Chapter 25

High Velocity Impact Welding

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High Velocity Impact Welding (HVIW) is one of the solid-state welding methods that are suitable for a wide variety of combinations of similar and dissimilar metals, wherein welding is achieved in a few microseconds. It is known that when metal plates, initially stationed at an angle, collide with each other at high velocities (several hundreds of meters per second), a metal jet is emitted that cleans the surfaces on each impacting plate resulting in a lap joint at the interface. Application of high pressure at the collision point promotes a strong bonding of the atoms at the joining interface with a characteristic wavy morphology [1, 2]. Lately, joining of dissimilar high-strength light alloys has been of significant growing interest. One of the most elegant ways to accomplish dissimilar metal welding is by impact welding because of its outstanding advantage of eliminating the formation of HAZ as well as minimizing the formation of inert-metallic phases at the interface of dissimilar metals bond.

25.1. Types of HVIW

There are several HVIW methods, including Explosive Welding, Laser Impact Welding and Magnetic Pulse Welding.

25.1.1. Explosive Welding (EXW)

EXW is a HVIW process that employs large quantities of explosives, which on detonation accelerates a flyer plate against a target plate and is now well established as a solid-state welding technique for joining a wide variety of materials. Figure 25.1 shows a schematic diagram of the basic process of EXW. The detonation of the explosive is initiated at a point or along a line. The contact angle established on impact of flyer over target depends on the relative velocities i.e. detonation front velocity and the flyer plate velocity. It is observed that the impact velocity and angle changes with change in the initial standoff, which is the distance between the flyer and target plates. The collision between the plates starts from the detonator and takes place along a line producing a plasma jet, which removes and cleans the surfaces. The parameters involved in EXW process includes the surface finish, the standoff distance, the explosive used and detonator placement decides the detonation velocity and the pressure generated [3]. These variables are responsible for development of the impact velocity and impact angle that ultimately resulting into a bond between the flyer and target.

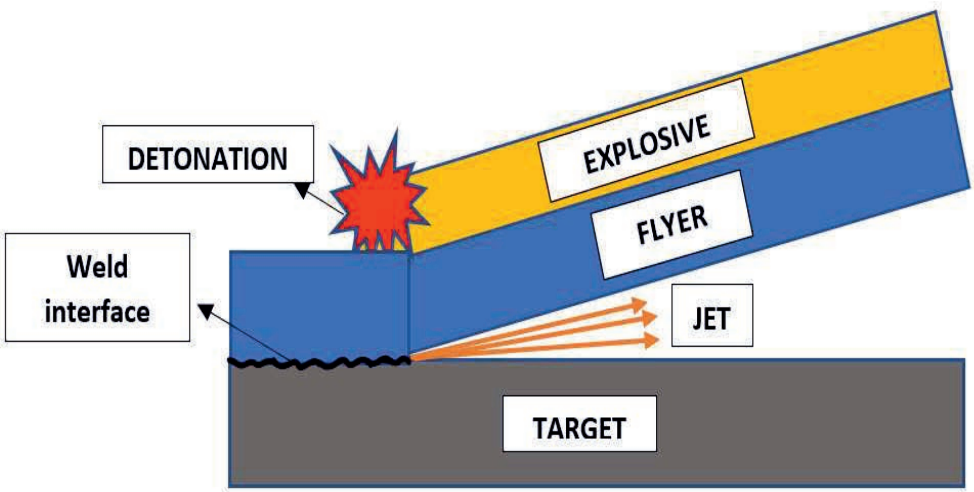

Figure 25.1. Explosive Welding (EXW).

25.1.2. Laser Impact Welding (LIW)

LIW is a solid-state impact welding technique for joining two metals, initially maintained at an impact angle and standoff distance, at temperatures that prevent bulk melting of the metals. As shown in Figure 25.2, a pulsed laser beam focussed through a transparent enclosure adjacent to the flyer that has an optically absorbent surface (darkened surface). The laser ablates the surface causing the plasma to react against the confinement. This generates a plasma-based pressure pulse, from the ablation, between the confinement and the plate to accelerate the flyer (within few nanoseconds). The plates collide with high velocity and the high-pressure pulse causes the surfaces to deform and establishing a metallurgical joining at the interface besides a plasma jet cleaning the metal surfaces [3].

