Laser Impact Welding – Process Introduction and Key Variables

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Abstract

Laser impact welding is a solid-state, collision-based welding process. In this process, laser-generated optical energy is converted to kinetic energy through the ablation at the surface and confinement of the gas generated between a flyer and backing plate. The launch of the flyer can be affected by many factors, for example, backing material, ablative layer, and flyer thickness. In this paper, the effect of three backing materials: glass, polycarbonate and cellophane tape, were studied with different laser spot size and commercially pure aluminum alloy 1100 was used as the flyer. The results show that glass can provide the most efficient launches, but is damaged. Polycarbonate is a good compromise between efficiency and robustness. Welding is possible between many similar and dissimilar material pairs. In this study, commercially pure nickel was joined to commercially pure nickel. There are several possible geometric arrangements of the target relative to the flyer. With flat targets, metallurgical bonding takes place along the edges of the spot, and jet was observed in the center of the spot. Corrugated targets provide more surface area for metallurgical bonding. In this paper, the flyer launch velocity-time profile is also demonstrated using a photon Doppler velocimetry technique.

Keywords

Laser impact welding, energy efficiency, Jet, impact angle, impact velocity

1 Introduction

Impact welding, as is typified by explosive welding, is carried out at ambient temperature and relies on very high velocity impact. There is no external heat input needed during the welding process. Figure 1 displays schematically a moment in time during impact welding, as has been surmised by observations after welding. In this process, a flyer is driven explosively to impact a target. The flyer will move toward the target at the velocity of several hundred meters per second [1]. At the moment that the flyer impacts the target, a jet consisting of oxide, contaminants and a thin layer of metal from below the oxide layer is generated at the collision point and ejected in front of the contact point. As a result, nascent metal surfaces are exposed and brought within atomic distance where metallic bonds are formed. This process is usually accomplished within several to tens of microseconds [1]. This bonding phenomenon has been widely studied for explosively driven welding where sample thicknesses are typically on the order of 25 mm or more [2]. Recent work by Zhang and co workers [2] has shown that there are similar phenomena in smaller-scale impact welding experiments, but there are also some key differences. In particular the waves reduce in relative proportion to the sheet thickness quite quickly as the size and energy scales downward in going from explosive to electromagnetic to laser impact welding, even though impact velocity may be similar in these three cases.

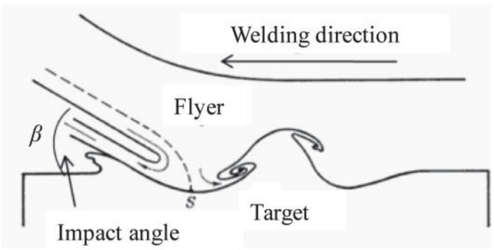


Figure 1: *Transient state of welding process at weld interface in impact welding [3].*

The purpose of this contribution is to introduce a relatively new method of joining metals at high velocity by using a laser to drive a thin flyer plate. This process is referred to as Laser Impact Welding and it may have outstanding utility for very thin and small features that are difficult to join by conventional means. Here the process basics and means of approaching the problem are emphasized. Later work will provide a more detailed analysis of the process, structures developed and the properties of these weldments.

The literature on laser-driven foil flyers gives considerable guidance on the conditions needed to accelerate a flyer to near 200 m/s using laser light for the input energy [4]. There have been a number of papers on using laser-driven launch of thin flyer plates for shock physics experiments [4-6]. The basic approach is to use a flyer foil, an ablative light-absorbent layer and a backing material. Coupling efficiencies relating the incident optical energy in the laser pulse to the final kinetic energy imparted to the sheet vary widely. A few on the high end are around 50% [7], and many are closer to 1-3% [5, 6]. Developing a launch procedure that produces routinely high efficiency is a key to developing a commercially viable process, and is one of the motivations for this work.

Laser shock peening is a related commercially practiced method for engineering the microstructure and state of residual stress at the surface of a part [8-10]. In a typical application, a component is given an optically absorbing coating and either placed under water, or a water stream moves over the part surface. Intense laser pulses ablate a small region of the surface and the high-pressure pulse locally deforms the surface of the material. This method is significant in that the technical objectives are very similar to those in laser-driven collision welding – a brief, large, local mechanical impulse is desired [5].

This paper presents an overview of the potential and challenges related to laser impact welding, and reviews the experimental methodologies that are being developed at The Ohio State University.

