SPOT WELDING OF FOILS BY WATER JETS

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INTRODUCTION

The manner in which the flyer plate deforms due to the impact of a high speed object is significant in defining spot welding geometry. Metallic materials are forcibly driven together by the use of an impactor in such a way that a strong metallurgical bond is formed. In this sense the resulting bonding may be called *impact bonding* instead of explosive bonding.

Early work on impact spot welding was conducted by Rolsten *et al.* [1] who observed that spot welding can be brought about by the action of a hypervelocity micro particle or a projectile impacting on the material. Later, Erdmann-Jesnitzer *et al.* [2–3] reported on impact welding by the use of a high-speed water jet. Further development on impact spot welding by means of a water jet was reported by Salem [4] who modified the process, and examined the effects of water speeds, stand-off distances, and flyer plate thicknesses. He obtained successful spot welds of a variety of metallic combinations. He concluded that aluminum (Al), copper (Cu), brass (Br), and mild steel (MS) sheets and their combinations can be joined by impact spot welding, with the exception of Cu/Al, MS/Al, and MS/Br combinations.

Salem [4] demonstrated the possibility of welding between 0.5 mm thick aluminum plate to a thick steel parent plate at zero stand-off. He pointed out that the assumed zero gap could not be guaranteed, and that ascertaining of the flatness of surfaces was difficult. Otto [5] showed that, under circumstances of explosive welding, bonding did take place with zero stand-off. Crossland *et al.* [6] found that welding took place when contact between two plates was maintained without clamping. These researchers attributed this occurrence to the possibility of flyer plate lift-up ahead of the collision point.

In what follows we report on an experimental study pertaining to the spot welding of sheet metal and foil combinations by the impact of a high speed water jet. The objective of the study is to investigate the possibility of spot welding of metal foils to various parent plates at several stand-off distances by the use of a slug of water jet.

EQUIPMENT AND MATERIALS

A 0.38″ calibre (9.652 mm) industrial stud driver gun was modified (Figure 1) to expel a slug of water instead of a stud. The barrel of the gun fits into a hardened steel cylindrical block (D) to which both the nozzle (G) and the gun adaptor (C) are secured by means of a bayonet lock. The nozzle is collinear with the impactor (E) located in the barrel of the gun. The impactor is a plastic projectile 9.63 mm in diameter and 16 mm long.

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The projectile was fired onto a plastic disk (F), which was used for capping the water (H) held in the mild steel nozzle. The nozzle was provided with an orifice of either 3 mm or 5 mm diameter for ejecting water jets at high speeds. The water contained a 0.5% polyox additive for stability of water jetting. The projectiles were inserted in the gun barrel such that they were either in contact with or in close vicinity of the cartridge. The gun was equipped with a safety locking mechanism to prevent accidental firing. Cartridges containing different amounts of low explosive propellants were used for obtaining different jet velocities.

EXPERIMENTAL WORK

Experiments were carried out for welding various combinations of aluminum, mild steel, and stainless steel foils and parent plates. For the case of welding of two thin foil sheets, the thin parent plate was held firmly on a steel backing plate by a double sided non-metallic tape. The stand-off distance between the foils was arranged by inserting non-metallic strips. The surfaces to be welded were cleaned with fine emery paper to remove excessive oxide and/or contaminated surface layers.

The distance between the flyer plate and the orifice of the nozzle (Figure 1) was maintained at approximately 25 mm. This distance was adjusted by using metal spacers placed under the edge of the nozzle holder and the backing anvil. The experiments were carried out at impactor velocities of 550 and 750 m/sec. The velocity of the projectile, V_p, was measured by the use of phototransistor and photodetector circuits. The stand-off distance, L, was varied from nil to well beyond 2.5 mm.

RESULTS

Figure 2 summarizes the results of experiments when aluminum sheets were utilized as flyer plates. Thus for a nozzle diameter N of 3 mm and projectile velocity V_p of 550 m/s it was found that 0.25 mm Al sheets will weld to Al base plates (Al/Al) over a fairly wide range of stand-off distances. Stand-off distances $L > 1.6$ mm result in the perforation of the flyer plate. Al/MS and Al/SS combinations do not yield welds for $N = 3$ mm and $V_p = 550$m/s.