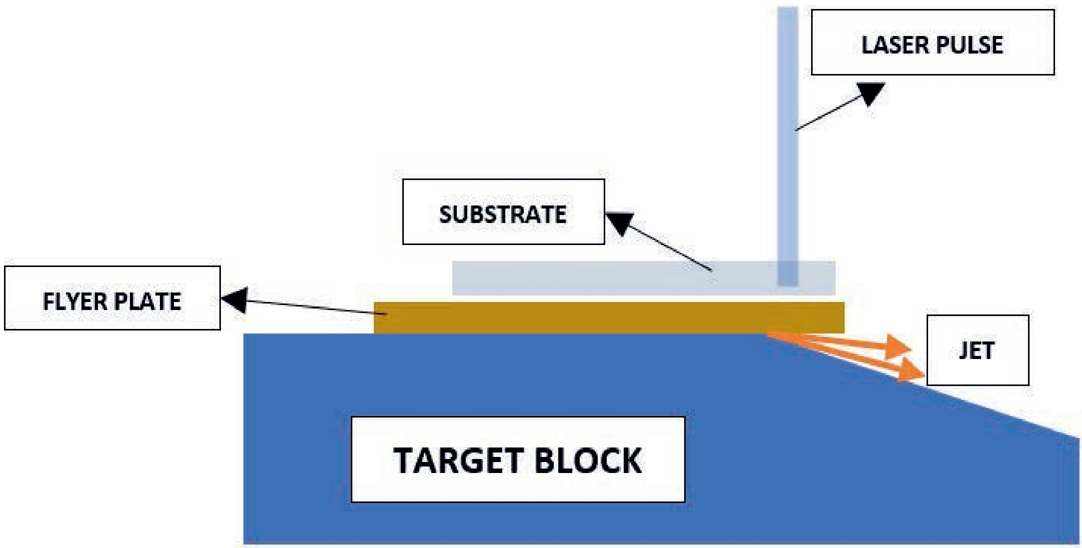

Figure 25.2. Laser Impact Welding (LIW) [3].

25.1.3. Magnetic Pulse Welding (MPW)

MPW technique is also a solid-state impact welding process wherein magnetic pressure is employed for joining of metals instead of heat source. In order to generate this magnetic pressure a capacitor bank is utilized to discharge the current into the tool coil, which in turn develops a transient magnetic field around. Interaction of this magnetic field with the induced eddy current on the conductive flyer causes its deformation and accelerates it to very high velocities to impact on the target material and form a bond between them, as shown in Figure 25.3. MPW is closely analogous to EXW and depending upon the magnetic fields, the impact angle and stand-off distance i.e the initial gap between the parts, the parts move and collide, thus creating microscopic interlocking. Both MPW and EXW are having similar bonding mechanism i.e the joint interface is observed to have a wavy morphology. However, compared to EXW, MPW is a safer, cleaner and more environmental friendly joining process.

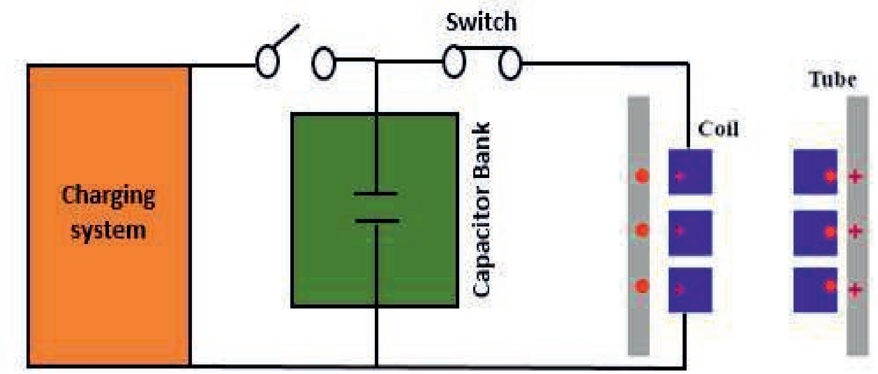

Figure 25.3. Magnetic Pulse Welding.