2 Methods and Results

The Nd:YAG laser source used in this study was a Continuum Powerlite™ Precision II Scientific System. The maximum energy available is 3J with a wavelength of 1064nm. It can provide optical pulses at 10HZ, each with pulse duration of 8ns. The low-divergence output beam has a diameter of 12.5 mm. For these experiments, an anti-reflection lens was used to focus the beam to nearly a point, but at a 2 Joule output if the beam diameter is reduced beyond about 1.6 mm, the optical energy density is so high that the air can be ionized. Therefore, larger beam diameters should be used. By changing the distance between the focus lens and the experimental setup, as illustrated in Figure 2, the diameter of the beam, which is incident on the flyer plate, can be changed In this experiment, three different beam diameters were investigated, namely 2mm, 4mm, 6mm, corresponding to energy and power densities of 9.6×10^5, 2.4×10^5 and 1.1×10^5 J/m^2 and 1.2×10^{11}, 3.0×10^{10} and 1.3×10^{10} kW/m2, respectively.

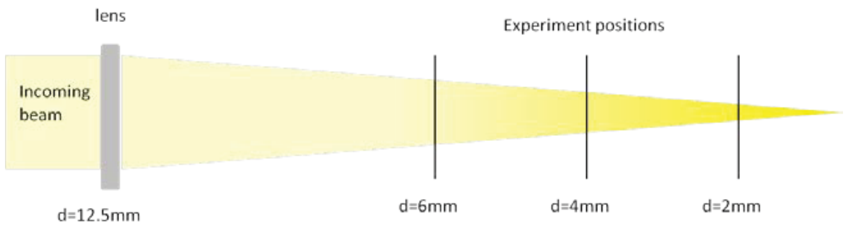


Figure 2: *Effect of varied experimental position relative to the lens to vary spot size and power density.*

Three experimental approaches have been developed for welding, as shown in Figure 3. Each produces different weld patch geometries. In each case the laser passes through the transparent backing and vaporizes the ablative layer. This separates the flyer and backing, and due to conservation of momentum, the flyer moves much faster than the more massive backing. The flyer moves to the target with a bulged shape and upon collision, if an appropriate combination of impact velocity and angle exists, bonding will occur. This work will focus on the use of flat and corrugated targets. Prior work at Ohio State has demonstrated that angled target plates will also produce satisfactory welds.

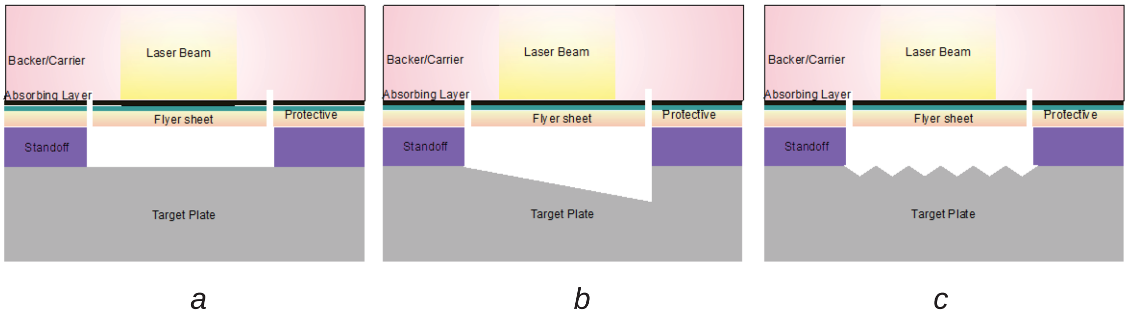


Figure 3: *Three modes of developing laser impact weld targets: a) flat, b) angled and c) corrugated.*

2.1 Effect of backing material on launch efficiency

The backing material attached to the flyer plate has an effect on the energy efficiency. The backing material must be transparent to the laser and confine the plasma that is generated by the ablative material. Three backing materials were studied in this experiment, 1) conventional soda-lime glass microscope slides (1mm thick), 2) polycarbonate (0.5mm thick), and 3) clear tape (Scotch packing tape with thickness of 0.07mm).

The experimental setup is shown in Figure 4. Commercially pure, 1100 aluminum flyer plate (0.076 mm thick) was painted with black RUST-OLEUM™ enamel aerosol paint, and was attached to the backing material with cyanoacrylate adhesive (Loctite 380). The backing material was attached to the holder with double-sided cellophane tape.

