn was transformed to potential by colliding with the base plate Al. This resulted in plastic deformation at the interface of Sn and Al plates. Due to higher intensive plastic deformation at d=30mm, a wavy morphology (Fig. 5) was formed at the interface, which swept the surface layers of Sn over Al base plate. However, the kinetic energy of flying plate, energy shockwave and plastic flow was found to be minimum at d = 60 mm due to which small waves in smaller wavelength (Fig. 6) were observed at the Sn/Al interface.

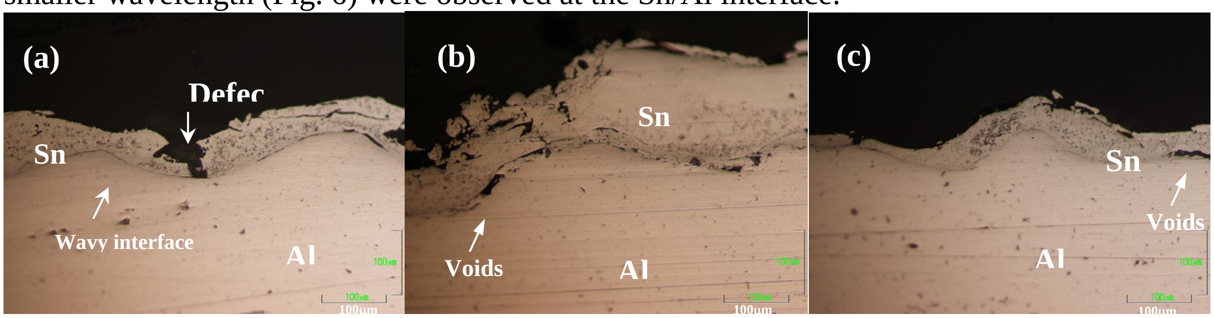

Fig. 5: Optical microstructures of explosive welded Sn/Al joints (d=30mm) at different locations

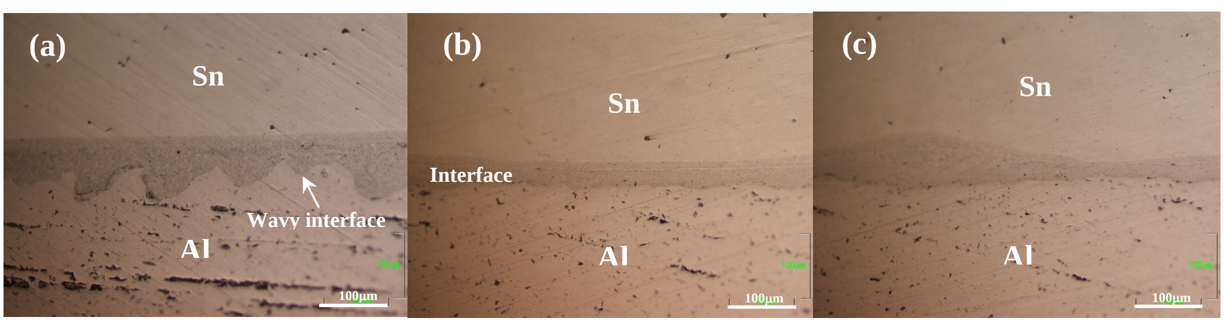

Fig. 6: Optical microstructures of explosive welded Sn/ Al joints (d=60mm) at different locations

At the interface of Sn/Al plates welded at d = 30 mm other than large waves, cracks and voids were formed because, the energy shockwave was more, and loss of kinetic energy of flyer plate was high compared to d = 60 mm. Microstructures indicated that the welding was not successful at interface of Sn/Al joints welded at d = 30 mm. However, a good bonding was observed at interface of Sn/Al joints welded at d = 60 mm.

Conclusion

Based on the results and discussion the following conclusions are drawn.

Sn and Al plates can be successfully bonded using underwater explosive welding method.

The size and morphology of wavy interface decreased with increase in the distance between the explosive and the center of the sample

The interface of samples welded at d = 30 mm associated with the cracks and voids, whereas samples welded at d=60 mm was found to be free defects.

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