A hybrid laser+GMAW process for control of the of bead humping defect

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Introduction

Weld bead humping is a defect which often sets an upper limit on the travel speed that can be used with a welding process. Because of its importance, bead humping has been the subject of research for many years. A first, relatively, thorough, qualitative study was reported by Bradstreet (Ref. 1). Humping was defined as a quasi-periodic weld bead shape defect that was always associated with undercutting. Capillary or Rayleigh instability (Refs. 2-4) of the molten weld deposit due to liquid metal surface tension, wetting of the weld metal on the adjacent solid substrate and weld pool fluid flow were identified as factors important in hump formation, documented experimentally to various degrees and analyzed. Also, it is reported that liquid deposits that are well-wetted to the substrate (i.e. have an internally-measured contact angle of less than $\pi/2$) are not susceptible to humping by capillary instability.

In the previous researches(Refs. 5-7), studies aimed at understanding and controlling the bead humping phenomena through the adjustment of weld parameters and the dual torch welding approach continue to the present time. In this article, a novel hybrid Laser Beam Welding (LBW) + Gas Metal Arc Welding (GMAW) process that provides for control of weld bead shape was investigated and its ability to suppress weld bead hump formation was characterized.

Approach

A GMAW welding apparatus that allowed for flexible integration of a laser beam heat source was integrated as shown in Fig. 1. A pulsed GMAW power source was used to deposit bead-on-plate welds in the flat position on hot-rolled steel sheet with as-received surface condition. With the exception of wire feed speed and travel speed, the GMAW process settings remained fixed during all tests. The laser beam focus spot was positioned in front of the leading edge of the GMAW weld pool and the focal point elevation was adjusted to produce a laser focus spot diameter measured normal to the travel direction. Relative positions and orientations of the arc and laser processes and other welding process variable settings are summarized in Fig. 1. The laser beam incidence angle setting remained fixed during the tests and the relative position of the laser spot and the arc were fixed at 0.1 in. to 0.2 in (0.25 mm – 0.5 mm). However, the laser power and focus spot size were varied to determine their effect on hump prevention. Argon was used as a shielding gas for some initial tests because of it was known to exacerbate weld bead humping. However, as more experience was gained with the bead humping defect, it was found that humping was obtained at feasible travel speeds with the more conventional 90% Argon-10% CO_2 shielding gas, which was used for the majority of the tests. After welding, the standard deviation and range (maximum – minimum) of the height and the weld toe angles of the bead-on-plate welds were measured using a laser line scan weld inspection system (Servo-Robot WISC).

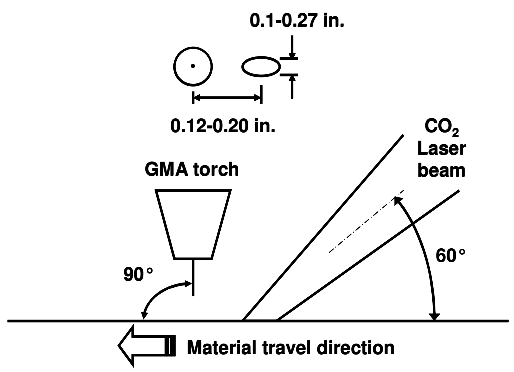

Fig. 1 Side view of hybrid welding configuration

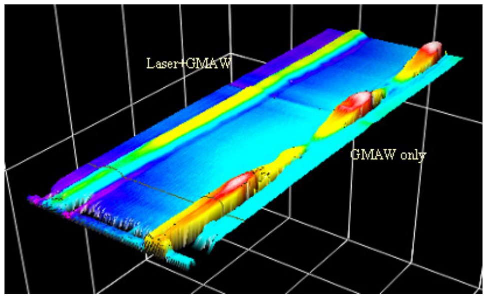

Fig. 2 Surface contour images of a GMAW-only weld with hump defects and hybrid process weld with desired weld bead shape.

Results

Hybrid and GMA bead-on-plate welds were made over a range of wire feed speed, travel speed and other process variable settings. A graphical illustration of the hump prevention capability of the hybrid process is shown in Fig. 2. Two bead-on-plate welds made the same GMAW settings are shown: one made with the hybrid process has a smooth contour while the other made with the GMAW process alone is severely humped. As shown in Fig. 2, the hybrid process was able to operate at a higher travel speed without bead humping: the speed for acceptable (non-humped) bead-on-plate was nearly a factor of two higher for the hybrid process. However, it is also interesting to note that beads deposited with the hybrid process also formed humps when the travel speed was sufficiently large.

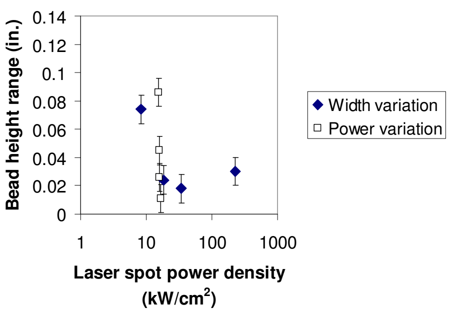

Fig. 3 Weld bead hump height variation as a function of laser power spot density. Threshold power density is about 16 kW/cm^2

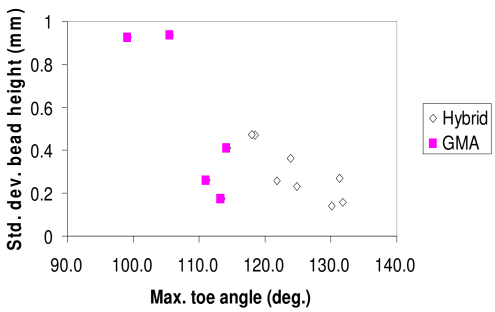

Fig. 4 Weld bead height variation vs. maximum toe angle for Argon shielding gas and varying process settings. smoothness to GMA welds.

The bead-on-plate welds were studied in more detail to determine parameter affects on humping. For these tests, 100 in./min.(42 mm/s) of weld travel speed and 550 in./min. (233 mm/s) of wire feed speed were fixed. Also, bead humping severity was quantified by measuring the range of weld bead height over the length of the weld. Humped beads were defined at those having a bead height variation along their length more than 0.03 in. (0.75 mm). Results plotted in Fig. 3 show that a laser power density of approximately 16 kW/cm^2 was sufficient to suppress bead humping.

To test whether the observed humping suppression was due to avoiding capillary instability of molten bead, toe angles (external angles measured by laser scanner) were compared to the critical angle of 90 degrees for various welding conditions as shown in Fig. 4. Note that the maximum toe angle is used based on a supposition that the stability of an asymmetrical weld deposit should be controlled by the larger of the two toe angles. The results, summarized in Fig. 4, show that the laser hybrid welds did indeed have a larger toe angles and less height variation as quantified by the standard deviation of weld bead height over the length of the weld. Also, it is notable that all of the measured toe angles are significantly greater than the critical static angle of 90 degrees. In itself, this indicates that factors besides capillary instability play a role in the bead hump formation in our experiments.

Conclusions

A novel LBW+GMAW hybrid process was investigated and its ability to suppress weld bead hump formation was characterized. It was found that, for given GMAW process settings, bead humping was suppressed by laser heat input of sufficient power density. Comparison of the aspect ratios of humped and non-humped weld beads made by the hybrid process and by the GMAW process suggested that capillary instability was not the only factor in bead humping. Observations made during the experiments suggested that weld pool fluid flows were also important.

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