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The Sensitivity of Hybrid Laser Welding to Variations in Workpiece Position

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Abstract

High speed imaging has been used to analyze the sensitivity of the Hybrid laser welding process to variations in the laser-arc-workpiece geometry along the axis of the laser beam. The welding process was found to be stable within a certain range of workpiece positions. Outside of this range the process became unstable. If the workpiece was too close to the laser/arc combination, the two energy sources did not supplement each other sufficiently. If the workpiece was too far away the droplets from the arc interfered with the laser-keyhole interaction.

Keywords: Hybrid laser welding; arc position; laser position; weld quality; process sensitivity

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1. Motivation / State of the Art

Laser hybrid welding, combining a laser beam with an electric arc (MIG/MAG), is a rapidly growing technology combining the advantages but also the complexity of both techniques [1-4]. Hybrid welding combines the laser advantages of high speed and narrow, deep welds with the arcs' ability to bridge gaps. Despite its commercial uptake, the basic physics of laser hybrid welding is still not fully understood. High speed imaging has enabled the study of drop transfer and the keyhole conditions for steel [5-7] and aluminium [8]. Different situations have been classified [8] dependent on the presence of a gap, the torch arrangement and the corresponding drop flight and heat and mass transfer. There have been recent successes in clarifying some aspects of drop transfer and melt pool flow [3,9], but analysis of many of the phenomena involved is limited.

This paper is part of an extensive survey of the effects of various geometrical aspects of the laser-arc-workpiece arrangement on the quality of the welds produced. In this case we present the results of an experimental program looking into the effects of increasing the standoff between the laser-arc combination and the workpiece.

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2. Experimental

The laser-MAG-hybrid welding experiment was carried out using an IPG 15kW Yb:fibre laser (Beam Parameter Product 10.4 mm·mrad, fibre diameter 200 µm, wavelength 1070 nm) together with conventional welding equipment consisting of a welding rectifier model ESAB Aristo LUD450W. This was combined with a MAG wire feed unit ESAB A10 MEK 44C. The laser axis was tilted to an angle of 7°, trailing with respect to the normal of the sample surface to avoid back reflections. The arc welding torch was inclined at an angle of 52°leading, (ie 59°with respect to the optical path). The process parameters are listed in Table 1. The 2:1 optics focused the laser beam to a spot diameter of 400 µm (Rayleigh length: ±3.5 mm).

Initially a reference weld was produced in 10mm thick DOMEX 400 high strength steel to establish a high quality weld datum with an optimum vertical workpiece position of z0= 0.0 mm. In the subsequent experiment the workpiece was raised at one end and lowered at the other, to ensure a linear variation of z from z= -5 mm when x=0 mm to z=+5 mm when x=200 mm along a 200mm long sample. ('z= -5 mm' indicates that the workpiece was 5mm closer to the laser/electrode combination than optimum, 'z=+5 mm' indicates that the workpiece was 5mm too distant).

The process was recorded using high speed imaging with a Redlake HS-X3 camera at 3000 frames per second, filtered for the illumination laser wavelength (808 nm). The camera was inclined 45 degrees from the surface, viewing from the side. The processing zone was illuminated, from the same side as the camera, by a diode laser beam (Cavitar) with (500W peak power) pulses of 0.5 µs pulse length at the same frequency as the camera.

Table 1. Good quality weld parameters

	Value
Laser power [kW]	8.0
Welding speed [mm/s]	35.0
Focal plane position [mm]	-5.0
Focal length [mm]	300
Laser angle [°]	7
Shielding gas	Mison8
Shielding gas flow rate [l/min]	25
Torch angle [°]	52
Torch position	Leading
Arc voltage [V]	36
Arc current [A]	440
Arc pulse frequency [Hz]	210
Arc pulse duration [ms]	2.5
Wire feed rate [m/min]	12
Wire diameter [mm]	1.2

3. Results and Discussion

Images taken from the high speed photography for cases where the laser/electrode-workpiece stand off is; a. too small, b. optimum, and c. too large, are shown in Figure 1.