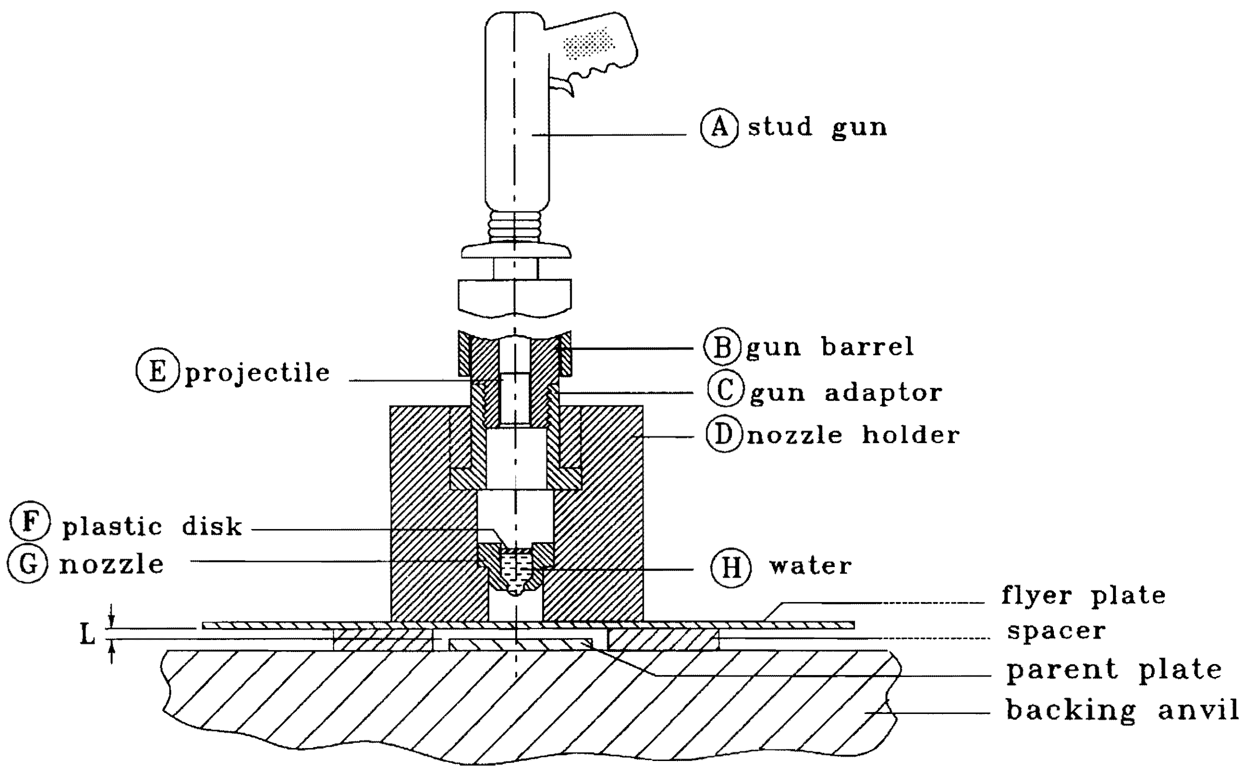

Figure 1. Schematic Representation of the Impact of a Jet of Water.

When N is increased to 5 mm, the same sheet of Al, of thickness $T = 0.25$ mm, will weld to Al, MS, and SS base plates over wide ranges of L at $V_p = 550$ m/s. No perforation is observed at this speed. The range of L is significantly reduced at $V_p = 750$ m/s, beyond which perforation starts to take place. Interestingly, both Al/Al and Al/MS pairs can be welded at zero L, while Al/SS requires a minimum gap of 0.03 mm.