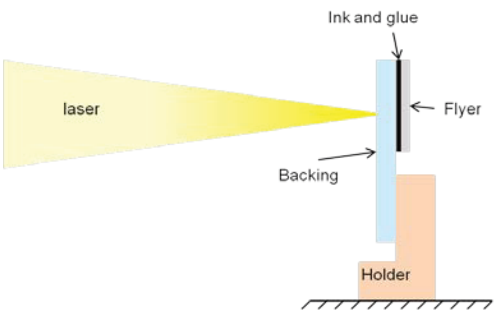


Figure 4: *Experimental setup for launching efficiency experiments*

Figure 5 shows one of the examples of energy efficiency experiments by changing backing material at 2mm and 4mm laser spot size position. With polycarbonate, the first hole is bigger than the other two. That was caused by the detachment of the flyer from the backing material after the first shot. Therefore, for the second and third shot, the plasma is not confined as effectively as the first one by the backing material. This result demonstrates that the important role of the backing material in the launching efficiency. The hole sizes indicate that clear tape is the least effective backing material. This can be attributed to the low mass of the tape layer relative to the aluminum, which is too thin to provide fully effective confinement for the plasma. Glass and polycarbonate have relatively similar effect on the launching efficiency. However, standard glass will crack with most impulses, making it relatively difficult to launch arrays of flyers with a single backing sheet.

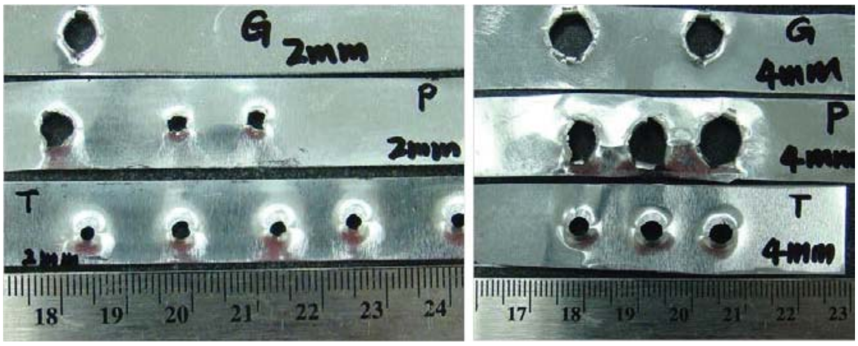


Figure 5: *Example of changing the backing system from Glass, to Polycarbonate and thin packing tape, using 0.076 mm Al1100 as the flyer material. (left 2mm position, right 4mm position, G: glass, P: polycarbonate, T: clear tape)*

2.2 Welding study

All three sample launch configurations shown in Figure 3 can result in effective bonding, but have different characteristics. Results with the flat and corrugated welds are presented here. In this study, a commercially pure Ni201 target was used with a flyer of commercially pure annealed 50µm thick Ni201.

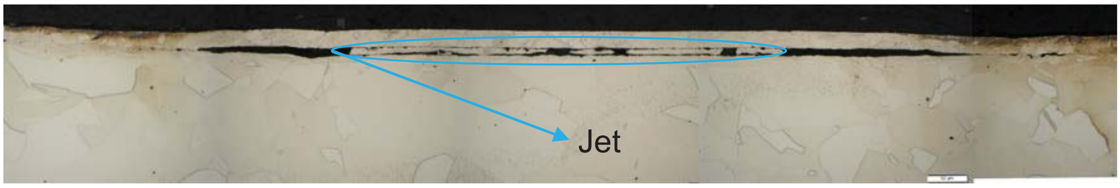


Figure 6: Weld interface of Ni201 to Ni201 using a flat-launch geometry (Figure 3a). The center of the image represents the center of an axisymmetric circular weld patch.

The weld interface from the flat-on-flat experiments is shown in Figure 6. This shows a characteristic morphology for this geometry. The bonded region is an annular ring about the center of the beam. This occurs because when the flyer starts to contact with the target, the impact angle is satisfied at the edges. However, in the center there is normal contact between the flyer and target (effectively zero contact angle, β, from Figure 1), and bonding does not occur. In the center of the spot, entrapped metal is observed, which is probably the result of material jetting. Figure 7 explains the entrapment of another piece of material in the center of the spot with the schematic drawing. After the flyer hits the target, the angular impact of the flyer and target will cause material to jet towards the center of the weldment.