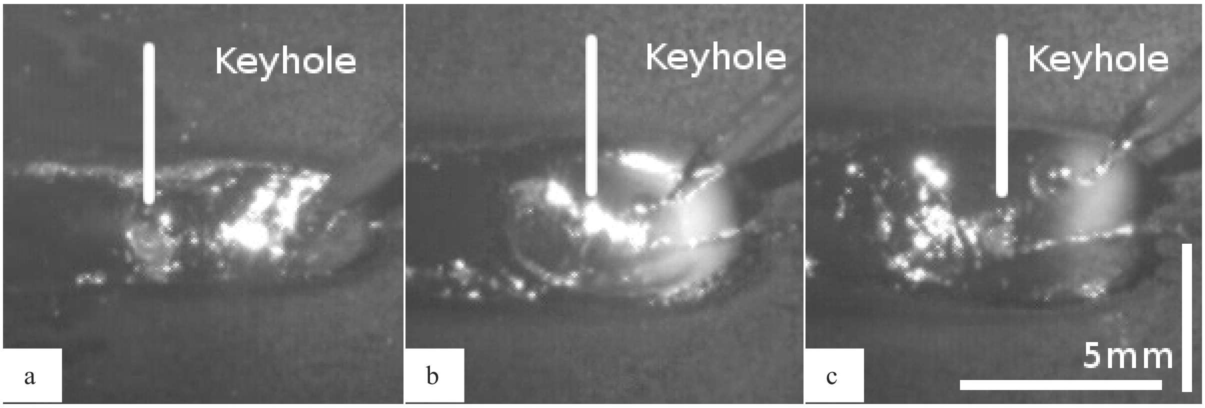


Figure 1. High speed image of the front region of the weld pool for (a) z = +3 mm, (b) z0 = 0 mm (optimum), (c) z = -3.4 mm.

The photographs in Figure 1 tell a very straight-forward story which is the central result of this paper;

- When the geometric arrangement of the electrode, laser and workpiece are optimized then the process produces a high quality weld. Droplets of melt from the electrode arrive in the melt zone just in front of the laser generated keyhole – then flow around the keyhole to join the solidifying melt just behind it.

- If the workpiece is too close to the laser/electrode combination (Figure 1a), then the weld pool on the top surface of the workpiece becomes narrower and is also extended in the direction of travel. This means that the distance from the keyhole to the leading edge of the melt is increased. The flight path of the droplets from the electrode is very short in this case and the two energy sources (laser and arc) act more like independent entities rather than a team.

- If the workpiece is too distant from the laser/electrode combination (Figure 1c), the weld pool on the workpiece surface becomes broader and the distance from the keyhole to the front edge of the melt becomes smaller. In this case the trajectory of the droplets leaving the electrode often takes them to the melt zone behind the keyhole – which means they have to travel through the laser beam, interrupting the supply of laser energy to the keyhole itself.

These principles are explained graphically in Figures 2 and 3.

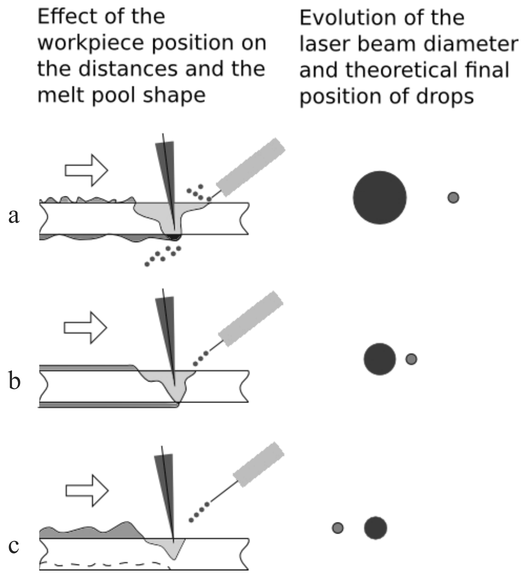
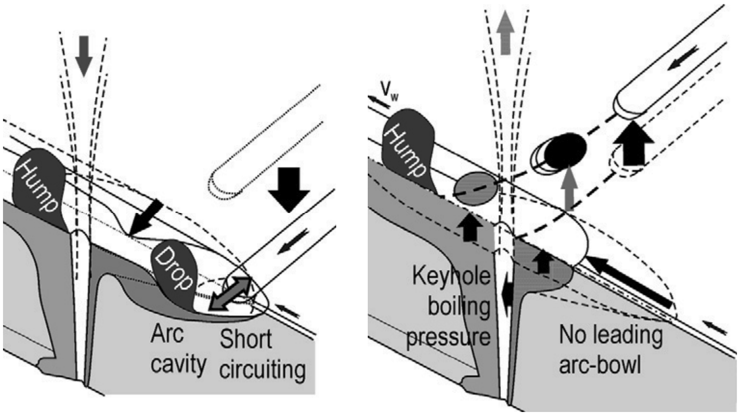


Figure 2. Illustration of the changes in weld pool shape and droplet trajectory with increasing workpiece standoff. a. (top image) Too close, b. Optimized, c. Too distant. The change in the diameter of the laser on the workpiece surface (larger, dark circle), and the average position of droplet impact with the melt, are shown on the right hand side of the illustration in each case.



a b

Figure 3. Illustration of the mass redistribution flow changes when the vertical position of the plate becomes (a) too close to, and (b) to distant from, the energy sources.

The process remains stable within a certain tolerance range, which in this case was z = -2.2...+1.5 mm. At small stand-off distances Figures 2a and 3a, the horizontal laser-arc distance increases and the temperature field induced by the laser cannot properly support the arc. The electric parameters of the arc are optimized for close interaction with the laser beam where the laser-induced temperature field supports the development of a stable, strong arc. Without this support the arc is now too weak for this high welding speed and the result is a short arc and drop transfer below the surface, where a cavity is formed during the high voltage part of the pulse cycle. The welding process does not collapse, despite the unusual geometry, but is subject to occasional short circuits – which disrupt the weld quality.