25.2. Joining mechanisms for HVIW

To explain the joining mechanism for HVIW, various theories have been discussed by researchers. Like Bahrani et al. (1967) and Ezra (1973) have established the impact welding principle based on the jetting effect that allows joining of metal surfaces [4, 5]. When two plates placed at a desirable impact angle collides with high velocity, a jet forms between the deforming metals. At the collision point, the impact stress exceeds the yield stress causing this deformation. The jet propagates along the mating interface, cleaning the surface oxide layer and creating two atomically clean surfaces. Simultaneously, the two surfaces are also under a large contact pressure. Bahrani et al. (1967) pointed out that the impact pressure brings the surface atoms into direct contact, forming a high strength chemical or metallic bond [4]. It is also concluded by Botros and Groves (1980) and Salem (1980) that for a quality weld jet is an essential phenomenon [5-7]. Palmer et al. (2006) found that the collision process also involves few other contributing phenomena like severe plastic deformation, mechanical alloying, local melting with rapid solidification, and high strain rate induced fluid-like behaviour [8]. A Kelvin-Helmholtz instability [9, 10], induces dynamic shear stress and shear strain that flows along the welded interface, which is equally critical for the development of wavy morphology. The study by Bahrani et al. (1967) and Grignon et al. (2004), reports that the interface morphology is dependent on the critical parameters like the impact angle, impact velocity, properties of the materials, and geometry of the welded plates [3, 11]. The impact velocity and impact angle being the most important parameters that determine the weld quality and interface microstructure [12, 13]. However, it is evident that excess impact velocity has caused significant melting, resulting in formation of inter-metallic or brittle damage whereas, insufficient impact velocity may not be able initiate the jet which is required to remove the surface oxides resulting in a weak or no bond [14]. It has been reported that the typical the strain rate may be as high as $10^7\ s^{-1}$ [15] that can be produced from an impact velocity which is about 250~400 m/s [16].

25.2.1. Collision Jetting

Marya *et al.* [4] reported that the high collision velocity removes the oxide layer on the surface of the colliding contact surface area as a jet, which is a mixture of the stripped surface oxides and the surrounding gas propagating along the colliding surfaces in a swirling motion. These cleaned metal surfaces are pushed into intimate contact under high pressure, forms a metallurgical bonding across the interface. This jet assistant welding mechanism has been widely accepted but reported research work to capture the jet is limited. High speed camera was used by M. Kimichi (2007) at Edison Welding Institute to capture the welding process and the induced jetting [3]. After the impact process, the jet was observed to have been deposited on the surface near to the weld region which could be regarded as the indirect evidence of the jet action.

25.2.2. Inter-metallic Phase Formation

It is known that the inter-metallic phases are usually formed during conventional welding of dissimilar materials and microstructure of the joining region is susceptible to cracking and could significantly influence the welding strength and toughness of the welded sample as shown in Figure 25.4, for Al-Cu MP weld joint. This makes fusion welding of dissimilar materials undesirable.

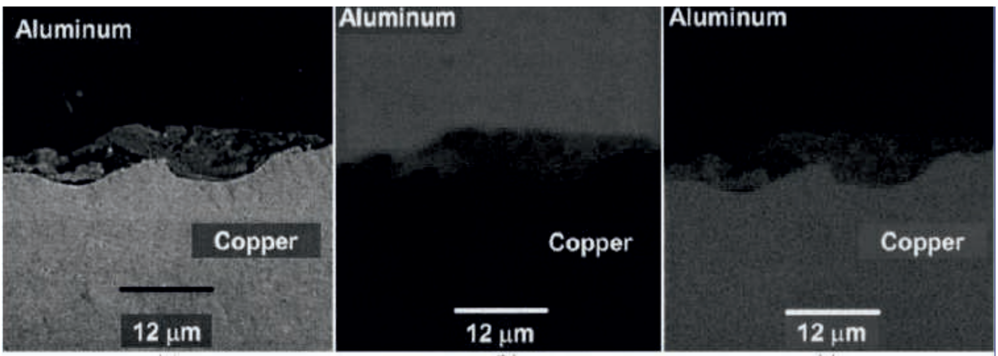

Figure 25.4. Secondary electron (SE) image of the Cu-Al interface [4].

Unlike fusion welding, MPW has very low localized heat formation and rapid cooling rate. This could either cause the complete elimination of occurrence of any inter-metallic phases or it's minimization, eventually leading to the desirable physical properties. Though, ideal joints are the ones free from inter-metallic, some researchers have found that the inter-metallic phases also occur in the transition zone of MPW joints for aluminum, copper, magnesium and steel. Marya *et al.* [4,21] found an inter-metallic composition at the Cu-Al MPW joint as shown in

Figure 25.4 where they claimed that the presence of inter-metallic phase supported the interfacial melting at the weld interface.

The local melting and rapid cooling process responsible for the changes in the physical properties at the interface may have caused the extensive mixing and phase transformation at the collision point. This suggests that inter-metallic phase formation is one of the possible joining mechanism for impact welding.