For the case when T is reduced to 0.13 mm, $V_p = 550$ m/s, and $N = 5$, all three pairs will weld over fairly wide ranges of L, with perforation commencing at the upper limit. The flyer plate is always perforated for all L when V_p is increased to 750 m/s. It is interesting to note that the flyer plate is welded to an aluminum parent plate at zero gap. On the other hand, the same flyer plate will weld to steel and stainless steel parent plates when a minimum gap is provided. All three metal combinations will be perforated from zero stand-off distance when the higher impactor velocity level is used.

The welding behavior of MS flyer plates is summarized in Figure 3. A flyer plate 0.1 mm thick welds to all three base plate materials when $N = 5$ and $V_p = 550$m/s, albeit the L range for Al/Al welding is very narrow. Perforation commences at the upper L values for MS/MS and MS/SS pairs. As may be expected, used at a $V_p = 750$ m/s, the L range for MS/Al improves considerably while the L ranges of the remaining two pairs shrink somewhat. Perforation commences at the upper limit of L for all three pairs. Both the MS/Al and the MS/SS pairs weld even when $L = 0$.

No welding takes place when T is increased to 0.25 mm at $Vp = 550$ ms. The only pair that will weld, and this over a rather wide range of L, is MS/MS when V_p is raised to 750 m/s and $N = 5$ mm. Perforation commences at the upper limit of L.

The welding behavior of SS foils 0.15 mm in thickness is depicted in Figure 4, where it is observed that very limited welding is to be expected when $N = 3$ and $V_p = 550$ m/s. The only possibility is the welding of SS/SS, and this over a limited range of L. The enlarging of the nozzle diameter to 5 mm enables the welding of SS/Al over a fairly wide range of L when $V_p = 550$ m/s. The application of $V_p = 750$ m/s drastically reduces the range of L for SS/Al, at

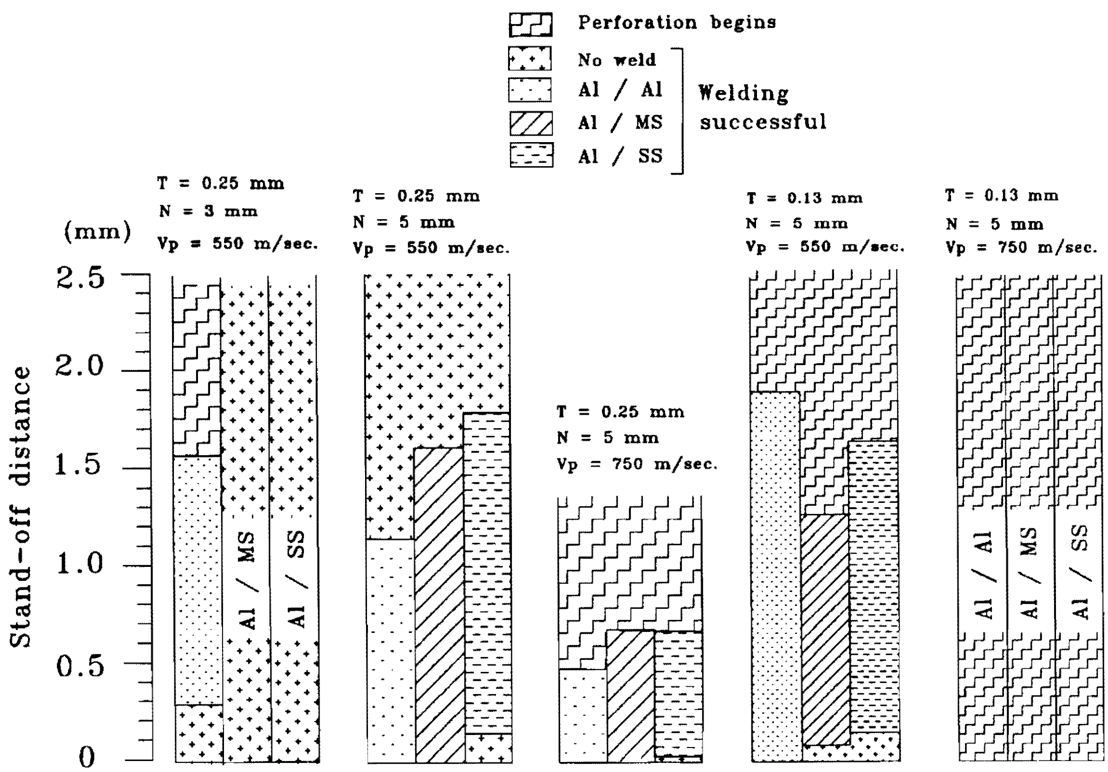

Figure 2. The Modifier Stud Driver for the Ejection of a Water Jet.