If the workpiece is too distant from the energy sources (Figures 2c and 3b), this also causes unstable welding, but by a different mechanism. When the wire is too far away from the surface, z > +2.4 mm, the drops occasionally enter the keyhole or pass through the laser beam, disturbing the laser-material interaction and causing violent evaporation and weld disruption.

For varying vertical surface positions (e.g. a bent or distorted workpiece) it can be concluded that too strong variation in either direction leads to an unstable weld. This view is supported by the overall picture of the weld results are given in Figure 4.

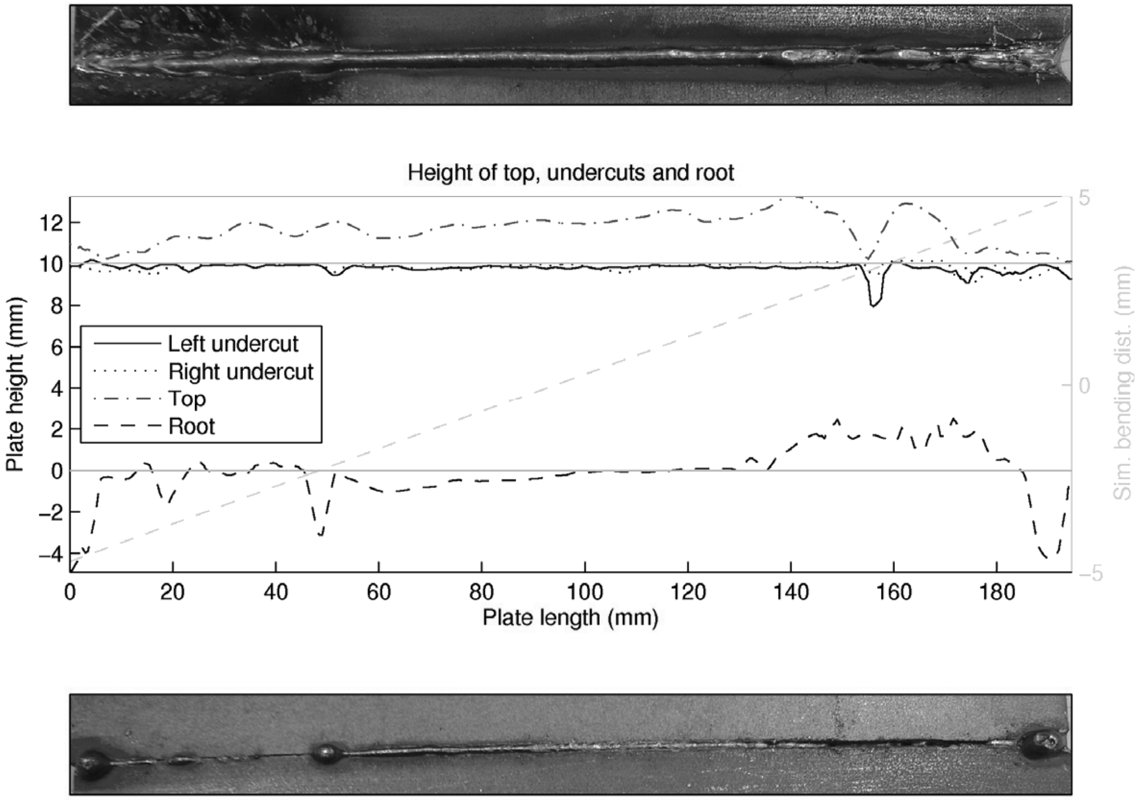


Figure 4. Photographs and surface profiles of the top and bottom of the weld made with the workpiece too close (towards the left and too far away (towards the right).

In Figure 4 we can see the central region of stable welding from plate length measurements from approximately 60mm to 130mm (equivalent to z = -2.2 to z=+1.5 mm.). To the left of this region (z= -2.2 to -5.0mm) the short circuits of the arc have lead to intermittent lack of penetration and an uneven top surface. To the right of the stable zone (z=+1.5 to +5.0mm) the interruption of the keyhole has lead to the same symptoms of lack of penetration and uneven top surface.

4. Conclusions

Although the Hybrid laser welding process is moderately robust from a practical engineering point of view it is important that the workpiece-laser/arc stand-off be constrained within certain limits. At greater stand-off distances the laser-material interaction is interrupted by droplets from the arc travelling through the laser beam and/or into the keyhole. At lesser stand-off distances the arc tends to short circuit in the melt pool. Both problems give similar symptoms – intermittent lack of penetration and an uneven weld top surface. In the setup used for this experiment, high quality welding was possible over a range of stand-off distances of 3.7mm.

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