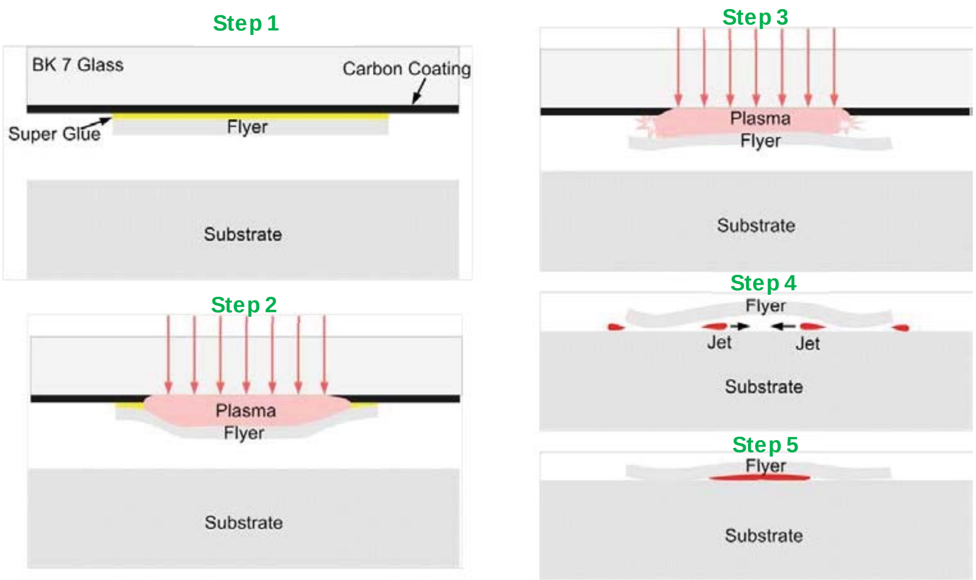


Figure 7: *Schematic for explanation of jet formation*

Machining easily produces corrugated targets. In this case, the interaction of impact angle and bonding can be investigated. The weld interface between a pure nickel, 50µm thick flyer and corrugated target is shown in Figure 8. This shows that at shallow angles, such as around 8°, bonding is achieved, while at larger angles (on the order of 30°, there is no bonding, and possibly no contact during impact. Normal impact, will not cause welding as was shown in Figure 6.

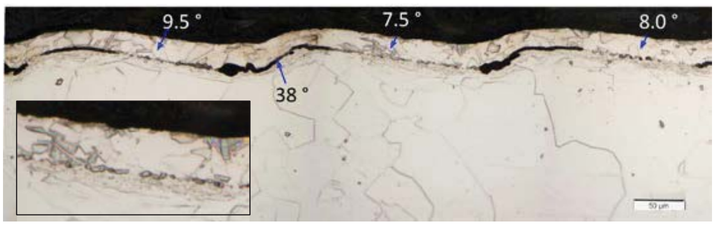


Figure 8: *Weld interface with corrugated target joining NI201 to Ni 201*

2.3 Impact velocity measurement

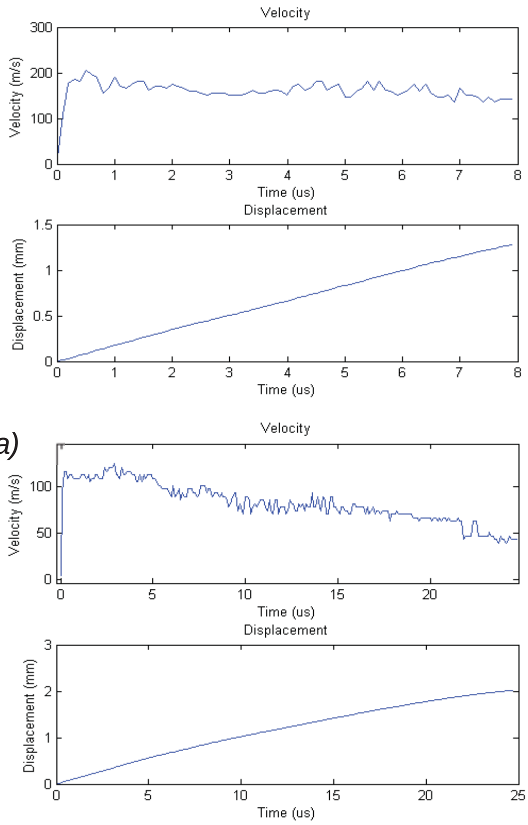
Aside from impact angle impact velocity is one of the critical parameters that determines if collision welding will take place. Photon Doppler Velocimetry (PDV) [11] was used to measure the velocity time profile and potential the impact velocity for one launch configuration. Figure 9 shows velocity-time profiles for experiments with the parameters shown in Table I and permanent (Sharpie pen) ink and tape and water as backing media. This experiment was done using similar equipment to that described in this paper at the facilities of LSP Technologies, Inc in Dublin, Ohio with their laser system and assistance.