the same time enabling the welding of the remaining two pairs. It is to be observed that the pair SS/SS can be welded over a sizable range of L values. It must be pointed out that stainless steel flyer plates with any parent plate always requires a minimum gap for welding at both projectile velocity levels.

Preliminary microscopic examination of some of the welded joints revealed plane and also wavelike interface zones (Figure 5). Figure 6 depicts a water jet as it impacts the flyer plate, and strives to explain the formation of flexural waves emanating from the impact zone and traveling radially outward to cause a transient gap.

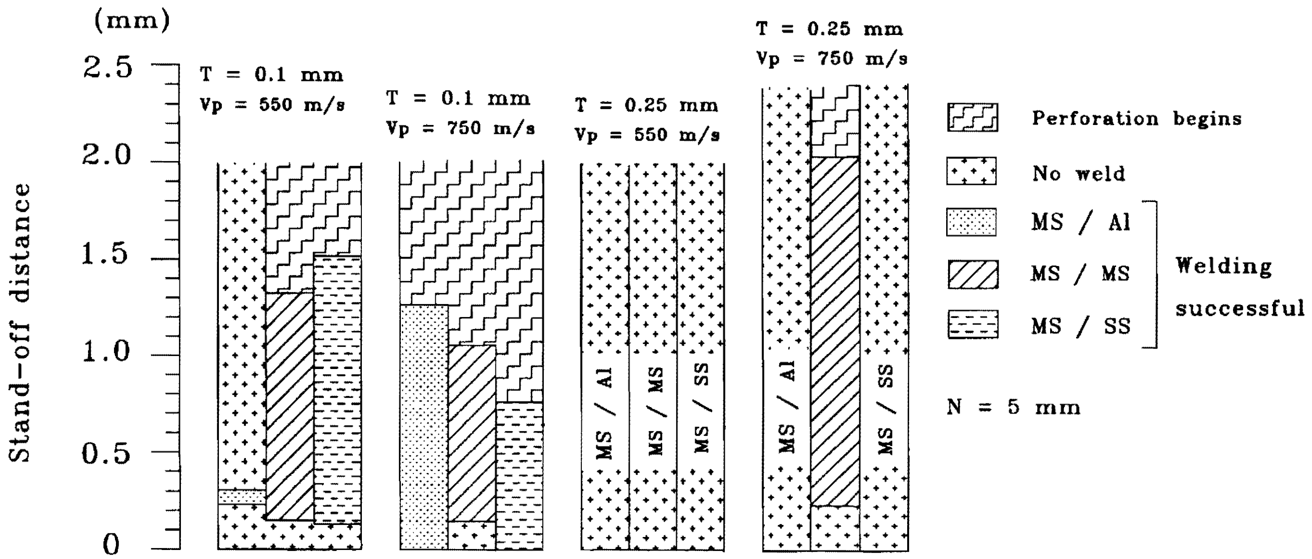

Figure 3. Results of Welding Experiments with Al Flyer Plates.