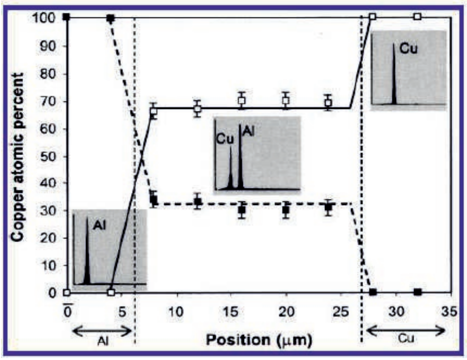

Figure 25.5. EDS scan across interfacial micro-constituent (solid line depicts copper concentration) [4].

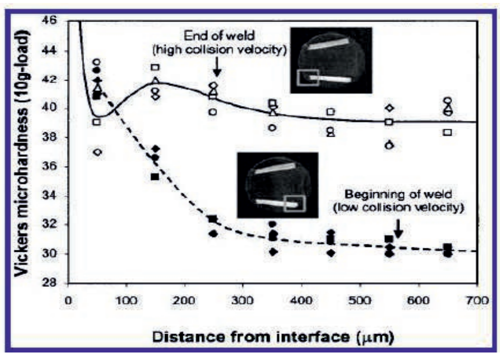

Figure 25.6. Micro-hardness profile in aluminium, as measured from weld interface [4].

25.2.3. Local Melting and Solidification

Volobuev *et al.* (1972) and Stern (2002) [22, 23] considered that during the impact most of the kinetic energy from the deforming flyer gets converted into Joule heat at the welded interface which causes the localized interface temperature to rise. Local melting occurs on the welded surface when the local temperature is above the melting temperature. During interfacial melting, both the composition and the microstructure changes within the transition zone as shown in Figure 25.7. The interfacial molten layer formed is found to be of various morphologies like straight, wavy or vortex kind. The laminar molten layer indicates the liquid/solid interface. This phase transformation also results in fine grained microstructure and the interfacial hardness increase [22].

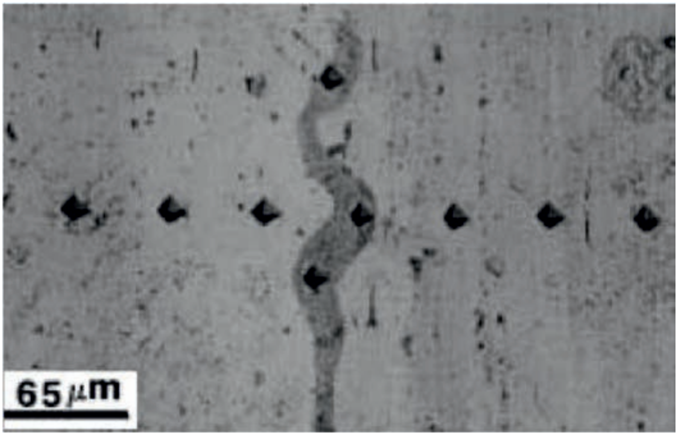

Figure 25.7. Al 7075 to Al 7075 MPW joint [22].

25.2.4. Inter Atomic Diffusion

It is widely reported that across a welded interface where the joints are subjected to high temperatures for a significant time, the dominant process occurring is diffusion. Similarly during MPW, it is reported that limited atomic diffusion is possible across the welded interface when the two work pieces collide with each other [24, 25]. Wakemen and Hultgren *et al.* [26] observed that for Al-Cu MPW joints, the interface temperature significantly influenced the diffusion of aluminum atoms into copper, and vice versa. This shows that the interface temperature is a critical parameter that affects the diffusion-controlled joining mechanism. However, there are some claims that owing to less diffusion time in MPW, atomic diffusion cannot occur, and the composition changes observed are only the result of the local melting and subsequent extensive mixing [4, 22] as interface temperatures have not been experimentally measured to support the theory.

25.3. Conclusion

Since the discussed joining mechanisms are related to each other, there can be one of the above mechanisms or a combination of them occurring for MPW joints. The local melting due to elevated temperatures can enhance the inter-metallic phase formation and the generation of waves at the interface. The phenomena may also be rising due to interatomic diffusion and intensive mixing with severe plastic deformation. It is necessary to point out that the impact conditions have significant effect on the joining mechanism, which could be studied carefully by simulation.

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Questionnaire

1. The HVIW techniques can be classified under which welding technique?

2. What can be regarded as the most significant advantage of HVIW while welding dissimilar metals?

3. What are the various joining/bonding mechanisms that could be causing bonds with HVIW process?

4. At the interface of metals joined by HVIW, what is observed over the hardness values at the weld interface? What could be the possible reason for the same?

5. In relation to inter-metallic formation at the interface, give comparative observation for fusion welding and impact welding.

6. What are the critical parameters that determine the weld quality achieved in HVIW?