Exp. No.	flyer	Energy	Spot size	Flyer thickness	Backing
1	Al6061-T6	6.5J	4mm	635µm	water
2	Al6061-T6	6.5J	4mm	635µm	Clear tape

***Table 1:** Experimental parameters for impact velocity measurement*

The launch velocity as a function of time was measured using water and clear tape as backings. Figure 9 shows the measured velocity and displacement. From Figure 9, it can be seen that full velocity can be achieved within 0.2µs. The terminal velocity is much higher with water as the backing material than with clear tape. Again, the cellophane tape does not have sufficient areal mass to provide effective backing. The important observation is that in both cases the peak velocity of the flyer is reached after less than 30 µm of displacement. This potentially allows a variety of configurations that will allow bonding to occur with very little initial standoff between the flyer and target.

(a)



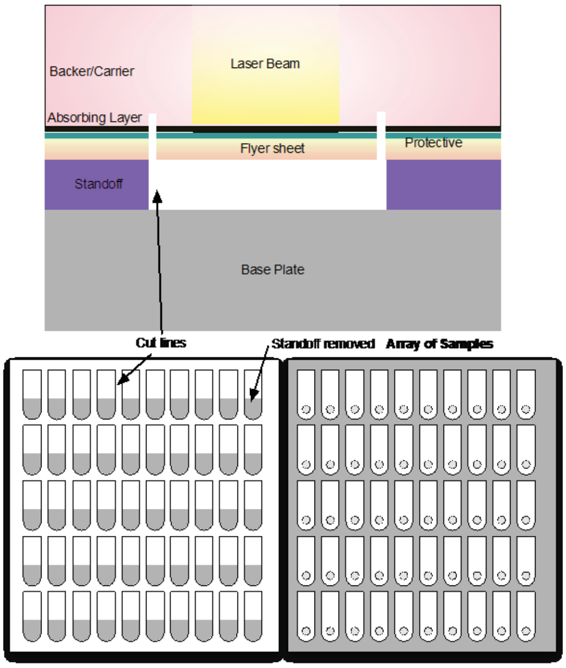
(b)

***Figure 9:** Impact velocity and displacement with (a) water and (b) transparent tape as the backing.*

3 Prognosis and Approach for Process Development

This process has great practical potential. Nearly arbitrary dissimilar metals can be bonded with one another. Pulsed lasers that provide pulse energies of about 5 joules or less are commercially available. These will operate easily at 10 Hz. This much energy will allow a metallurgical patch of a couple square millimeters in extent to be created with a metal flyer on the order of 150µm. This gives great practical potential for creating large arrays of solid-state metallurgical welds between dissimilar metals, and this process has the potential to be scaled to almost arbitrarily small length scales. One of the key challenges is the development of methods to fabricate flyer/backer systems on a large scale. Some initial ideas on this are presented here.

As shown in Figure 10, several layers (backer, absorbing layer, protective layer, flyer sheet) can be laminated together with properly cut and aligned sheets using adhesives. With a CNC profile cutter shapes can easily be cut in planar sheets (Silhouette Cameo is for example inexpensive and precise), many samples can be cut in one step. This array of samples can be attached to the CNC controlled 3-axis stage (shown in Figure 10) for laser impact experiments. This will be used in an automated manner with the laser to create samples for the statistical study of sample strength and properties. This also demonstrates a potential approach for manufacturing.



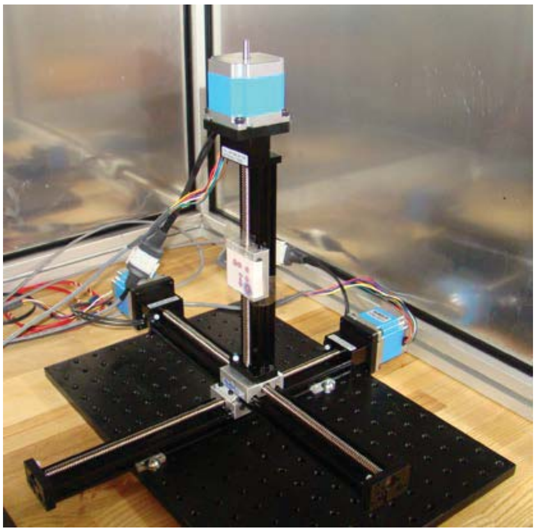


Figure 10: *Array of samples from CNC cutter, and (right) a 3 Degree of Freedom CNC stage in the laser experimental chamber.*

4 Conclusions

Laser impact welding is an easily practiced form of solid state welding that will allow the metallurgical bonding between almost arbitrary pairs of dissimilar metals. The key features of the approach along with a development path have been described here. An approach to create large numbers of samples using CNC cutting and motion control is described and it is suggested that polycarbonate or other transparent polymers may become effective backing materials. The fact that full flyer velocity can be achieved over a very short distance suggests that many geometric arrangements may be possible for impact welding.

A facility to study this process has been developed and some promising initial results from that facility are presented here.

5 Acknowledgements

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