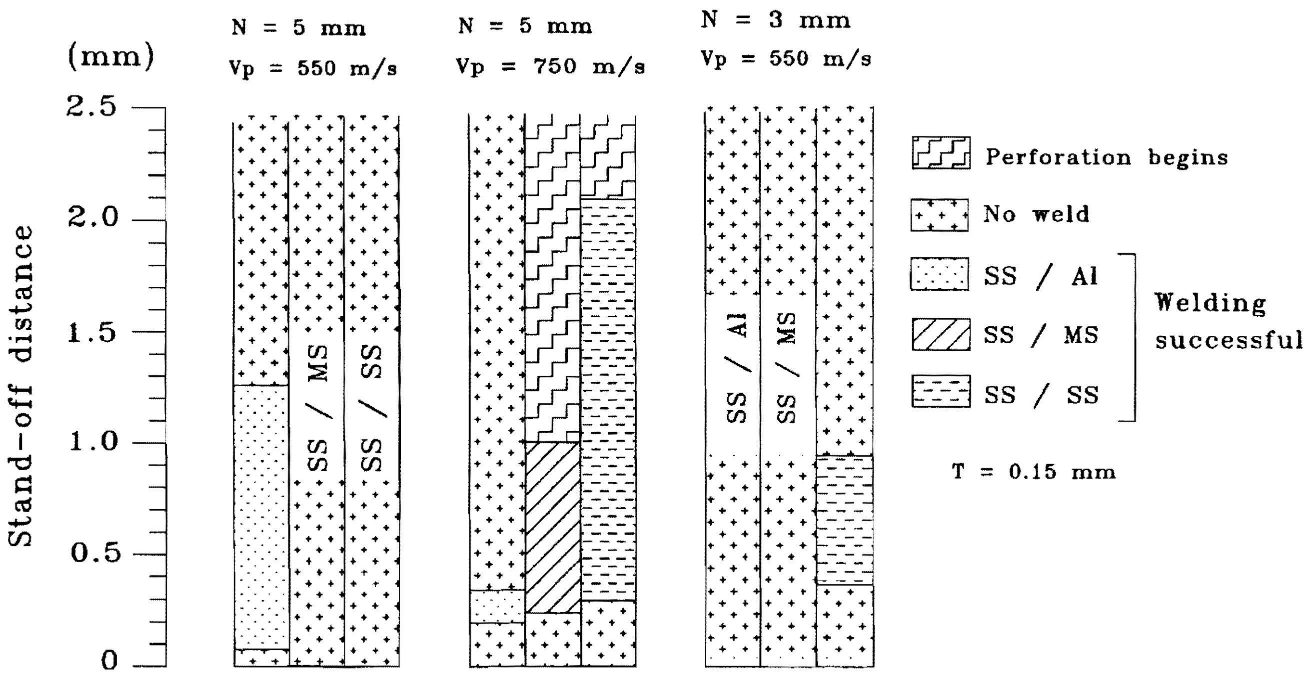

Figure 4. Results of Welding Experiments with MS Flyer Plates.

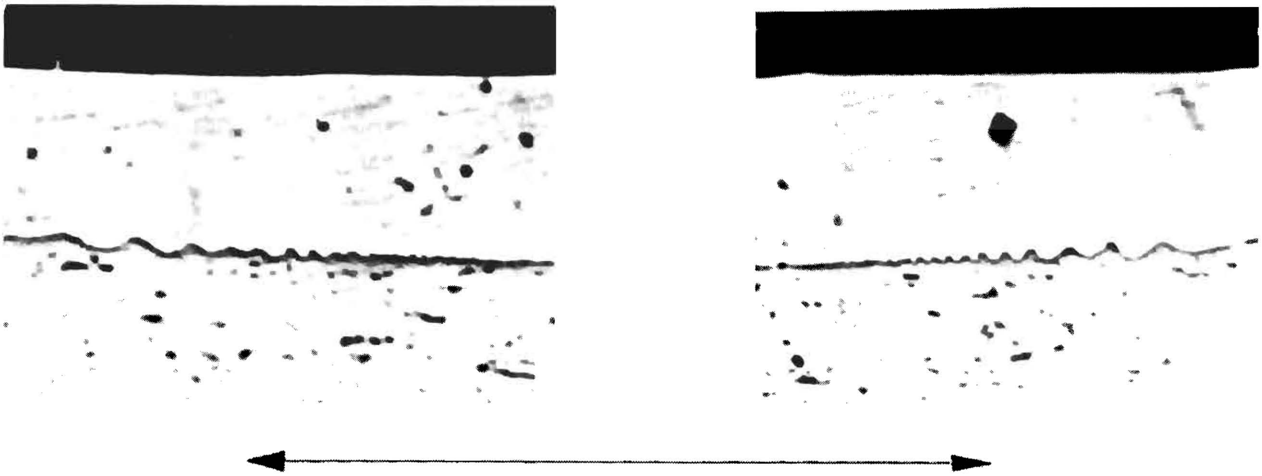

Figure 5. Results of Welding Experiments with SS Flyer Plates.

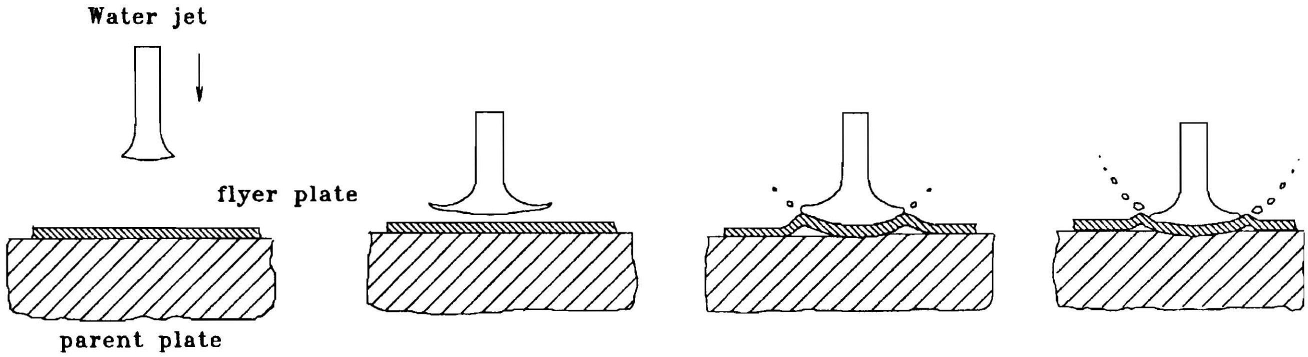

Figure 6. Wavelike Interface Zones at a Welded Joint.

DISCUSSION AND CONCLUSIONS

The rate of energy transferred to the flyer plate is closely related to the nozzle diameter N as well as on projectile velocity V_p. The effect of energy rate is clearly reflected in Figure 2, where it is observed that the utilization of the larger nozzle enables the welding of all three combinations throughout wide ranges of L for the lower V_p. The range of L is significantly reduced, however, for $N = 5$ and $V_p = 750$ m/s, where the early onset of perforation can be attributed to the delivery of excessive energy to the weaker Al flyer plate in the vicinity of impact. The thinner flyer plate is seen to be particularly susceptible to perforation under these conditions. It may be concluded for this particular case that the velocity of impactor must increase for increasing strength of the flyer plate if the toughness of the latter is equal to or less than the toughness of the parent plate.

The same hypothesis seems to hold for the case of the MS flyer plate (Figure 3) for $T = 0.1$ mm and $N = 5$ mm. Welding is no longer possible when T is increased to 0.25 mm and V_p stays at 550 m/s. At $V_p = 750$, the MS/MS pair is welded. It is anticipated that higher energy rates would be needed to weld the MS/SS pair, and lower rates for the pair MS/Al. Similarly for the SS flyer plate (Figure 4), welding at $V_p = 550$ m/s is possible only for the SS/SS pair for $N = 3$ mm and the SS/Al pair for $N = 5$ mm. The SS/MS and SS/SS pairs are welded when V_p is set to 750 m/s. It is observed that this speed is rather high for the MS/SS pair and practically inadmissible for the SS/Al pair.

Although combinations of soft metal and foil can be welded at zero stand-off distance, higher strength foil to metal pairs generally require a predetermined stand-off distance, with the exception of very thin foils (below 0.1 mm thickness). It is considered plausible, for the special case of welding at zero stand-off distance, that a lift-up of the flyer plate may occur ahead of the collision point, causing flexural waves to travel radially outward from the impact zone.

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